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Hydroponics Farm Powered Through Photovoltaic Cells

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ABSTRACT:
This research project proposed implementing an alternative form of electricity generation using a photovoltaic system to power the lighting, ventilation, and office equipment of a hydroponics company, thereby reducing billed consumption. The company's total energy demand was calculated, and an analysis of the location's geography and the average monthly and annual sunlight level were conducted to determine the parameters of the system for capturing, storing, converting, distributing, and consuming the electrical energy obtained from the photovoltaic system. Information related to the different components of a grid-connected photovoltaic system, as well as a description of its installation, was also investigated and provided. An economic analysis of the project was conducted to determine its feasibility.

KEYWORDS: Battery, photovoltaic, hydroponics, inverter

I. INTRODUCTION

Environmental conservation is one of society's biggest challenges, and some current forms of agriculture pose a threat. In fact, the Food and Agriculture Organization of the United Nations (FAO) identifies it, along with other sectors, as one of the most common anthropogenic causes of soil pollution. Deforestation, largely caused by the conversion of land for agricultural use, and greenhouse gas emissions produced by Own farms question the sustainability of the current model. However, there are alternatives such as hydroponics, a more sustainable form of cultivation that can be implemented in urban environments to be closer to consumers. Hydroponics is a cultivation system that grows plants in a nutrient-rich water solution, meaning it does away with soil. Additionally, the water used can be recovered and recycled, and nutrients can come from various sources, including fish waste (a technique known as aquaponics). Hydroponics has gained relevance to produce food with higher yields and lower use of land, water, and energy. Hydroponics emerges as a solution to fight against climate change, environmental degradation, and species extinction caused by overexploitation and intensive farming. It also allows for a more rational use of water, an increasingly scarce resource. Furthermore, hydroponic crops are more profitable and easier to manage, making them a tool to combat hunger and strengthen food security, especially in developing countries. According to the consulting firm Berkshire Hathaway, the global hydroponics market is expected to grow to$725 million by2023, with a compound annual growth rate of 18.1%. Hydroponics is also part of the latest trends in smart farming, or precision agriculture, which involves using technological tools, from geolocation to big data, artificial intelligence, the Internet of Things, or drones, to achieve the highest crop yields. The first vertical hydroponic farms, true skyscrapers dedicated to plant cultivation, areal ready under construction in Droten (Netherlands), a country where soil and sunlight are scarce. [1]

BACKGROUND

In Mexico, the origins of hydroponics are the floating gardens of the Aztecs, called chinampas. The chinampas were built with reeds and vines that floated on Lake Tenochtitlán (Mexico)and were also filled with mud taken from the lake itself. Later, in 1860, the Germans Sachs and Knop were the first to grow plants in a nutrient solution, calling the process 'Nutri culture.' In 1938, W.F. Gericke, a professor at the University of California, successfully established soil-less cultivation units commercially, naming this productive system hydroponics and is considered the father of this modern cultivation technique. Subsequently, commercial hydroponics spread worldwide in the 1950s. Hydroponics has been widely used for research in the field of plant mineral nutrition, in addition to being today the most intensive horticultural production method. Generally, this production system is high-tech, with a strong capital investment, which is why it is successfully applied in developed countries. Among the existing systems that stand out in hydroponics are the recirculation systems NFT (Nutrient Film Technique) and NGS (New Growth System), as well as systems where the growing medium is a substrate. The most profitable hydroponic crops under these hydroponic systems are tomato, cucumber, pepper, lettuce, strawberry, and cut flowers. [2]

II. METHODOLOGY

SELECTION OF THE SITE FOR THE PHOTOVOLTAIC SYSTEM

To properly select the location site, various factors must be considered, such as an economic study of the area, the electrical demand, and the geographical location.

Geographic allocation

The Company Hydrocutions is in the State of Mexico, in the municipal seat of Lerma de Villada, between the parallels 19°14’and19°26’north latitude; the meridians 99° 22’ and 99° 34’ west longitude; at an altitude between 2,500 and 3,500 meters above sea level.

Boundaries

It borders to the north with the municipalities of Xonacatlán, NaucalpandeJuárez, and Huixquilucan; to the east with the municipalities of Huixquilucan and Ocoyoacac; to the south with the municipalities of Ocoyoacac, Capulhuac, and San Mateo Atenco; to the west with the municipalities of San Mateo Atenco, Toluca, Otzolotepec, and Xonacatlán. [3]

Climate

Temperature range: 8 – 14°C
Precipitation range:800–1,300mm

Subhumid temperate with summer rains, with higher humidity (70.87%) and subhumid semi-cold with summer rains, with higher humidity (29.13%).

