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Topological alternatives for photovoltaic integration in rural areas

Alternativas topológicas para integración fotovoltaica en áreas rurales

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ABSTRACT

The importance of implementing solar generation systems in rural areas in Colombia lies not only in providing access to the electric power population, but also in the use of current technologies to enhance their socioeconomic growth. The difficulties for its realization lie in technical limitations and access to the site, preventing mayors, heads of council and communities in general can correctly estimate the topology that suits their needs, falling into deceptions by companies that offer them oversized systems or those that do not meet your technical needs. In this document an analysis is made of the different possible topologies for rural areas, offering a methodology for its implementation with two cases of use as real examples.

Palabras clave:
Baterías
Topologías de distribución eléctrica
Zonas No Interconectadas
Fotovoltaica
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RESUMEN

La importancia de implementar sistemas de generación solar fotovoltaica en zonas rurales en Colombia radica no solo en brindar acceso a la población de energía eléctrica, sino también en el aprovechamiento de las tecnologías actuales para potenciar su crecimiento socioeconómico. Las dificultades para su realización radican en limitantes técnicas y de acceso al sitio, impidiendo que los alcaldes, jefes de cabildo y las comunidades en general puedan estimar correctamente la topología que se adecue a sus necesidades, cayendo en engaños por parte de empresas que les ofrecen sistemas sobredimensionados o que no cumplen con sus necesidades técnicas. En este documento se realiza un análisis de las diferentes topologías posibles para zonas rurales ofreciendo una metodología para su implementación con dos casos de uso cómo ejemplos reales.

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1. Introduction

According to the last generation variables and the Colombian electrical market monthly report available online, °from March 2017, the resources used in the generation of electrical energy in Colombia are: bagasse, water, biogas, biomass, carbon, fuel oil, gas, Jet-Ar and wind [1], among which water is mainly used with a 69.92%, followed by gas with 12.53% and carbon with 8.09%, the rest of the resources represent a negligible percentage [2].

Nowadays, energy generation in Colombia is highly favorable regarding the demand it has, the capacity of generation surpasses the 17000 MW (last data from the information system of XM, from 2015) which has increased [3]. Power generated from water is 12000 MW, and its charge manages almost surpass 11000 MW; but not in every area of Colombia there are the same resources available, this is the case of the Atlantic regions: Bolívar, Cesar, Córdoba, La Guajira, Magdalena and Sucre [4], in which the use of water to generate energy it is not common, the main resources for generation are gas and carbon, and it's due to this situation that this resources are part of the most used, thus causing a big dependence on fossil fuels [5].

Based on the national consolidation of service provision in the Non-Interconnected Areas or ZNI by its initials in Spanish, of the current total there is 75.8% that has service, a 4.6% has an intermittent service, and the rest of the ZNI are distributed among 14.9% without service and of 4.7% there doesn't exist any information [6], this means that although it is a ZNI most of these have a continuous service [7]. Its infrastructure is mainly composed by diesel generating plants, and its interconnection with National Interconnected System's substations, this involves a series of technical, economic and geographic restrictions that hinder the performance of the system [8].

Focusing on other alternatives, currently in the world there is a very strong tendency towards the so-called "energy transition", define as "a significant set of changes in the patterns of energy use, affect the resources, carriers, devices and energy services" [9].

To be able to meet the demand of the ZNI or the demand of the areas with little reliability in the electric service, no conventional and of renewable resources generation systems are used [10]. With the purpose of reduce expenses, in this point technologies as wind, solar thermal, geothermal and photovoltaic [7], in which this project will concentrate.

This project will show possible alternatives of topologies to implement in the photovoltaic systems for rural areas of Colombia. In the section 2 the criteria for selecting the alternatives are established, in the section 3 the topologies are displayed, in the section 4 the evaluation of the topologies alternatives found is done, with based on two studies; in the section 5 will be concluded with respect to the evaluation of the alternatives.

2. Criteria for the selection of alternatives

To be able to design the topologies, the elements that make up the photovoltaic systems are recognized, which are: Panels, batteries, inverters, regulators, protections and conductors. The sizing of these devices depends on three main criteria: the power demanded by the load, the energy performance, and the irradiation on the photovoltaic module.

