SPECIFIC ASPECTS IN THE DESIGN OF HYBRID SYSTEMS POWERING THE TELECOMMUNICATIONS TOWERS

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Abstract - This paper aimed to identify the main aspects and influencing factors in the design of hybrid systems for powering base transceiver stations based on solar resources, with the goal of optimizing both the design and the initial investment costs for these systems. For this purpose, a hybrid solar-Diesel system with battery storage was designed for a low-power transceiver station, located in an area with a well-defined solar resource. Both the main design stages and the influencing factors on the design and, implicitly, the costs were identified, with the study's conclusions highlighted at the end.

Keywords: base transceiver stations (BTS), hybrid power system (HPS), design current, storage days, depth of discharge (DOD)

1. INTRODUCTION

In the modern era of telecommunications, the demand for mobile connectivity continues to grow, with BTS stations increasingly being located in isolated areas, far from national electrical grids [1,2]. This necessitates power generation systems based on local renewable resources, which can ensure the efficient and reliable operation of these stations. Hybrid power systems for electricity generation based on renewable resources represent an attractive solution for these cases, particularly due to the technological maturity achieved in this field and the existence of a developed market for their components.

By understanding the influencing factors on the design of hybrid energy systems, it becomes possible to develop more cost-effective and efficient solutions for powering BTS.

On the other hand, conclusions drawn from studies of this kind can provide valuable insights for optimizing hybrid power systems for BTS, highlighting both technical and economic considerations.

2. DESIGNING THE HPS FOR BTS POWERING

The power supply systems of BTS must be designed to withstand extreme weather conditions on-site, ensuring uninterrupted telecommunications operation.

In order to identify the specificities of the HPS used to power BTS isolated from the national electricity networks, a case study was considered, namely the need for a BTS within a telecommunications network. For this purpose, we consider a BTS located at an altitude of 1500 meters in the area of Ineu , Bihor country at an elevation of 600m, where temperatures range from -25 to +47 degrees Celsius, has been chosen.

For HPS design, we consider a preliminary stage in which we adapt the mathematical model taken from [3], in which a list of the receivers included in the BTS component is drawn up. Thus, the loads within the telecommunications tower consist in: a microwave radio for GSM communications, a VHF radio, a warning collision beacon and security lighting during the night, Table 1. For this study, both BTS with and without an active air conditioning system are considered.

Table 1. The loads included in the BTS

DC Load	Qty	Load current [A]
Microwave radio:		
Rely	1	5
VHF radio:		
Transmit	1	15
Receive	1	3.2
Standby	1	0.32
Warning collision beacon:		
LED (dc)	1	2
Flasher	1	0.2
Surge current	1	0.4
Night lighting/security:		
LED (dc- equiv.100W/ac)	2	0.7
CCTV+motion sensor	1	0.5
Air conditioning:		
Small 150W 24V dc unit	1	6.25

The microwave radio in this case operates at 24V while the VHF radio operates at 12V due to the fact that in transmission mode, VHF radio has the highest load current, Table 2. Operating the VHF radio at a voltage higher than 12V would lead to an increase in the daily amp-hour load [3].

The daily duty cycle varies, as shown in Table 2: the microwave relay and air conditioning must operate 24 hours/day, while the VHF radio we consider to operates only for 13.5 hours/day, with 3 hours in standby mode.

The operating time of the warning beacon is considered to be 1s on and 3.6s off, i.e., a total operating cycle time of 4.6 s. This represents a daily cycle duration of 1/4.6 s = 0.22, or 22% of the day. The beacon operates only at night, and for this, the duration of the longest night is considered to be 13 hours, resulting in a daily usage cycle of 0.22 * 13 = 2.9 hours/day.