Potentiall and use Agricultural

For continuous mechanized agriculture(24.46%)For continuous animal-driven agriculture (17.43%) For continuous manual agriculture (45.88%) Not suitable for agriculture (12.23%). [3]

Live stock

For the development of cultivated pastures(24.46%) For the use of natural vegetation other than grassland (22.95%) For the use of natural vegetation solely for goat grazing (40.36%)Not suitable for livestock use (12.23%). [3]

Load Determination

During the site visit, the following data were collected, obtaining a total load of 11.69 kW ≅ 11.7 kW, and an estimated daily power of 55.46 kWh/day ≅55.5kWh/day. As shown in Table1. Harper (2010) & Bella (2004). [4] & [5]

Table 1.Load Chart.

Equipment	Power (W)	Quantity	Total Power (W)	Hours of Use (H)	Consumption kWh/day
Incandescent Bulbs	100	2	200	8	1.6
LED Lamps	22	4	88	8	0.704
LED Lamps	48	5	240	13	3.12
LED Lamps	25	9	225	13	2.93
LED Lamps	200	8	1600	14	22.4
Metal Halide Lamps	1000	1	1000	1	1
Simple Contacts	5313.6	41	5313.6	0.9	4.78
Computer 1	65	2	130	8	1.04
Computer 2	90	1	90	8	0.72
Printer 1	263	1	263	5	1.32

Printer 2	70	1	70	5	0.35
Modem	191	1	191	24	4.584
Fans	508	4	2023	3	6.096
Mini fridge	254	1	254	19	4.826
totals			1169 6.6		55.46

From the total installed capacity and the power consumed per day, a safety margin of 17% will be considered for possible future load growth in the installation, as shown in Table 2. [5]

Table 2. Load growth application.

Power kW	Consumption on kWh/day	Safety Margin %	Final Power kW	Final Consumption ion kWh/day
11.7	55.5	17	13.4 55	64.93

Calculation of Solar Panels

According to the company's geographical location, an annual average of 5.64 HSP of maximum solar radiation in the area is obtained. Using Eq. 1, we have.

$$SPPower=\frac{[Powerconsumed]}{[Peaksolarhour]} \quad (1)$$

Where:
SP Power = Required power without losses in kWp
Power consumed=Total power consumed none day.(kWh /day).
Peak Solar Hour=Peak Solar Hour of the Location. HSP

$$SPPower=\frac{65kWh/day}{5.64HSP}=11.52kWp$$

Now, considering losses due to excessive temperature and voltage drop in the conductor, using a performance coefficient (k) at 0.9 of the nominal value of the panels, as shown in Eq. 2.

$$CPPower=\frac{SP\ Power}{k} \quad (2)$$

With the data from the selected solar panel, the number of solar panels needed to cover the power consumed by the specified load is calculated using Eq. 3.

$$No.Paneles=\frac{Power\ HP}{Panel\ power} \quad (3)$$

Where:
No. Panels = Number of Calculated Panels.
Power kW = Required Power with Losses in kWp.
Panel Power = Generation Power of the Selected Panel in kW.

$$NumberofPaneles=\frac{12.8\ kWp}{4625W}$$

Number of Paneles=27.52
Rounding this to a value of 28 solar panels of 465 W

Inverter calculation

For the selection of the inverter, the required power of the inverter will first be calculated, which is recommended to oversize by applying a safety margin(SM) due to possible load increases, as shown in Eq. 4. [4] & [5]

$$Inverter\ Power=MS\ (CP) \quad (4)$$

Where:
Inverter Power=Power with which the Inverter will be Selected in KWp.
MS = Safety Marg into Use.
CP = Required Power with Losses in kWp.
Inverter Power = [1.15] * [12.8 kWp.]
Inverter Power = 14.75 kW

Therefore, an inverter with a power of 15 kW and a voltage of 220/127 V will be selected. Based on the result obtained, a Growatt brand inverter, model MAC 15KTL3-XL with a capacity of 15 kW, is proposed. [7]

Arrangement of the Photovoltaic Panels

The calculation of the arrangement of the solar panels in series and parallel will be carried out based on the data from the GROWATT MAC 15KTL3-XL inverter. Equations 5 and 6 are applied respectively.[8]

$$\text{No.SerialPanel}=\frac{\text{RatedVoltage inv.}}{\text{PMPPT}} \quad (5)$$