- Load: To establish the consumption of the installation, aspects like: the number of devices, the type of energy they use (AC or DC), the power, the operating hours per day and daily consumption. This in order to calculate the total daily energy, E_d, it is a necessary value for to be able to calculate the capacity of the system's batteries. For a general study, charges of 0.45 kW, 0.06 kW and 0.09 kW are considered. Having in mind that the documents consulted establish a wide variety of loads present in rural areas, it highlights the pumping load, food and grain grinding, product refrigeration, irrigation and spraying, livestock feeding systems, electric fences and battery charging. A type of load that is also mentioned, but not in the same proportion as the previous ones, is related to resistive heating load for greenhouses. This type of load is relatively "heavy" for these solar generation systems but can be considered in the sizing of these systems or can be left within the "reserve" to be installed in the future.
- Energy efficiency (PR): This value considers the losses that can occur in the photovoltaic modules due to external factors, but it is standardized as: PR = 0.7 in systems with inverter and PR = 0.6 in systems with inverter and battery.
- Irradiation over the generator G_{dm} (α, $_{\beta}$) [11]: To find this value you need to know the value

of daily irradiation on the horizontal surface (G_{dm}), that is in the Atlas of Solar Radiation, Ultraviolet and Ozone of Colombia, elaborated by the UPME. For the study to be considered, Cundinamarca will be taken as location where G_{dm} varies between 3.5 [kWh/m²xday] and 5 [kWh/m²xday]. From this is obtained:

$$G_{dm}(\alpha,\beta) = G_{dm}(0) \cdot K \cdot FI \cdot FS \qquad (1)$$

Where:

G_{dm} (α, β): Is the irradiance value on the generator, where α corresponds to the value of azimuth and β to the angle of inclination, α=0 since the panel is heading all the way south and β corresponds to the latitude of the location where the panel is located [12], which for Cundinamarca is 4 °.

G_{dm} (0): Daily irradiance value on the horizontal surface, which for this study will be taken as 4.25 [kWh/m²xday] [13].

K: It is the profit constant, which is taken from tables as 1.15 [11].

FI and FS: These are factors of losses by inclination and shadows respectively. The FI value was not considered, however, the FS was taken as critical case is 10% maximum recommended value.

Apart from these quantitative criteria, the following qualitative criteria are considered: ease of operation, reliability, security, flexibility and reserve capacity; which are defined by:

- Ease of operation or simplicity: It refers to that characteristic of a scheme or alternative related to the simplicity of operation; that is, the property that causes no fault committed by the operator.

- Reliability: It refers that the distribution scheme works even after a failure occurs (overload or short circuit) and that do not operate improperly. Reliability implies guarantee in the continuous supply of energy. A scheme with a large number of elements has a lower reliability than a scheme with a low number of components.

- Security: It is the quality that has a distribution scheme that does not operate in the presence of strange causes, avoiding incorrect actions. Security is closely related to the absence of risky conditions for staff and for the equipment that make up the distribution scheme.

- Flexibility: It is the ability of a distribution scheme to adapt to changes and to allow its expansion quickly and easily.

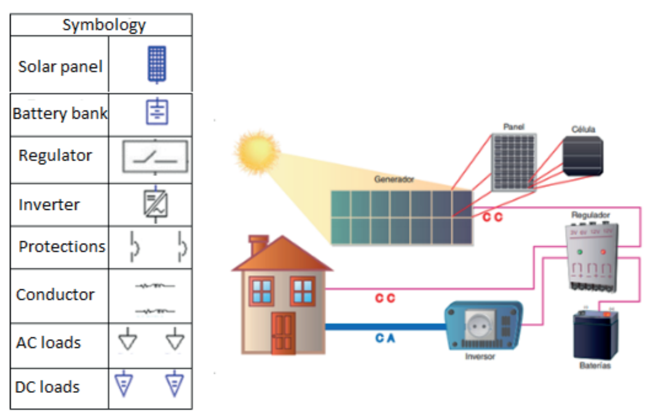
- Connection to the normal supply system: It is the capacity of a distribution scheme to allow its connection to the normal public supply system of the locality.

