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Analysis and Design of a Photovoltaic Power Plant to Improve the Electrical Service in the Island District of Anapia

Heraclio Quispe Quispe, Magister[1], René Huayna Chambilla, Magister[2], Julio Fredy Chura Acero, Doctor[3], Alex Mario Lerma Coaquira, Magister[4], Washington Miguel Soncco Vilcapaza, Doctor[5], Huber Rony Hurtado Arhuata, Magister[6] and Juan Churata Huaraya, Magister[7]
[1,2,3]Universidad Nacional del Altiplano, Perú, heracliusquispe@gmail.com, huaynaing2020@gmail.com, jchura@unap.edu.pe
[4,5,6,7]Universidad Nacional de Juliaca, Perú, a.lermac@unaj.edu.pe, wm.soncco@unaj.edu.pe, h.hurtado@unaj.edu.pe and j.churata@unaj.edu.pe,

Abstract*– This The present investigation presents the analysis and design of a photovoltaic plant to improve the electrical service of the Anapia district belonging to the Yunguyo province, Puno region, due to frequent failures in the underwater power section of its primary network. The electricity market study was carried out with which the maximum energy demand was determined. then we proceeded to analyze the solar resource and design the photovoltaic plant to cover the maximum demand. Finally, the calculations of the magnitude of the electrical parameters were carried out, obtaining a maximum demand of 440,309KWh/year (1206.33KWh/day), at peak solar hour of 6.20h; The photovoltaic plant will consist of 627 photovoltaic modules of 390Wp, to 175KV-380/13.2KV step-up, 10 grid inverters of 25KW, 360 lithium-ion batteries of 1.5KWh, transformer. In conclusion, the results obtained lead to the solution of the problem.

***Keywords*-- Photovoltaic system, electrical system, irradiance, Anapia, Yunguyo.**

I. Introduction

At present the population of the insular district of Anapia belonging to the province of Yunguyo, Puno region suffers hardships due to power cuts electrical energy that is presented in a frequent from years ago to the present; where the energy reset time it lasts days, weeks and even months; this due to deterioration of the underwater conductor of average voltage installed in 2007. Currently electricity is supplied with restrictions to public lighting by means of two groups generators Therefore, those directly affected by the unreliability of the electrical supply is the general population, students, the sector health and other institutions that provide services. In this context, it is evident the need of a reliable and quality electrical service. By Therefore, the present project will allow solving in a practical and concise way the problem of electrical service in the insular district of Anapia, harnessing the inexhaustible solar resource at scale human resources to design a photovoltaic plant. He contribution that is made with this project is the design of a photovoltaic plant to inject energy electricity to the area network there are 13.2KV. For it is necessary to determine the maximum demand for energy required by the Anapia district and with this will analyze and design the photovoltaic plant.

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A. Electricity Market Study

The main objective of the market study electricity carried out in the district of Anapia is that of quantify the projection of demand for power and electrical energy [1], in a horizon of 20 years [2]. Considering the features of the localities that comprise the district island of Anapia such as its geographical location, socioeconomic activities, population, number housing, population growth rate, etc.

B. Description of the Technology to be Employed

The technology used by the plant photovoltaic will be to convert solar energy into electrical energy through modules photovoltaics [3], [4].

When solar radiation hits the modules photovoltaics, this is converted into electrical energy of direct current and after that converts to alternating current for distribution, which is achieved by grid inverters. For take advantage of the energy in the electrical network is used of elevating distribution substations tension [5], so that the energy is injected into the primary network.

The energy storage system you need bi-directional inverters that set the voltage and frequency parameters of the network, so that if, for example, it is required to load the battery bank and there is generation power available, take advantage of this energy and store it in the battery banks, making it available of the demand [6], [7].

If the energy accumulation is insufficient to meet demand, automatically activates a generator set [8], to supply the missing energy demand, while charges the battery bank; the operation of generator set is conditioned until satisfies the demand requirement and/or a desired charge level in the battery bank.

