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Design and evaluation of a distributed generation system based on renewable energies applied to a rural area of the state of Veracruz

Diseño y evaluación de un sistema de generación distribuida basado en energías renovables aplicado a una zona rural del estado de Veracruz

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Abstract

This article aims to show the dimensioning and evaluation of a Distributed Generation system based on renewable energies for its application in a rural area in the state of Veracruz, Mexico. The main motivation of this work arises from the shortage of energy or a deficient supply in numerous localities located in the state of Veracruz, derived from different reasons. A methodology based on the application of HOMER Pro software is proposed for the sizing and optimization of a renewable hybrid system, considering it as an isolated set from the supply network, achieving the optimization and evaluation from technical and economic aspects. Initially, the meteorological data of the site were obtained, from its geographical coordinates; subsequently, the demand profile of one of the households in the community is determined to extrapolate it to the total number of dwellings. The results obtained in this research can serve as a basis for its implementation and, therefore, improve the conditions in which the population of rural communities or isolated from supply networks usually live.

Distributed generation, Optimization, Rural electrification

Resumen

Este articulo tiene como objetivo, mostrar el dimensionamiento y evaluación de un sistema de Generación Distribuida basado en energías renovables para su aplicación en una zona rural en el estado de Veracruz, México. La motivación principal de este trabajo surge a partir de la escasez de energía o de un suministro deficiente en numerosas localidades ubicadas dentro del estado de Veracruz, derivado de diferentes motivos. Se propone una metodología basada en la aplicación del software HOMER Pro para el dimensionamiento y optimización de un sistema híbrido renovable, considerando este como un conjunto aislado de la red de suministro, logrando así la optimización y evaluación a partir de aspectos técnicos y económicos. Inicialmente se obtienen los datos meteorológicos del sitio, a partir de sus coordenadas geográficas; posteriormente, se determina el perfil de demanda de uno de los hogares de la comunidad para extrapolarlo al total de viviendas. Los resultados obtenidos en esta investigación pueden servir de base para la puesta en marcha del sistema y, por tanto, mejorar las condiciones en las que viven los habitantes de comunidades rurales o aisladas de las redes de suministro.

Generación distribuida, Optimización, Electrificación rural

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Introduction

Nowadays, electrical energy is an essential part of people's lives, since, thanks to it, some needs can be solved, such as: food storage, lighting, and even as a support to generate a more pleasant environment with the help of air conditioning or heating systems; among many other applications.

In Mexico there are still many rural communities where there is no or a deficient supply of electricity, which is an important service to achieve a better quality of life.

The concept of Distributed Generation is not new, it has been used since the beginning of electricity generation, since the latter is based on generation at the place of consumption. Subsequently, due to population growth and demand, it has been changing to centralised generation systems located in the geometric centre of consumption areas, and locating loads around them (Comisión Nacional para el Uso Eficiente de la Energía [CONUEE], 2014).

During the first decade of the 21st century, Mexico achieved 96.6% of the population with electricity supply nationwide, of which 60% is in indigenous communities. Most of the people who suffer from a deficient electricity supply are those living in small communities, far from large towns or cities, which hinders the availability of the service due to the lack of infrastructure, roads, water, telecommunications, schools or health care (Banco Nacional, 2017).

One way to estimate the influence of having electricity in a population is by evaluating the human development index (HDI), which is an indicator that assesses the quality of life of people based on three main criteria: life expectancy, education and gross domestic product (United Nations Development Programme [UNDP], 2016). Table 1 shows the direct relationship between the HDI and electricity consumption (kWh per inhabitant) and people's access to electricity (%) (Carrillo, 2019).

IDH	Electricity consumption (kWh/inhab.)	Access to electricity (%)
0.351-0.555	39 - 537	4.5 - 84.9
0.466-0.768	144 -3,419	27.9 - 100
0.637-0.826	271 - 6,603	49.6 - 100
0.779-0.948	2,202 - 19,592	96.4 - 100

Table 1 Relationship of HDI to energy consumption per capita
Source: (Carrillo, 2019)

Community selection

The locality of Atolka was selected in the municipality of Omealca, in the state of Veracruz. It is a town with a total of 35 inhabited dwellings, none of which have electricity supply, according to data obtained from the 2020 population census (Instituto Nacional de Estadística y Geografía [INEGI], 2020a). Table 2 summarises the characteristics of the dwellings in Atolka.