Table 2. Amp hour load for the BTS components

DC Load	U_n [V]	Duty cycle [h/d]	U_{nHPS} [V]	Ah load [Ah/d]
Microwave radio:				
Rely	24	24	24	120.00
VHF radio:				
Transmit	12	10.5	24	98.44
Receive	12	10.5	24	21.00
Standby	12	3	24	0.60
Warning beacon:				
LED (dc)	12	2.9	24	2.90
Flasher	12	2.9	24	0.29
Surge current	12	0.29	24	0.58
Night lighting/security:				
LED (dc-equivalent 100Wac)	12	13	24	9.10
CCTV+motion sensor	12	24	24	6.00
Air conditioning:				
Small 150W 24V dc unit	24	24	24	150.00
TOTAL Ah LOAD*				**254.00**

* Roundup value

Whenever the flasher is activated, there is a surge current of 0.4 A that lasts 1/10 of the time the flasher is on thus, its daily usage cycle will be 1/10 * 0.29 = 0.29 hours/day.

Due to the nominal voltage of the hybrid system being chosen as 24V, a DC-DC converter is provided for the 12V DC load.

To ensure the uninterrupted operation of the BTS, both an energy storage system in battery and a Diesel generator are provided. The Diesel generator is designed to power the load and charge the batteries when the photovoltaic system does not provide electrical energy during the night or in inclement weather conditions, Figure 1.

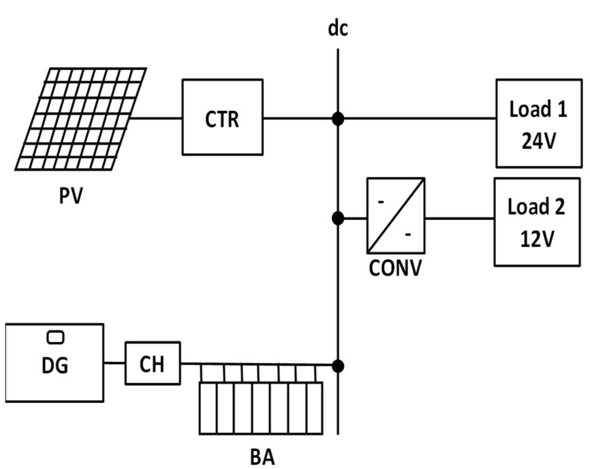

Fig. 1. Diagram of the hybrid system for powering the BTS

Taking into account the receivers within the BTS considered in Table 2, a total of 254 Ah load needed to be covered per day.

Considering the cable losses and the efficiency of the battery storage system (0.98 and 0.95, respectively - default values [3]), the corrected daily required load will be 273 Ah.

Before moving on to sizing the components, we conduct a test to determine if the application is suitable for a hybrid system. For this we calculate and represent graphically the daily load in watt-hours versus the array/load ratio, Fig.2.

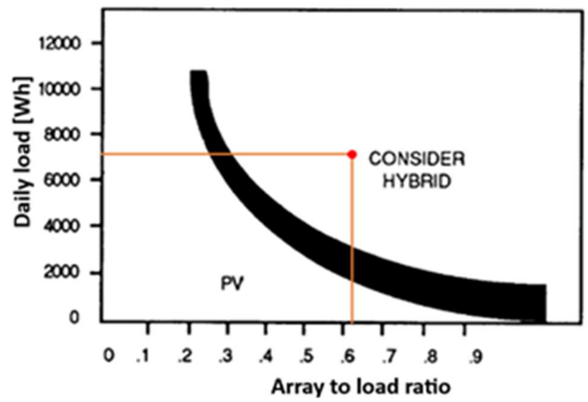

Fig. 2. The decision graph for an HPS

Due to the fact that the point of intersection of the two calculated values falls in the consideration area for a HPS, the necessity of such a system is confirmed and we move on to sizing its components. By adapting the mathematical model from [3], the following sizing steps resulted:

1) Calculating the design current and array tilt

The current required to meet the system load (design current I_{desg} [A]) depends on two very important parameters: corrected amp-hours per day and peak sun hours [4] noted in this paper with I_{day_cor} [A] respectively S_{sun} [h/d].

The peak sun hours quantify the solar resource in the location and, in our case, it is determined for different angles of inclination of the photovoltaic panels, Table 3 using an on-line calculator [5].