Where:
No. Serial Panel = Number of Panels in Series.
Nominal Inverter Voltage = Nominal Input Voltage of the Inverter in Volts (V).
TPMPPS = Maximum Power Point Voltage of the Solar Panel in Volts (V).

$$No.SeriesPanel=\frac{360V}{40.8V}=8.82\approx 9$$

For the solar panels in parallel, Eq.6 will be applied. NCYT (2021).

$$\text{No.ParallelPanel}=\frac{\text{TPMPPS(MPPT)}}{\text{CPMPPS}} \quad (6)$$

Where:
Parallel Panel No.= Number of Parallel Panels.
MPPT=Maximum Current of the Inverter in Amperes (A).
CPMPPS=Current at the Maximum Power Point of the Solar Panel in Amperes (A).

$$\text{No.ParallelPanel}=\frac{46\text{ A}}{11.4\text{A}}=4.03$$

With the previously obtained data, it is possible to set up to a maximum of 9 panels in series and 4 in parallel for this inverter.

Calculation of the Voltage and Current Levels Generated by the Array.
To calculate the voltage and current levels generated by the calculated array, Eqs. 7 and 8 are applied. [4] & [5]

$$V=\frac{\text{No.PanelSeries}}{\text{TPMPPS}} \quad (7)$$

Where:
V=Voltage Generated by the Calculated Array, in Volts (V).
No. Series Panels=Number of Panels in Series Calculated.
TPMPPS=Voltage at Maximum Power Point of the Solar Panel in Volts (V).

$$V=7(40.8V)=285.6V$$

I=(No. Parallel Panels) (CPMPPS) (8)

Where:
I=Current Generated by the Calculated Array in Amperes (A).
No. Parallel Panels=Number of Parallel Panels Calculated.
CPMPPS=Current at Maximum Power Point of the Solar Panel in Amperes (A).

$$I=4\,[11.4\text{A}]=45.6\text{A}$$

Likewise, it is determined that this arrangement does not exceed the maximum voltage and current values at the input of the previously selected inverter.

Calculation of the Tilt Angle and the Orientation Angle.

To determine the tilt angle of the photovoltaic panels, the latitude of the location where the company Hydroponics is located should be used, to which 5° will be added. Eq. (9). [4] & [5]

<INC+<LAT=19°14' +5°=24°14'south. (9)

Calculation of the photovoltaic array area:

For the sizing of the total area of the photovoltaic array, the spacing between panels must first be calculated to avoid shadows caused by adjacent panels. For this, the following considerations are made. Fig. 1.

Figure 1. Separation between panels.

The design of the installation is considered for the Municipality of Lerma, in the State of Mexico. (Latitude19°14'northlatitude).

It is necessary to determine the spacing between panels to avoid shading between arrays;

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for this, the following calculations need to be carried out. Fig. 2

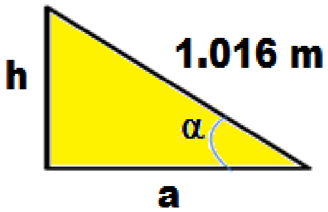

Figure 2. Representation of panel tilt.

By performing the calculations for h, the following is obtained for the municipality of Lerma, in the state of Mexico.

$$h = 1.016 \sin 24.4333° = 0.42 \text{ m}$$

Subsequently, a factor k must be determined based on the latitude of the installation site; for this, Equation 10 is used.

$$k = \frac{1}{[\text{Tan}(61 - \text{latitude})]} \quad (10)$$

Substituting values gives:

$$k = 1 \div [\text{Tan}(61 - 24.4333°)] = 1.35$$

Finally, the spacing between panels will be the product of the factor k by the distance h, resulting in Eq. 11.

$$d = [k] * [h] \quad (11)$$
$$d = [1.35] * [0.42] = 0.567 \text{ m}$$

Once the separation distance between panels has been calculated, it is necessary to calculate the minimum distance between panel edges to avoid shading (dmin.)by adding the remaining portion of the lower panel to the upper edge of the same relative to the horizontal in meters.

Where:
d min=Minimum distance between panel edges to avoid shading. (m).
L = Length of the panel. (m).
H=Solar height at noon.(m).
α=Degree of inclination of the panel with respect to the horizontal (Degrees).
θ=Angle of the shadow with respect to the horizontal.(Degrees).
a=Distance from the edge. (m).
d=Distance from the lower edge of the panel to the lower edge of the other. (m).