Dwellings	Total
Private	38
Inhabited	35
With electricity	0
With water	0
With drainage	26
With sanitation	0

Table 2 Characteristics of dwellings in Atolka
Source: (INEGI, 2020a)

Once the area where the study is going to be carried out has been selected, it is necessary to know the geographical coordinates of the site, in order to obtain the meteorological data useful in the development of the system. Therefore, from the information obtained (INEGI, 2020b), we know that the locality of Atolka is located at latitude 18.76326 and longitude -96.89923.

Load profile

As it is a rural community, the technological needs are usually lower than those of dwellings in large cities. This is why the load profile for a house in this population is estimated, with the equipment shown in table 3. It is intended that each household will use 3 luminaires, a washing machine, a small refrigerator, a television and a fan (Lamnadi and Boulezhar, 2016).

Apparatus	Power (Watts)
Luminaire 1	23
Luminaire 2	23
Luminaire 3	23
Washing machine	250
Refrigerator	90
Television	70
Fan	50

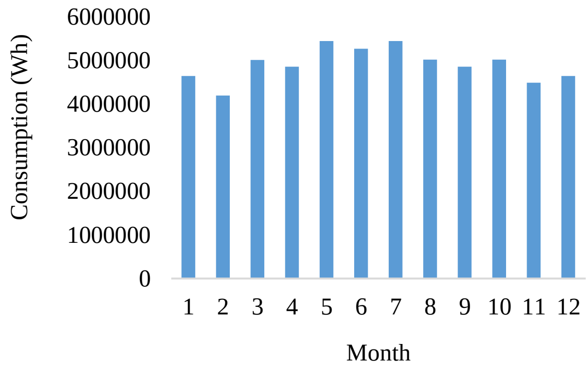
Table 3 Proposed equipment for a community household
Source: Own Elaboration

After obtaining load profiles, a consumption pattern is established for the entire community, depending on the hours of the day and the season of the year. An estimate was made of the operation of the devices during each of the hours of the day in the 365 days of the year, thus obtaining a total of 8760 consumption data. Table 4 shows the consumption data for one day in January. According to López et al. (2018). The consumption of each hour in a dwelling is multiplied by the total number of dwellings (35), to obtain the total consumption of the site.

Day	Hour	Consumption 1 house (Wh)	Consumption locality (Wh)
01/01/2021	01:00:00 a. m.	90	3150
01/01/2021	02:00:00 a. m.	90	3150
01/01/2021	03:00:00 a. m.	90	3150
01/01/2021	04:00:00 a. m.	90	3150
01/01/2021	05:00:00 a. m.	90	3150
01/01/2021	06:00:00 a. m.	90	3150
01/01/2021	07:00:00 a. m.	113	3955
01/01/2021	08:00:00 a. m.	136	4760
01/01/2021	09:00:00 a. m.	136	4760
01/01/2021	10:00:00 a. m.	206	7210
01/01/2021	11:00:00 a. m.	206	7210
01/01/2021	12:00:00 p. m.	229	8015
01/01/2021	01:00:00 p. m.	229	8015
01/01/2021	02:00:00 p. m.	136	4760
01/01/2021	03:00:00 p. m.	183	6405
01/01/2021	04:00:00 p. m.	183	6405
01/01/2021	05:00:00 p. m.	183	6405
01/01/2021	06:00:00 p. m.	206	7210
01/01/2021	07:00:00 p. m.	453	15855
01/01/2021	08:00:00 p. m.	453	15855
01/01/2021	09:00:00 p. m.	229	8015
01/01/2021	10:00:00 p. m.	206	7210
01/01/2021	11:00:00 p. m.	160	5600
02/01/2021	12:00:00 a. m.	90	3150

Table 4 Consumption data for one day in the month of January
Source: Own elaboration

Graph 1 shows the graphical behaviour of consumption throughout the year.