Table 3. Insolation values at different tilt angle for the BTS location [5]

Month	Peak sun hours S_{sun} [h/d]			
Tilt angle	**35°**	**45°**	**50°**	**57°**
January	1.97	2.03	2.06	2.1
February	2.95	3.07	3.1	3.11
March	4.14	4.21	4.21	4.18
April	4.85	4.73	4.63	4.45
May	5.76	5.49	5.31	5.02
June	6.28	5.91	5.68	5.31
July	6.64	6.31	6.08	5.72
August	6.19	6.01	5.87	5.6
September	5.02	5.04	5	4.9
October	4.23	4.39	4.43	4.43
November	2.33	2.46	2.5	2.53
December	1.63	1.73	1.77	1.8

From Table 3 it can be seen that the most unfavorable month from the point of view of the solar resource is December and for this month, the highest value of S_{sun} is 1.8 at an PV panel inclination of 57 degrees.

With these values, the current design is calculated for each month, the results being summarized in Table 4.

Table 4. Design current of each month

Month	I_{day_cor} [Ah/d]	S_{sun} [h/d]	I_{desg} [A]
January	273.0	2.1	130.0
February	273.0	3.1	87.8
March	273.0	4.2	65.3
April	273.0	4.5	61.3
May	273.0	5.0	54.4
June	273.0	5.3	51.4
July	273.0	5.7	47.7
August	273.0	5.6	48.8
September	273.0	4.9	55.7
October	273.0	4.4	61.6
November	273.0	2.5	107.9
December	273.0	1.8	151.7

Table 4 shows that for the highest S_{sun} value of 5.7 h/d in July, we have the lowest I_{des} of 47.7A, marked with yellow and for December we have an I_{des} of 151.7 A at S_{sun} of 1.8 h/d. The later will be the values that will be considered, because it is necessary to size the PV panel for the most unfavorable month [3].

The **design current** of 151.7A is the current that PV panels give for the standard operating conditions [3]. In order to adjust this current to the real conditions in the field (which are influenced by covering of surfaces with dust, degradation over time, etc.) the **derate factor coefficient** (K_{tFV}) must be taken into account. If data from the PV panels manufacturer is not available, the implicit values of 0.9 for crystalline PV and 0.8 for amorphous PV are entered. For this case study we will use crystalline PV panels, so we will consider K_{tFV} = 0.9 resulting a **derated design current** of I_{PV} = 168.52 A

2) PV design

Usually, for systems that require high reliability, the PV contribution to load coverage is chosen between [90-95] %. In the present case, due to the climatic zone with a long period of unfavorable weather, the percentage provided by PV was adjusted so as to take into account the climate conditions and the initial cost to be as low as possible.

Thus, it was considered that PV should provide 75% of the annual electrical energy required for the load, which implies a hybrid to array ratio of 0.3. It results a necessary power installed in the photovoltaic system of P_{SFV} = 1965.6W.

In order to satisfy this requirement, photovoltaic panels of the CO-MEM type were chosen, whose technical characteristics are summarized in Table 5.

Next, a number of 11 PV panels in parallel resulted from the calculations, and due to the fact that the HPS voltage is equal to the photovoltaic panel voltage, the number of PVs in series will be 1, thus, the total number of PV panels required for the system will be 11 units.

Table 5. The chosen PV panel characteristics [6]

Polycrystalline ECO-MEM 50316			
Characteristics	**Symbol**	**Value**	**[Unit]**
Rated Power	P_{PV}	300	W
Voltage required for load	U_n	24	[V]
Rated voltage	U_r	28.5	[V]
Open circuit voltage	U_{opc}	32.3	[V]
Voltage at highest expected temperature	U_{mppt}	27	[V]
Rated current	I_{nPV}	7.85	[A]
Short circuit current	I_{sccPV}	8.16	[A]
Price	p	483	[$]

3) BA design

The sizing of the HPS storage subsystem depends on three main factors: storage days, maximum depth of discharge and derate for temperature of the battery.

By storage days is meant "the consecutive number of days the battery subsystem is required to meet the load with no energy production by the array" [3].

In the case of stand-alone PV systems that require an availability of over 99%, such as the current BTS case, the number of storage days is estimated using the chart in Figure 3.