II. Materials and Methods

A. Place of study

This research was carried out at the Anapia Island, located in the Puno region, Yunguyo province, Anapia island district. With UTM coordinates 515511.00 m E, 8197421.00 m S, zone 19 K, with an altitude of 3856 m.s.n.m.

B. Population

In this research, it has been study population energy supply electric company of the Anapia district.

C. Sample

In this investigation, it has been study sample maximum energy demand electric company of the Anapia district.

D. Methodological design

This research has a focus. quantitative, because it uses data collection and numerical measurement [9]. It is descriptive and non-experimental design.

E. Data Collection

For the electricity market study, information on the population and housing was sought from the database of the National Institute of Statistics and Informatics (INEI) identifying in the year 2022 the amount of 631 subscribers, then the identification was made of the type of subscribers through the work of field obtaining 602 domestic subscribers, 18 subscribers for general use and 11 subscribers for commercial use with which the maximum demand in the year 2042.

Then we proceeded to analyze and design the plant photovoltaic to cover the maximum demand, for this, the available data was taken between the years 1984-2021 of the solar resource and the years 1984-2021 of the solar resource and the temperature available in the project area from the database of the National Aeronautics and Space Administration (NASA) obtaining direct irradiation of 6.20 KWh/m^2/day and average minimum temperatures 2 meters above the ground at -6.58°C, temperature average 7.64°C and maximum temperature of 22.65°C.

III. Results

A. Electricity Market Study

To determine the maximum demand, determined the following:

- Number and type of subscribers, see Table I.
- Population growth rate.
- Projection of subscribers to year 20.
- Demand projection criteria.
- Projection of maximum demand.

To determine the population growth rate, the INEI database referring to district censuses shown in Table II was accessed and (1) was used.

$$t_c = \sqrt[n]{\frac{P_n}{P_0}} - 1 \ [\%] \quad (1)$$

Where t_c is the population growth rate, Pn is the projected population, P_0 is the initial population, and n is the number of years.

TABLE I
LOCATIONS AND NUMBER OF SUBSCRIBERS

N°	Localidad	Distribución de Abonados			Total, de Abonados
		Abon. Domes.	Uso General	Uso Comercial	
1	ANAPIA	393	11	8	412
2	CAANA	20	1	0	21
3	PAMPACCATA	4	0	0	4
4	SIPSIPAMPA	6	0	0	6
5	YAMPUPATA	2	0	0	2
6	KASAPAMPA	4	0	0	4
7	KELE	1	0	0	1
8	UTAPUJRUPAMPA	9	0	0	9
9	YANISTIPAMPA	2	0	0	2
10	PATAMANTA	4	0	0	4
11	TAQUISIÑA PAMPA	7	0	0	7
12	ARACCA	20	0	0	20
13	CAÑO	3	0	0	3
14	SUANA	91	6	3	100
15	PATA HUATA	12	0	0	12
16	CHIRUAKA	7	0	0	7
17	KESKAPI	3	0	0	3
18	TINAKACHI	2	0	0	2
19	TARQUI	4	0	0	4
20	KANTUTANI	8	0	0	8
	TOTAL	602	18	11	631

TABLE II
POPULATION GROWTH RATE

CENSOS DISTRITALES	Población		TCP (%) Interanual	TCP (%) ELEGIDO
DISTRITO	AÑO	Población		
ANAPIA	2018	1826		1.00%
	2019	1787	-2.14%	
	2020	1743	-2.46%	
Promedio Global			-2.30%	1.00%

He growth rate obtained is negative. Therefore, a 1% population growth rate is assumed for type I and II localities. With the growth rate of proceeds to project the amount by type of subscriber to year 20, using (2), which is the result of clearing the projected population see (1). The results are shown in the Table III.