Graphic 1 Hourly consumption profile in a year
Source: Own Elaboration

It can also be seen that in the months of May, June and July, consumption is higher due to higher temperatures.

Application of HOMER Pro

For this case study, the software HOMER Pro was used, which is a tool that performs the simulation and optimisation of energy microgrids, in this case, that of a Distributed Generation system (Homer Energy, 2020).

Fortunately, within the HOMER Pro interface it is possible to insert the load profile from a text format. In this case, the load profile is generated in Microsoft Excel software and saved in .txt format for import into HOMER Pro (Homer Energy, 2020). Once the load profile is available, HOMER Pro displays the window with the summary of the load of the case study in one year, as shown in figure 1.

Figure 1 Load profile in HOMER
Source: Own Elaboration

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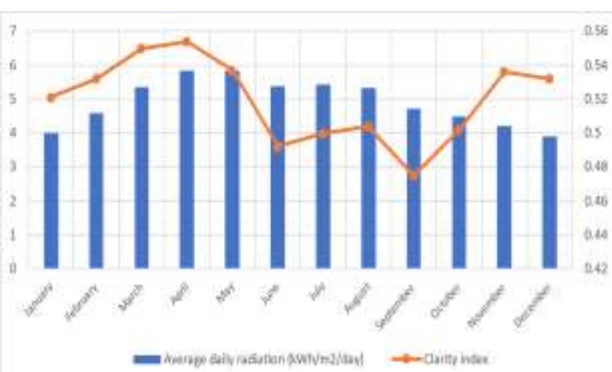
Renewable Resource Assessment in HOMER Pro

The renewable resources that can be used in the selected area for electricity generation are evaluated.

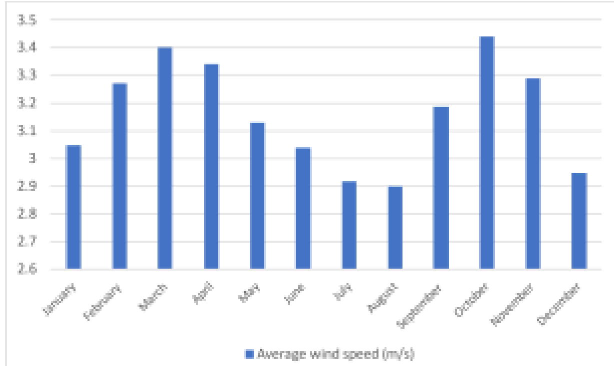
In the case of the community of Atolka, there are no nearby water currents that can be used for electricity generation due to its location. However, energy from the sun and wind can be harnessed, as these are available. Therefore, only the available wind and solar resources are evaluated.

For this study, the data of the renewable resources available at the site are required. In this case those corresponding to the solar resource (radiation) and the wind resource (wind speed). Therefore, a database was sought that would collect such information on an hourly basis (24 data per day taken every hour) for one year. NASA's Prediction Of Worldwide Energy Resources (POWER) Data Access Viewer database was selected. In this platform, the coordinates of the desired location are entered to collect the data in the defined period (Carrillo et al., 2019).

In HOMER Pro, the coordinates of the study site are entered to obtain the meteorological data within the software. These data are taken by HOMER Pro from the NASA POWER database. This generates graphs 2 and 3, which show the average daily radiation data and the average wind speed.



Graphic 2 Solar resources at HOMER
Source: Own Elaboration



Graphic 3 Wind Resources in HOMER
Source: Own Elaboration

Selection of system components

The use of photovoltaic panels and wind generators is proposed, in addition to the incorporation of a diesel generator and a battery bank for the constant supply of electricity. This is because the solar panels only generate energy in the presence of the sun, i.e. during the day, and at night the system would have a lack of generation (Gómez et al., 2018). Table 5 shows the techno-economic data for each of the system components.