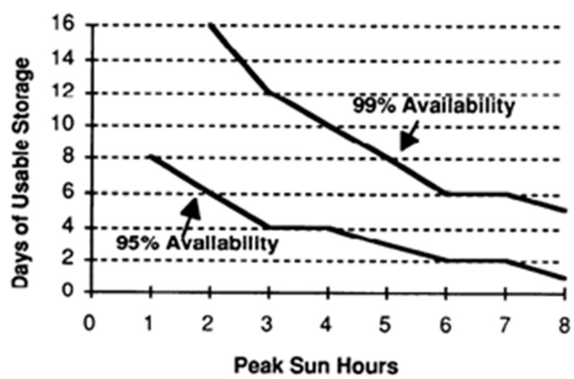

Fig. 3. Storage days defaults [3]

In the case of isolated hybrid systems, due to the fact that a Diesel group is available for backup, the number of storage days can be lower [3]. Therefore, it is decided that the average number of days during which electricity from the solar resource is not available is 5.5 days.

In the case of HPS, batteries with a deep cycle discharge are used, so for sizing, the DOD value of 0.8 is usually taken. To protect the battery and thus extend its service life, the value of 0.75 is considered, and the charge controller is set according to this value.

If not provided by the manufacturer, the default value for the factor that derates the battery capacity with decreasing temperature is 0.9.

Considering the values resulting from the reasons stated above, a battery capacity required to meet the daily load for the required number of storage days of 2224.4 Ah/d.

Choosing a battery of 3000 Ah and 2V nominal values, the storage system results in a number of 12 batteries in series and one in parallel, i.e. a total number of 12 batteries. The technical characteristics for the chosen battery are presented in the Table 6.

Table 6. The chosen BA characteristics [7]

Rosen Solar gel deep cycle		
Characteristics	**Value**	**Unit**
Nominal Voltage	2	[V]
Capacity	3000	[Ah]
Price	570	[$]

At a DOD of 0.75, this battery provides the system with a capacity of 2250 AH/d sufficient to cover the design requirement of 2224.4 Ah/d and at the same time ensures increased battery protection.

4) Diesel group design

For these values obtained for the storage system and for the calculated currents, the following results necessary for the DG sizing were obtained, summarized in Table 7.

Table 7. Values obtained for DG sizing

Parameter	Value	Unit
Battery discharge time	136,8	[h]
Considered battery charge time	10	[h]
Charging power required	5338.67	[W]
Generator size	7851	[W]

The altitude at which BTS is located and, implicitly, DG being 1500m, the coefficient of influence of altitude on the DG engine will be Kalt = 0.85.

Due to the fact that, when it is on, the DG is supposed to supply energy both for the BA load (7851 W) and for the load supply (390.24 W), the total power of the DG must be greater than their sum, i.e. 8241.2 W.

From the manufacturers' catalogs, a 9 kW DG was chosen with the technical characteristics presented in the Table 8

Table 8. The chosen DG characteristics [8]

Cummings RS 1200 GRCA			
Characteristics	**symbol**	**value**	**[unit]**
Rated power	P_n	9000	[W]
Nominal voltage	U_{nP}	120/240	[V]
Rated current	I_n	75.7/37.5	[A]
Operating speed	n	3600	[rpm]
Fuel consumption at full load	f_c	7.5	[l/h]
Sound level at 7m	β	70	[dB]
Fully automatic operation			Yes
Electronic governor			Yes
Need for concrete pad			No
Fuel			Natural gas

Taking into account the typical oil change interval for gas generators of 50h [3] , for the selected DG, an annual maintenance interval of 3 resulted.

5) Power electronics sizing

As for power electronics, in the case of this system, a DC/DC 24V/12V converter has been dimensioned for the lower load, along with the charging controllers, their technical characteristics being summarized in Table 9.

Table 9. Converter characteristics [9]

Willmore Electronics Model 1645-24-12-30	
Input voltage	24V
Output voltage	12V
Output current	30A

Four charging controllers in parallel were necessary, so the PV system was divided into two, providing also an increased reliability for the system, Table10.