Therefore, the minimum separation distance between panels corresponds to:

$$d_{min} = 1.016 \cos 24.4333° + d = 0.9250 + 0.567 = 1.49 \text{ m}$$

DC Conductor Calculation

Based on Eq.12, we have the following current in the conductor.

$$I_{cond} = [1.56] * [I_{cc}] \quad (12)$$

Where:
Icond=Conductor Current.
Icc=Short-Circuit Current.

$$I_{cond} = [1.56] * [12.05A] = 18.798 \text{ A}$$

By selecting a conductor from table 310-15(b) (16) of NOM-001-SEDE-2012 in the 90°C column, it is found that for a USE-2 insulation, a14 AWG (2.08 mm²) conductor will support 25 A.

Having 8 modules in series, there is a total length of 14m, likewise the resistivity of copper is 0.017Ω·mm²/m and a total area of the selected conductor of 2.08mm².Using Eq.13and the data, the resistance of the circuit will be as follows:

$$RC = \boldsymbol{\rho}[L \div AT] \quad (13)$$

Where:
RC = Circuit Resistance.
ρ = Resistivity of Copperinohm - square millimetre per meter (Ω·mm²/m).
L=Total Length in meters(m).
At = Total Area of the Conductor in square millimeters (mm²).
$RC = [0.017 \Omega \cdot mm^2/m] * [14m / 2.08mm^2]$ $RC = 0.1144\ \Omega$

For the power lost in the circuit based on Eq.14,it will be:

$$PPC = [I_{mod}^2] * [RC] \quad (14)$$

Where:
PPC = Power Loss in the Conductor. I mod =Module Current.
RC = Circuit Resistance.
$PPC = (11.4A)^2 (0.1144\Omega) = 14.8674$ W
And for the percentage of conductor loss, equation 15 is used.

$$\%PC = \frac{PPC}{PGSF} \qquad (15)$$

Where:
% PC = %Conductor Loss. PPC= Circuit Power Loss
PGSF = Power Generated by the Photovoltaic System.

$$\%PC = \frac{[14.8674W}{13.020W}(100) = 0.114\%$$

Finally, by substituting the values into Eq.16, it will give the allowable conductor loss percentage.

% PA =1 %- % PC (16)

With the above calculations, it is verified that the selected conductor is correct for transmitting energy from the Photovoltaic System (PV) to the inverter input.

Determination of Fuses and Grounding Conductor

Having a 14 AWG(2.08mm²) conductor, which will carry a current of 25A, the appropriate protection for the photovoltaic system is selected, which corresponds to a Litte lf use Class RK5-IDSR Fuse, capable of handling a nominal current of 25 A.

Based on the above, the grounding conductor is selected according to Table 250-122 of the NOM-001-SEDE-2012 standard, for a 25 A protection, which corresponds to a 12 AWG (3.31 mm²) grounding conductor.

Calculation of AC Conductors and Thermo magnetic Circuit Breaker

For the selection of the inverter output conductor, the provisions mentioned in section 690-8a) 3 of NOM- 001-SEDE-2012 will be used, which states that "the continuous output current of the inverter (maximum current) will be used."
According to section 690-8b) 2)a), Eq.17 is used.

Ic= [1.25] * [Isc] (17)
Ic=[1.25]*[43.6 A]

The conductor's ampacity is calculated using Eqs.17 and 18, and the method that results in the highest current value is selected. With Eq. 17.

Ic= [1.25]*[43.6 A]=54.5A

With Eq.18.
Ic= [43.6A] ÷[0.8* 0.91]=59.89 A

For the above reason, the conductor gauge is selected according to the value obtained with Eq. 19. For the current of 59.89 amperes, and based on Table 310- 15b)16) of the NOM-001-SEDE-2012 standard in the 60°C copper section, a4AWG (21.20mm²) conductor will be used.