Component	Capacity	Cost (DLS)
Photovoltaic panel	0.34 kW	350
Wind generator	10.4 kW	5,000
Battery 1	400 kWh	10,000
Battery 2	2.3 kWh	800
Battery 3	2.36 kWh	780
Inverter	24 kW	2,500
Diesel Generator	22 kW	11,000

Table 5 System components
Source: Own Elaboration

Optimisation in HOMER Pro

The HOMER Optimizer option is selected to obtain the most economical options that meet the load requirements that have been previously entered. As a result, a number of possible combinations are obtained, so that the analysis and selection of the arrangement according to the needs of the system is effective (Homer Energy, 2020).

Results

The top 10 arrays provided by HOMER Pro were chosen (see table 6), ranked in order of increasing net present cost (NPC).

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No. Arrangement	PV (kW)	Eol (kW)	Gen (kW)	Bat 1 (Pza)	Bat 2 (Pza)	Bat 3 (Pza)	Inver (kW)
1	52.1	0	0	2	0	0	24
2	52.5	0	22	2	0	0	24
3	50.0	1	0	2	0	0	24
4	49.7	1	22	2	0	0	24
5	141	3	0	0	69	0	24
6	145	0	0	0	92	0	24
7	142	3	22	0	84	0	24
8	113	4	0	0	0	74	24
9	138	0	22	0	104	0	24
10	99.3	4	22	0	0	94	24

Table 6 Comparative table of optimal arrays PV=Photovoltaic panel, Eol=Wind turbine, Gen=Diesel generator, Bat (1, 2 and 3)= Batteries, Inver= Inverter
Source: Own Elaboration

Table 7 shows the comparison between the first ten arrays, their net present cost (NPC), cost of energy (COE), operation and maintenance (O&M) cost and the renewable fraction (RF), which refers to the percentage of energy generated from renewable sources (Das et al., 2020).

No. Arrangement	CPN (DLS)	COE (DLS)	OyM (DLS/año)	FR (%)
1	$ 98,088	$ 0.129	$ 4,436	100
2	$ 106,861	$ 0.140	$ 4,253	100
3	$ 108,601	$ 0.143	$ 4,918	100
4	$ 116,779	$ 0.153	$ 4,709	100
5	$ 357,329	$ 0.470	$ 18,198	100
6	$ 381,300	$ 0.501	$ 19,679	100
7	$ 386,773	$ 0.508	$ 18,677	100
8	$ 391,225	$ 0.515	$ 20,436	100
9	$ 400,071	$ 0.526	$ 19,742	100
10	$ 420,436	$ 0.553	$ 20,844	100

Table 7 Costs of the ten optimum arrangements
Source: Own Elaboration

The options can be viewed in order of increasing net present cost (NPC). In different configurations, not all components of the system may be considered, so it is important to consider whether or not to sacrifice any suggested component in exchange for a better NPC (Avila et al., 2011).

As shown, HOMER Pro provides multiple options for possible arrangements. So that the set load requirement can be met and with the climatic conditions of the site in question. However, the optimal option is usually the first option, but it is possible for the designer to select another alternative that allows, for example, a balance between cost and renewable fraction. For this case study, the aim was to meet the load profile at the lowest possible cost. Therefore, the option to be selected is the one in the first row of the comparative table provided by HOMER Pro, because it is the most economical arrangement, as well as having a 100% renewable fraction.

If we go into detail, we can see that this arrangement has only a photovoltaic array and an energy storage system (batteries), without considering the inclusion of wind turbines or a diesel generator. In the case of the wind generator, it is not feasible to implement it in the study site, as wind speeds are too low for a generator such as the one proposed to generate enough energy to cover the requested demand. Table 8 shows the summary of the costs of the selected system, where the NPC is the value of all costs over the lifetime of the system minus the value of savings over the same period of time. CI is the Initial Capital of all system components, O&M is the operation and maintenance costs and COE is the cost per kWh consumed (Das et al., 2020).