Table 10. Charge controller characteristics [10]

Specialty Concepts Model SC1	
Nominal voltage	24V
Charge current	30A
Volt meter/amp meter	YES
Charging steps	2

Considering the design steps presented above, a BTS system resulted with the components summarized in Table 11 at an initial investment cost of approximately $24,000.

Table 11. HPS components and its costs

HPS	Qty	Price/unit [$]	Cost [$]
PV	11	480	5280
BA	12	570	6840
GD	1	5000	5000
Conv	1	45	45
CTRL	4	54	216
BA Ch	1	1500	1500
Misc.	1	5000	5000
TOTAL INVESTMENT CAPITAL			23881

3. HYBRID SYSTEM DESIGN ASPECTS

The hybrid systems for powering BTS assume high reliability, easy maintenance and, last but not least, lower investment and operation costs. In this paper, some specific factors that can influence the design of such systems have been identified.

3.1. Air conditioning installations for BTS equipment

The main issue in designing of hybrid power systems is the electrical energy required to cover the load.

In the case of BTS, the power requirements for such stations can vary based on factors, including the employed technology (3G, 4G, 5G), the configuration of the telecommunications network, and the installed power capacity at the station.

Usually, for BTS, there are two methods for cooling the equipment: free cooling and active heating and cooling.

In this regard, for a BTS unit of a certain power, the decision to equip it or not with the cooling system is crucial, when the situation permits in terms of the electronic equipment used and the climatic conditions.

For this case study, the HPS powering the same BTS type was sized with an active cooling system added to the load, the results being summarized in Table 12.

Table 12. HPS design with active cooling system

HPS	Qty	Price/unit [$]	Cost [$]
PV	17	480	8160
BA	24	570	13680
GD	1	5000	18000
Conv	1	45	45
CTRL	6	54	324
BA Ch	1	1500	1500
Misc.	1	5000	5000
TOTAL INVESTMENT CAPITAL			46709

The comparative results between the two designs are presented in Figure 4.

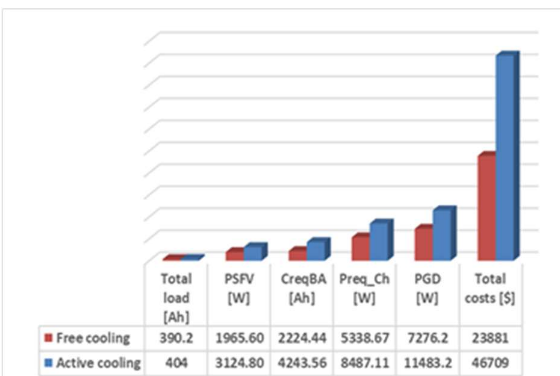

Fig. 4. BTS in the two cooling configurations

It follows from Figure 4 that the most important effects on the HPS design due to the addition of an active cooling system to the load lead to the following main consequences:

- The increase in total amp hour load, which leads to the need for a PV system with increased installed power. In the present case, this meant an increase in the number of PV panels from 11 to 17, see Table11and 12;
- An increased capacity of the storage system: this leads to a doubling of the number of batteries from 12 to 24 units, which is significant;
- The installed power of the DG increases, attributed to the need to ensure increased charging power for the BA;
- HPS initial investment costs are increasing, in this case study, they have almost doubled.

3.2. BTS local insolation

One of the factors that strongly influences the design of a BTS based on a PV system is the availability of solar resources on site. This means determining the average daily solar energy, which is represented by the indicator *peak sun hours per day* (S_{sun}).

S_{sun} directly influences the value of the design current (I_{des}). In Fig. 5, it can be observed that for the analyzed system, with a PV system tilted at 57°, an increase in S_{sun} to 6 [h/d] leads to a sixfold decrease in the design current.