III. ANALYSIS OF RESULTS

According to the calculations obtained, the following equipment and materials were selected for the design of the photovoltaic system that will provide electrical energy to the Hydroponics Company, see Table 3. As well as their respective costs, see Table 4.1e=$20.72 (01/10/2024)

Table 3.Selected Equipment for the System

Description	Features
Mon crystalline Panel.	465W,1.665mx0.035mx 0.992m,IUSASOL brand
15 KW Inverter,	Growatt Three-Phase brand, 220/127Voutput.
Adjustable Aluminum Frame	For7 Solar Panels
Cable	THW-LS4AWG.Brand: IUSA100mblack
Cable	USE-214AWG.100m Black Brand: Voltech.
Cable	bare12AWG copper
Cable	bare10AWG copper
Circuit Breaker	3x70BrandSQUARE-D
Fuse	Brand:LittelFuse,25A, class:RK5-IDSR

Conduit Tube	3/4" thick wall
Conduit Tube	11/4" thick wall
Set of Connections	For piping
Junction box	Racko
Load center	3-pole,three-phase, CCO3E. Brand: IGESA
Fuse holder	Brand: Litte lf use, class: H/K5 and R

Table 4.Costs of the equipment selected for the design of the photovoltaic system

Description	Quantity	Unit Price MXN	TOTAL MXN
Mon crystalline panel of 465W, 1.665 mx0.035 m x 0.992 m, brand IUSASOL	28	5,556.8	155,590.4
15KWinverter, Growatt brand, three-phase, 220/127Voutput	1	47,963.86	47,963.86
Adjustable Aluminum Structurefor7 Solar Panels	4	6,497.00	25,988.00
THW-LS4AWG Cable. Brand: IUSA100mblack	2	8,605.00	17,210.00
USE-214AWG Cable. 100 m black. Brand: Voltech	1	2,500.00	2,500.00
12 AWGb are copperwire	1	800.00	800.00
10AWGbare copper wire	1	1,212.00	1,212.00
Thermo magnetic Switch 3 x 70 Brand SQUARE- D	1	1,428.00	1,428.00
Fuse Brand: Litte lF use, 25 A, Class:RK5-IDSR	2	208.00	416.00
3/4"ThickWall Conduit Pipe	7	113.00	791.00
11/4"Thick Wall Conduit	4	158.00	632.00
Pipefitting set	1	527.00	527.00
Racko Junction Box	4	28.00	112.00
3-pole load center, three-Phase, CCO3E. Brand: IGESA	1	550.00	550.00
28 Fuse Holder Brand: Little Fuse, class: H/K5 and R	1	896.86	896.86
	Total		256,617.12

Table 5.Labor Cost

Job description	Monthly	Salary Amount MXN	Total Project Salary MXN
Electrical engineer	3	12,000	36,000
Electrical Technicians	2	8,000	16,000
Installers	2	7,000	14,000
TOTAL			66,000

TOTAL PROJECT COST

Table 6 shows the total project cost with the specifications mentioned.

Table 6.Total Project Cost, Equipment and Labor

Concept	Total Cost MXN
Equipment	256,617.12
Labor	66,000
Total	322,617.12

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IV. ECONOMIC ANALYSIS

The following section presents the economic analysis of the project, which is an income statement used to determine its viability.

To conduct this analysis, the total project investment must first be determined, as well as the payments made to the electricity generating company, CFE, for energy consumption. See Table 7.

Table7. Return on Investment

Bimonthly Consumption on Payment To CFE (MXN)	Annual CFE Consumption on Payment (MXN)	Project Invest me Total (MXN)	Return on investment in years
$15,606	$93,636	$322,617. 12	3.4

The project will have a total investment of $322,617.12MXN. Based on the above, the project's return on investment can be calculated using Equation 21.

$$R_{INV}.=I\div P \qquad (21)$$

Where:

RINV=Return on Investment I = Total Project Investment

P = Annual Payment for Electricity Consumption to CFE.

R_{INV}. = [$358,617.12]÷[$93,636.00]=**3.4**

Return on investment will be in 3.4 years

V. CONCLUSIONS

The primary objective of this project—to supply electricity to a hydroponics company located in the municipality of Lerma de Villada in the State of Mexico—was achieved. Using the information gathered on-site, a calculation report was prepared, which includes the total load of 11.7 kW, the estimated daily power consumption of 55.5kWh/day, and the calculation and selection of the equipment and materials required for the photovoltaic system installation.

An important part of the project was conducting an economic analysis of the photovoltaic system to determine its viability. The investment will be recovered in approximately three and a half years, given that the design has a useful life of 25 years. Once the investment is recovered, the company will not have to pay for electricity consumption from the CFE(Federal Electricity Commission) for the next 21 years or so. With savings in energy consumption payments of $1,966,356 MXN, the design of a photovoltaic system for the company Hydroponic is therefore viable.

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