$$P_n = P_0(1 + t_c)^n \quad (2)$$

TABLE III
SUBSCRIBER PROJECTION FOR YEAR 20

N°	Localidad	TCP (%)	ABONADO DOMÉSTICO	ABONADO USO GENERAL	ABONADO COMERCIAL	TOTAL ABONADOS
1	ANAPIA	1.00%	480	13	10	503
2	CAANA	1.00%	25	1	0	26
3	PAMPACCATA	1.00%	5	0	0	5
4	SIPSIPAMPA	1.00%	7	0	0	7
5	YAMPUPATA HUENCALLA	1.00%	3	0	0	3
6	KASAPAMPA	1.00%	5	0	0	5
7	KELE	1.00%	1	0	0	1
8	UTAPUJRUPAMPA	1.00%	11	0	0	11
9	YANISTIPAMPA	1.00%	3	0	0	3
10	PATAMANTA	1.00%	5	0	0	5
11	TAQUISIÑA PAMPA	1.00%	9	0	0	9
12	ARACCA	1.00%	25	0	0	25
13	CAÑO	1.00%	4	0	0	4
14	SUANA	1.00%	111	7	4	122
15	PATA HUATA	1.00%	15	0	0	15
16	CHIRUAKA	1.00%	9	0	0	9
17	KESKAPI	1.00%	4	0	0	4
18	TINAKACHI	1.00%	3	0	0	3
19	TARQUI	1.00%	5	0	0	5
20	KANTUTANI	1.00%	10	0	0	10
	TOTAL		**740**	**21**	**14**	**775**

Criteria for energy projection shown in Table IV, were from energy consumption receipts from the Anapia district and were compared with the consumption of similar electrical services to determine the growth rate of electrical energy consumption. In addition, electrical energy losses were taken according to technical report No. 0432-2013-GART (Osinergmin).

TABLE IV
UNIT CONSUMPTION OF ELECTRICAL ENERGY BY TYPE OF SUBSCRIBER

Tipo de Localidad	C.U. Inicial kWh-mes	C.U. Final kWh-mes	Tasa de Crec. (%)
SECTOR DOMESTICO			
I	20.00	28.30	1.75%
II	16.00	21.13	1.40%
SECTOR COMERCIAL			
I	22.00	31.13	1.75%
II	17.60	23.24	1.40%
SECTOR USO GENERAL			
I	130.00	250.00	3.32%
II	98.00	135.00	1.61%
ALUMBRADO PÚBLICO			
Tipo de Localidad	I	II	
KWh-mes/usuario	11.00	6.30	KALP

With the projection of the subscribers and with the criteria of electrical energy consumption, the maximum demand for energy consumption shown in Table V was determined.

TABLE V
PROJECTION OF THE ENERGY DEMANDED

N°	Localidad	ABONADO Domestico	ABONADO Uso General	ABONADO Comercial	Alumbrado público	Pérdidas BT	Pérdidas MT	Total energía
1	ANAPIA	162,982.45	39,000.00	3,735.60	66,396.00	22,094.12	5,707.64	299,915.80
2	CAANA	6,338.70	1,620.00	0.00	1,965.60	854.76	209.11	10,988.18
3	PAMPACCATA	1,267.74	0.00	0.00	378.00	136.16	34.57	1,816.46
4	SIPSIPAMPA	1,774.84	0.00	0.00	529.20	190.62	48.40	2,543.05
5	YAMPUPATA	760.64	0.00	0.00	226.80	81.69	20.74	1,089.88
6	KASAPAMPA	1,267.74	0.00	0.00	378.00	136.16	34.57	1,816.46
7	KELE	253.55	0.00	0.00	75.60	27.23	6.91	363.29
8	UTAPUJRUPAMPA	2,789.03	0.00	0.00	831.60	299.54	76.05	3,996.22
9	YANISTIPAMPA	760.64	0.00	0.00	226.80	81.69	20.74	1,089.88
10	PATAMANTA	1,267.74	0.00	0.00	378.00	136.16	34.57	1,816.46
11	TAQUISIÑA PAMPA	2,281.93	0.00	0.00	680.40	245.08	62.22	3,269.64
12	ARACCA	6,338.70	0.00	0.00	1,890.00	680.78	172.84	9,082.32
13	CAÑO	1,014.19	0.00	0.00	302.40	108.92	27.66	1,453.17
14	SUANA	37,689.69	21,000.00	1,494.24	16,104.00	6,463.75	1,605.38	84,357.07
15	PATA HUATA	3,803.22	0.00	0.00	1,134.00	408.47	103.71	5,449.39
16	CHIRUAKA	2,281.93	0.00	0.00	680.40	245.08	62.22	3,269.64
17	KESKAPI	1,014.19	0.00	0.00	302.40	108.92	27.66	1,453.17
18	TINAKACHI	760.64	0.00	0.00	226.80	81.69	20.74	1,089.88
19	TARQUI	1,267.74	0.00	0.00	378.00	136.16	34.57	1,816.46
20	KANTUTANI	2,535.48	0.00	0.00	756.00	272.31	69.14	3,632.93
	TOTAL (KWh/año)	**238,450.80**	**61,620.00**	**5,229.84**	**93,840.00**	**32,789.29**	**8,379.44**	**440,309.37**
	TOTAL (KWh/mes)	**19,870.90**	**5,135.00**	**435.82**	**7,820.00**	**2,732.44**	**698.29**	**36,692.45**
	TOTAL (KWh/día)	**653.29**	**168.82**	**14.33**	**257.10**	**89.83**	**22.96**	**1,206.33**