CPN (DLS)	$98,088.42
CI (DLS)	$40,735.55
OyM (DLS)	$4,436.5/ year
COE (DLS)	$0.129/kWh

Table 8 Summary of selected system costs
Source: Own Elaboration

Since the chosen system does not have a wind or diesel generator, the largest investment will be for the photovoltaic panels and batteries. Table 9 shows the cost summary of the system by selected component. It is possible to appreciate the initial capital, the costs for replacement if required, operation and maintenance costs, the cost for fuel use and savings.

Comp	Capital ($ DLS)	Reemp ($ DLS)	OyM ($ DLS)	Savings ($ DLS)	Total ($ DLS)
PV	18,235.55	-	23,574.03	-	41,809.58
Bat 1	20,000.00	6,376.15	25,855.03	3,593.37	48,637.81
Inverter	2,500.00	2,208.59	3,231.88	299.45	7,641.03
System	40,735.55	8,584.74	52,660.95	3,892.82	98,088.42

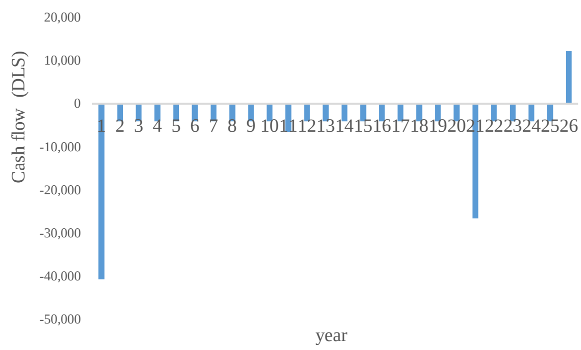
Table 9 Summary of investment costs by component
Source: Own Elaboration

Another figure provided by HOMER Pro was the total energy production of 81,143 kWh for each year the system is in operation.

A Distributed Generation system from renewable resources contributes to the generation of energy through the implementation of clean technologies. In addition, it is possible to obtain economic benefits, as savings would be obtained in the billing of electricity consumed from the conventional supply line by the use of natural energy and an economic saving is generated.

This could be equivalent to the total of our investment over time (CONUEE, 2014).

During the duration of the project (25 years), different passive and active money movements are made. Initial investment, replacement costs and operation and maintenance costs are reflected. Figure 4 shows the cash flow over the 25 years.



Graphic 4 Investment over time
Source: Own elaboration

It is observed that in year 25 there is a positive cash flow, this is due to the fact that at the end of the 25 years, it is possible that there is equipment with a useful life.

Distributed Generation systems have the benefit of a payback period. This refers to the estimated time it takes for the project to pay back the total investment made. Therefore, they are considered to be high profit jobs.

For this case study, the payback period is calculated in years using the following equation:

$$SP = \frac{CI}{AEP * \$/kWh - AOM} \qquad (1)$$

Where, CI is the initial installation cost, AEP is the annual energy production (kWh/year), $/kWh is the cost per kWh and AOM is the annual operation and maintenance costs according to Nelson and Starcher (2015). All money units are shown in dollars.

Substituting the project values into equation 1 yields:

$$SP = \frac{40{,}735.55}{81{,}143 * 0.129 - 4{,}073.55} = 6.37 \text{ years}$$

This means that, if the project is implemented, it is estimated that in approximately six years and five months, enough energy will have been generated to complete the total investment cost.

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Conclusions

Distributed Generation systems allow users to generate a lower environmental impact due to the generation of electricity itself, as it does not depend on traditional energies. In addition, economic benefits are obtained by obtaining a return on investment and savings due to unconsumed consumption of electricity supply lines throughout the time that these alternatives are in operation.

It is important to take into account the services of operation, maintenance and replacement costs for the equipment that requires it in a given period of time, with the intention that the system remains in good working order.

In this particular case, it is not feasible to install wind turbines at the study site due to low wind speeds. This made it possible to supply 100% with solar panels and batteries for energy storage.

The HOMER Pro software resulted in the most economical options for distributed generation systems with 100% renewable fraction, which made it possible not to use energy generated from fossil fuels.

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