- Reserve capacity: Refers to the provision of connection, in the scheme or alternative distribution, of new sources and charges in the future. A usual criterion for reservation, in the case of electrical installations, is that between 10 and 20% of the nominal capacity is left.

3. Topologies raised

In order to design the best technologies, it is necessary to establish the symbology and the general connection of the devices that make up the photovoltaic system, Figure 1, respectively.

Figure 1. Symbology for photovoltaic systems and general connection of photovoltaic systems [14].



Based on this information, and the criteria mentioned in section 2, the alternatives proposed are:

3.1. Alternative 1: Centralized supply (MODULE A)

This alternative is made up of two distribution panels, one of these is of alternate current and the other of the direct current, as shown in Figure 2.

The components are: the set of solar cells, the battery bank, the inverter, the transference and the two distribution panels. It is planned in the future the arrival, to the panel AC, of a supply circuit from a source of renewable energy.

This alternative contemplates the installation of user loads in three distribution circuits of 0.5 kVA, 120 V and a reservation composed of two circuits of 0.5 kVA is left, all this for a total of 2.5 kVA of capacity.

From the DC board is included a 12 V circuit, this is for supply the specific purpose charges. Just like in the AC panel, a reserve is also left but this is just of one circuit. An AC load of 200 VA is estimated. The total load on this circuit would be then 2.7 kVA.

This alternative is conceived for low installations in which it is unknown the number or type of load.

3.2.Alternative 2. Distributed supply (MODULE B)

This alternative consists of two main distribution panels, one of alternating current and the other of direct current, as illustrated in Figure 3.

Figure 2. Solar generation system with concentrated load.

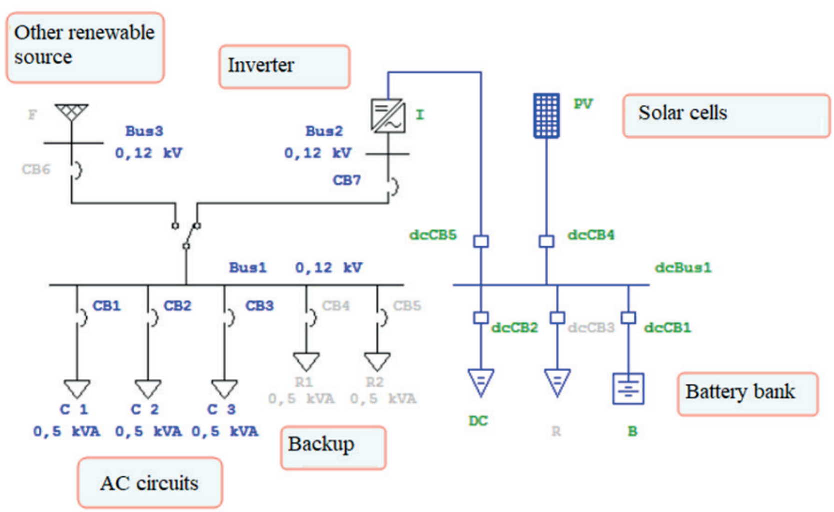


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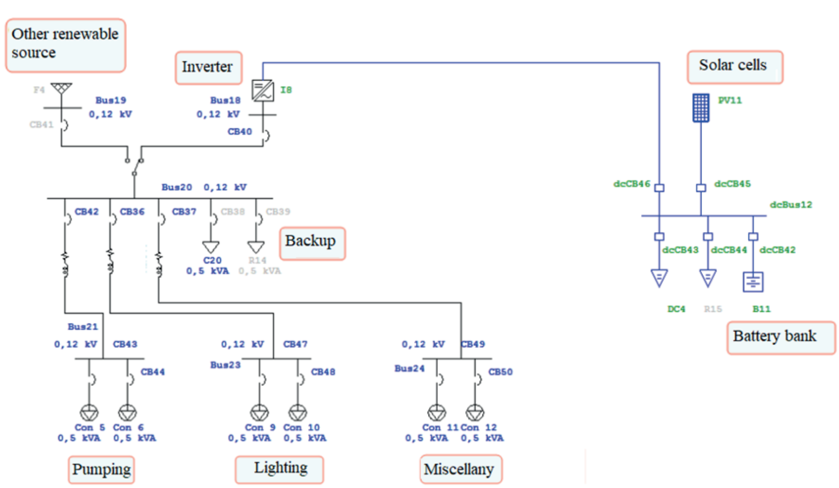
Figure 3. Solar generation system with distributed load.