B. Design of the Photovoltaic Power Plant

Know the demand for energy and power, as well as an energy resource are essential for the design of the photovoltaic plant. For this, it is need to know the following:

1) Power requirement.

Annual energy at year 20: 440,309.37 kWh/year

Monthly energy to year 20: 36,692.45 kWh/month

Daily energy of year 20: 1,206.33kWh/day

2) Location of the photovoltaic plant.

The study site for the photovoltaic power plant is located on the north side of the island of Anapia the which has UTM coordinates 515511.00 m E, 8197421.00 m S, zone 19 K, or coordinates geographic latitude -16.3041 and longitude -68.8548, to an altitude of 3856 m.s.n.m.

3) Available solar resource of 6.2 KWh/m2 /day, dividing this value by the irradiance of 1 KW/m^2, the HSP is obtained being equal to 6.2 h/day.

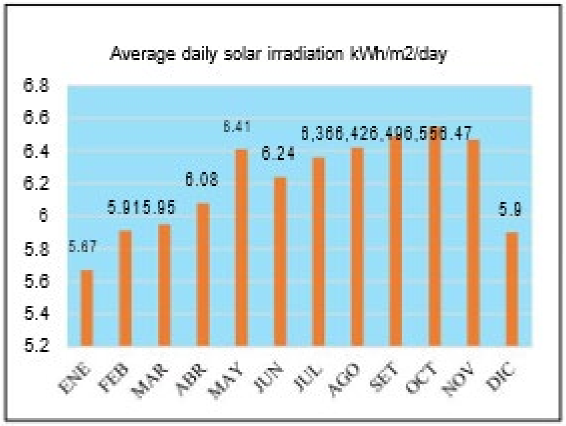

Fig. 1 Average daily solar radiation.

4) Technical specifications of the technology to use. For the design of the plant, a technical characteristics photovoltaic module shown in Table VI, and a grid inverter technical characteristic shown in Table VII.

TABLE VI
TECHNICAL SPECIFICATIONS OF THE MODULE

peak power	390	wp
Short circuit current (Isc)	9.45	TD
Vacuum voltage (Voc)	52.9	V
MPP current	8.85	TD
MPP voltage	44.1	V
Coeff Tem Open Circuit Voltage	-0.38% / °C	
Coeff Tem short circuit current	0.04% / °C	
Coef Tem power MPP	-0.47% / °C	
TONC	[illegible]	°C
panel width	998mm	
panel length	2067mm	

TABLE VII
TECHNICAL SPECIFICATIONS OF THE INVERTER

Maximum allowable tension	1000V
maximum admissible intensity	33A
MPP voltage range	
Minimum	390V
Maximum	800V
Rated input voltage	600V
DC power	25000W
AC power	25000W
Short circuit current	43A

5) Energy loss factor. The estimation of the energy loss factor. It is essential to determine the efficiency of the photovoltaic generation system.