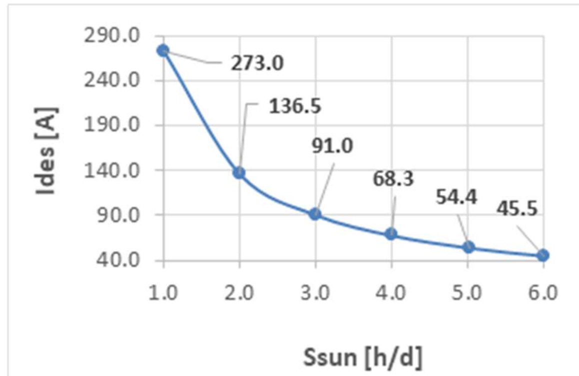

Fig. 5. Design current versus peak sun

This is very important because the design current determines the number of PV panels the system needs to cover the load. In Fig. 6, for the analyzed system, it can be observed that if S_{sun} increases from 1.8 to 5.7 [h/d], the total number of required PV panels decreases from 22 to 7.

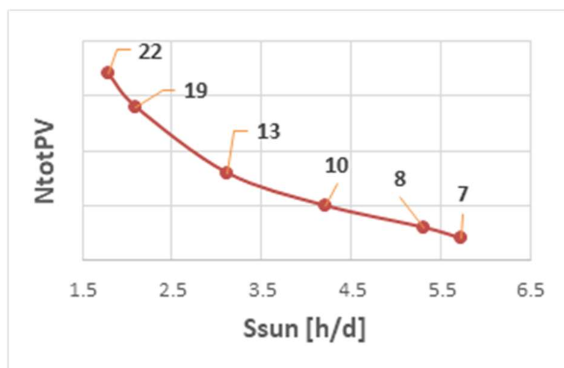

Fig. 6. The decrease in the total number of PV panels as S_{sun} increases

A reduced number of PV modules implies a decrease in the total costs of the hybrid system, but for its optimization, the energy storage system must be considered for periods with low insolation and during the night.

3.3. Storage days and total BA required

The determination of storage days can be done either by using implicit estimative graphs (Fig.3) or by setting a specific number based on local conditions for the unavailability of solar energy.

For the hybrid system in the studied case, it is observed that an increase from 3 days to approximately two weeks in the number of storage days leads to a fourfold increase in the required capacity for the storage system, as shown in Table 13.

Table 13: Influence of storage days on BA capacity

Storage days [d]	BA required capacity C_{reqBA} [Ah]	System BA capacity C_{sysBA} [Ah]	Usable BA capacity C_{useBA} [Ah]
3	1213.33	3000	2250
5	2022.22	3000	2250
8	3235.56	6000	4500
11	4448.89	6000	4500
13	5257.78	6000	4500
16	6471.11	9000	6750

Table 13 shows also that batteries with high ampere-hours (over 2000 Ah) are used, and taking into account the depth of discharge (DOD), there is a twofold increase in both the system BA capacity (C_{sysBA}) [Ah] and the usable BA capacity (C_{useBA}) [Ah].

These two indicators, depending on the chosen nominal voltage for the hybrid system, ultimately determine the number of batteries required for the storage system of the BTS. The relationship between the number of storage days, the number of parallel batteries required, and the total number of batteries to cover the BTS load is highlighted in the Fig. 7.

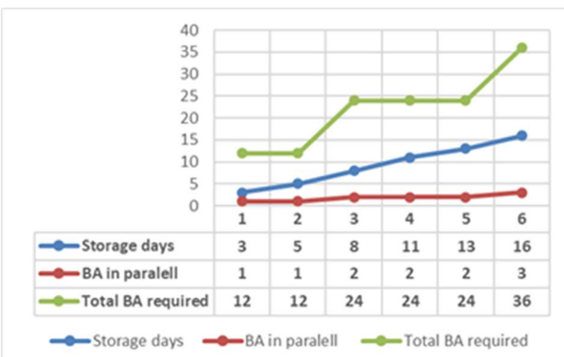

Fig. 7. Storage days influence on numbers of BA required

These numbers hold significance as deep-cycle batteries utilized in modern hybrid systems come at a high cost, especially considering the imperative for telecommunication systems to maintain maximum reliability.