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In addition to the previous boards, it is planned to install another three AC boards for loads of different types: pumping, lighting, miscellaneous load.

The components are: the set of solar cells, the battery bank, the inverter, the transference and the two distribution panels. It is planned in the future the arrival, to the panel AC, of a supply circuit from a source of renewable energy.

This alternative contemplates the installation of charges in three distribution circuits of 0.5 kVA, 120 V and a reservation composed of two circuits of 0.5 kVA is left, all this for a total of 4 kVA of capacity.

From the DC board is included a 12 V circuit, this is for supply the specific purpose charges. Just like in the AC panel, a reserve is also left but this is just of one circuit. An AC load of 200 VA is estimated. The total load on this circuit would be then 4.2 kVA.

This alternative is conceived for big installations, in which it is know the number and type of charge.

3.3.Alternative 3. Distributed-independent hybrid supply (MODULE C)

This alternative consists of two centralized distribution boards, one of alternating current and the other of direct current, as illustrated in Figure 4.

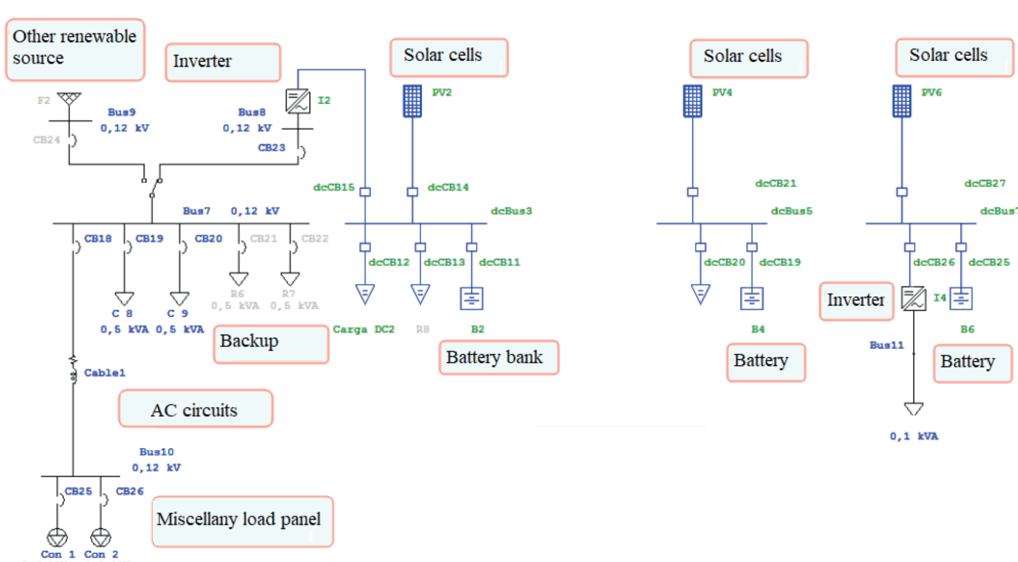
In addition to the previous boards, a secondary distribution board is provided for miscellaneous loads. The components are: The arrangement of solar cells, the bank of batteries, the inverter, the transfer and the three distribution boards. It is planned in the future the arrival, to the main alternating current board, of a feeder circuit from a renewable energy source. The arrival of a feeder circuit from a renewable energy source is foreseen in the future to the main board of alternating current.

This alternative includes the installation of loads in two centralized distribution circuits of 120 V, 0,5 kVA, each one, and a consistent reserve of 2 circuits of 0,5 kVA is left, for a total of 2,0 kVA. On the other hand, from the main board would come a feeder circuit to the secondary distribution board, from which would leave two circuits of 120 V, 0.5 kVA each one, then, the total charge in alternating current is 3 kVA. A circuit of 12 V DC sockets is included from the DC board, for supply specific purpose loads.