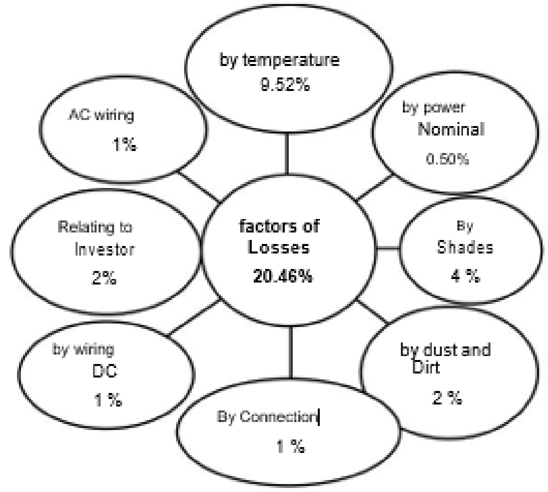

Fig. 2 Loss factor consideration.

The efficiency of the photovoltaic plant will be 79.54%.

6) Calculation of the number of photovoltaic modules. To calculate the number of photovoltaic modules, see (3) was used.

$$N^0_{module} = \frac{E}{n_{system} * P_{module} * HSP} \tag{3}$$

Where:
E : Energy demanded (KWh/day).
HSP : Peak solar hour (h)
Pmodule: Peak power of the module (Wp).
n_{system} : Efficiency (%)

Replacing the values in (3), the result is the number of 627 photovoltaic modules.

7) Determination of the photovoltaic arrangement.
Maximum photovoltaic modules in series : 17 units.
Minimum photovoltaic modules in series : 8 units.
Photovoltaic modules will be installed : 13 units.
Number of network inverters : 10 units.
Number of module chains per inverter : 5 units.
Maximum number of chains per inverter input: 3 units

8) Calculation of the storage system. Characteristics of the selected battery.
Battery power 1,500.00 Wh.
Nominal Capacity of the Batteries 30.00 Ah.
Maximum discharge depth 5%.
Group voltage 52 V.
Capacity of accumulation groups 18 kWh.

To calculate the number of batteries, in (4) was considered.

$$Nro_{batteries} = Cn/C\ bat \tag{4}$$

Where:
C_n : Required charge capacity (Ah).
C_{bat} : Nominal battery capacity

6 banks of 60 batteries were used, for this 360 Lithium Ion batteries were determined.

9) Calculation of the generating set. Necessary Parameters:
Nominal Power: 200 kwm
Installation Altitude: 4100 meters above sea level
Derating: 3% for every 500 over 1000m.s.n.m.
System Power: 151.44 kw.
Power with Derating: 153,453 kwm.
Electrical power Pm*0.8: 122.7616kwe.

10) Calculation of the step-up transformer. To determine the capacity of the transformer, (5) was considered.

$$P_{trafo} = \frac{(P_{dem} + P_{P(Re,Cu,Fe)})}{cos\emptyset} \quad (5)$$

Where:
$Ptrafo$: Power of the required transformer.
$Pdem$: Maximum demand power.
$Pp\ (\ Re\ ,\ Cu\ ,\ Fe\ )$: Power losses.
cos $\emptyset$: Power factor of the transformer.

Apparent power of the transformer will be the ratio of active power and power factor, resulting in 172.83 KVA. Therefore, a 175KVA step-up transformer will be selected.

If a 30% transformer overload is considered, a 150KVA transformer could be selected, in order not to oversize the transformer.

IV. Discussions

At the end of this work, where the values of maximum demand for electrical energy were analyzed to design a photovoltaic plant, it is technically feasible. This is corroborated by the studies carried out by [10], [11] who designed an isolated photovoltaic power plant.