3.4. DG installed power

As we showed in the previous paragraph, the storage capacity in the BA required by the hybrid system increases with the increase in the number of storage days chosen. On the other hand, the higher this storage capacity is, the more the Diesel group (DG) must have a higher installed power, so that it can ensure the loading of BA in a reasonable time and, at the same time, be able to cover the load demand of BTS.

In the case studied in this paper, for a storage subsystem charging time of 10 hours, the installed power required for the Diesel Generator (DG) was calculated based on the number of storage days, as shown in Figure 8.

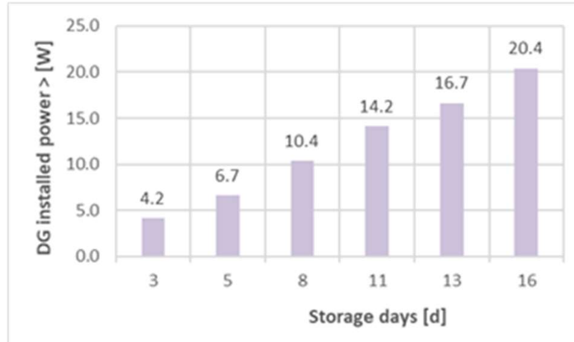

Fig. 8. Storage days influence on DG installed power required

It is observed that an increase in the number of storage days from 3 to two weeks leads to a fourfold increase in the power installed in GD, this having direct implications on the acquisition costs of DG and, finally, on the total investment cost of hybrid system.

4. CONCLUSIONS

Powering telecommunication systems located in remote areas without access to the national electricity grid presents some specific aspects related to:

- Renewable energy resources: the most commonly used are systems based on solar and/or wind resources to produce clean and reliable electric energy for a long time;
- Energy storage subsystems: those based on batteries (BA) are especially used to handle fluctuations in energy production from renewable sources to ensure a stable and continuous supply;
- Automatic operation and remote control: the power supply systems of telecommunication towers not connected to the electricity grid must operate autonomously. Remote monitoring and control equipment are used to allow efficient interventions and effective resource management;
- Adaptability to climatic conditions: the system design must take into account local climatic conditions to ensure the optimal operation of the equipment in extreme conditions, such as high or low temperatures, heavy rainfall, or freezing conditions;
- Energy efficiency: the system design targets energy efficiency by optimizing consumption and reducing losses during energy conversions. Additionally, the use of energy-efficient technologies and equipment contributes to the system's sustainability;
- Costs and sustainability: In designing hybrid power systems for BTS, economic and sustainability aspects must also be considered to optimize long-term costs and contribute to reducing environmental impact

Thus, designing hybrid power systems for telecommunication systems requires a complex approach that takes into account the particular conditions in which these systems operate.

One of the influential factors in the HPS design is the air conditioning system, because it adds a significant increase in amp-hours to the load, as a result of the increase in the dimensioning of all system components and, finally, the increase in initial investment costs.

Thus, whenever possible, passive cooling systems will be used, and where cooling of telecommunications equipment with an active system is required, solutions with as few amp-hour loads as possible will be sought.

The availability of renewable resources on site is very important in the design of hybrid BTS power supply systems, the peak sun hours per day indicator directly influencing the number of PV panels required for the system. The decrease in the number of PV panels required for the system is significant with a small increase in the peak sun at the location.

On the other hand, because the storage system for these systems is overwhelmingly in the form of batteries (BA), the number of units per system significantly influences the total cost of the system.

The size of the storage system, and thus the number of units required, is determined by both the system BA capacity and the usable BA capacity, this depends heavily on the indicator "number of storage days". It is very important to ensure a balance between the energy required to be stored in the batteries (BA) and the availability of energy under specific weather and operating conditions of the system. An oversized value of this indicator can lead to increased costs, without an improvement in the operation of the BTS.

The storage days indicator influences directly the installed power in Diesel group, used generally as a backup system. This is due to the fact that a high-capacity storage system, corresponding to a significant number of storage days, requires a higher nominal charging power for a reasonable charging time.

In conclusion, when designing hybrid systems for powering BTS, a specific aspect must be considered so as to obtain an optimal system in terms of appropriately sized components and reliable energy availability, all at optimal costs.

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