"Design, implementation and economic analysis of a 3 KW grid-connected photovoltaic system (SFCR) with DC/DC converters analyzed in the geographical and climatological conditions of the city of Juliaca" [12], indicates that a photovoltaic system connected to network is viable with a 12-year amortization of the investment, being technically and economically feasible. Likewise in the Work "design of a 30MW photovoltaic solar plant, for technical analysis. Operational and economic in the SEIN, located in Tacna-2017" an economic analysis of the design of a 30MW interconnected plant was carried out, indicating that the installation of plants interconnected to the National Interconnected System is technically and economically feasible. To carry out the economic comparison of the present project with the aforementioned background, the economic analysis was carried out [13].

V. Conclusions

A photovoltaic plant was designed to cover the maximum demand and thereby improve the electrical service in the island district of Anapia. The most important thing about the design was to determine the maximum demand and have the solar resource throughout the year; What helped the most to design the photovoltaic plant was the information obtained on the number and type of subscribers, because it allowed the demand to be projected and thus dimension the photovoltaic plant.

The electricity market study of the insular district of Anapia was carried out, with the maximum energy demand being 440,309 KWh/year, with the energy demanded by 740 domestic subscribers, 21 general use subscribers and 14 commercial use subscribers.

The magnitude of the electrical and mechanical parameters of the photovoltaic plant was determined according to the maximum demand required for which the photovoltaic plant was designed, composed of 627 photovoltaic modules of 390 watts peak, distributed in chains of 13 photovoltaic modules in series, 19 boxes of connection, ten grid inverters of 25,500watt, 360 lithium-ion batteries of 1,500watt hour, 18 6,000watt bidirectional inverters and a pedestal-type step-up transformer of 165 kVA.

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References

[1] A. F. Gutiérrez Huamán, "El Estudio del Mercado Eléctrico en Proyectos de Electrificación Rural," 2006. Accessed: Feb. 26, 2023. [Online]. Available: https://www.lareferencia.info/vufind/Record/PE_8cfde8d2b6851116273320e833950e85
[2] Ministerio de Economía y Finanzas, "Guía para la formulación de proyectos de inversión exitosos electrificación rural," MEF 2011.
[3] O. P. Lamigueiro, *ENERGÍA SOLAR Fotovoltaica*. 2020. [Online]. Available: https://github.com/oscarperpinan/esf
[4] D. Barberá Santos, "Introducción a la Energía Fotovoltaica 2. Introducción a la Energía Fotovoltaica 2.1. Introduction," 2011. Accessed: Apr. 04, 2023. [Online]. Available: https://biblus.us.es/bibing/proyectos/abreproy/70271/fichero/02+INTRODUCCI%C3%93N+A+LA+ENERG%C3%8DA+FOTOVOLTAICA%252FIntroducci%C3%B3n+a+la+Energ%C3%ADa+Fotovoltaica.pdf
[5] M. A. Rodríguez Pozueta, *TRANSFORMADORES*. 2012. Accessed: Apr. 02, 2023. [Online]. Available: http://personales.unican.es/rodrigma/primer/publicaciones.htm
[6] A. Forget, "Manual de diseño de sistemas fotovoltaicos aislados," 2011.
[7] J. Vera, "Diseño de una Instalación Fotovoltaica de 10 KWp Conectada a la Red de Baja Tension," 2009.
[8] G. Rojas, "GENERATING SETS BASIC PRINCIPLES," 2018.

[9] R. Hernández Sampieri, Methodology of the Research, Sixth Edition. 2014.
[10]JA Peralta Berlanga, “Design of a central wind-photovoltaic electricity of 50KVA in the town center of Chaucalla district of Toro and Chichas Department of Arequipa,” 2019.
[11]MA Castro Sánchez, “Photovoltaic system isolation, medium and low voltage networks for the Amantaní Island, province and department of Puno,” 2019.
[12]V. Chavez Chambi, "Design, Implementation and Analysis Economics of a System Photovoltaic Connected to the Network (SFCR) of 3 Kw with CC7CC Converters Analyzed in the Geographical Conditions and Climatological Conditions of the City of Juliaca,” Juliaca, 2020.
[13]JP Rojas Bismarck, “Design of a central 30MW photovoltaic solar, for analysis technical, operational and economic in the SEIN, located in Tacna-2017” 2018.