As in the alternating current board, also here a reservation is left, but of a single circuit. A DC load of 200 VA is estimated. Then the total load on this circuit would be 3.2 kVA.

The particularity of this distribution scheme is that it contemplates the electrical supply of individual

Figure 4. Solar generation system with concentrated-distributed load and independent loads.



Source: own.

isolated loads, from your own cell or solar cells, as it is observed in the part of the right of the Figure 4 where there are loads of DC and AC fed individually.

This alternative is designed for medium installations, with dispersed loads and where there are loads that are at considerable distances from the distribution boards (main or secondary).

3.4. Alternative 4. Combination of alternatives 1 and 2.

This alternative 4 consists of the installation of a module A (Alternative 1, centralized power supply) together with a module B (Alternative 2, distributed power). The total expected load is 6.9 kVA.

3.5. Alternative 5. Combination of alternatives 1 and 3.

This alternative 5 consists of the installation of a module A (Alternative 1, centralized power supply) together with module C (Alternative 3, distributed-independent hybrid power supply). Total expected load is 5.9 kVA.

3.6. Alternative 6. Combination of alternatives 2 and 3.

This alternative 6 consists in the installation of a module B (Alternative 2, distributed feeding) together with module C (Alternative 3, distributed-independent hybrid power supply). The total expected load is 7.4 kVA.

3.7. Alternative 7. Combination of alternatives 1, 2 and 3.

This alternative 5 consists of the installation of a module A (Alternative 1, centralized power supply), of a module B (Alternative 2, distributed feeding) and a module C (Alternative 3, distributed-independent hybrid power supply). Total expected load is 10.1 kVA.

4. Evaluation of the alternatives

Regarding the qualitative characteristics, the following results are presented according to the definition of each of these, as to the topologies.

To do the cost analysis, initially all the values necessary for the selection of the elements of the system are determined, an operating time is defined for all loads of three hours, and thus determine the KWh / day, from the Gdm (0) previously established, the constant K and the loss factor (FI) for shadows that was defined in 10%, the value of Gdm (α, β) of 4.39875 kWh / (m2day) is obtained, which is used to calculate the minimum power required in the network. As evidenced in Tables 2, 3, 4 and 5, for different panel references.

Later, for the selection of system elements, a previously made database is used which includes the costs of the elements of a PV system. The panels must not exceed 20% of the minimum power obtained for each set of micro grids topologies. Additionally, from that minimum power, the voltage level is determined, and based on this the panels are chosen.

Considering power, voltage and, additionally, the number of panels as this involves installation area required and simplicity of the system

In the selection of batteries there is a fundamental aspect that must be considered; that is, the maximum discharge depth of the battery. It is determined at 60% when the discharges are deep as lighting, for example, and in another case where it is not 80%, this is why an intermediate value of 70% is taken, to proceed with the selection calculations. Additionally, since the elements are not ideal, it is necessary to establish efficiencies, investor is determined at 85% and for the regulator together with the battery 80%.

Table 1. Qualitative evaluation of feeding alternatives.

Alternative	Ease of operation	Reliability	Security	Flexibility	Reservation capacity
1	Excellent	Good	Good	Acceptable	Good
2	Good	Good	Good	Excellent	Good
3	Good	Excellent	Good	Excellent	Good
4	Acceptable	Good	Acceptable	Good	Good
5	Good	Excellent	Good	Excellent	Good
6	Acceptable	Good	Acceptable	Good	Good
7	Regular	Good	Acceptable	Good	Good

Source: own.

Table 2. Study 1 of costs of the main proposals.

Alternatives	Load power [kW]	Daily consumption [kWh/day]	Nominal system voltage [V]	Minimum generator power [kW]	Panel reference	Quantity	Rows	Price panels [€]	Battery capacity [Ah]	Battery reference	Quantity	Price batteries [€]
1	2,43	7,29	48	2,76	Munchen 150 P	20	10	3.980,00	957,20	OPzS Solar 985	24	8.712
2	3,78	11,34	48	4,30	CSUN100-36M	45	15	6.156,78	1.302,85	20 OPzS 2500	24	31.824
3	2,88	8,64	48	3,27	TSM-275 PD05	12	6	2.060,71	992,65	7 OPzS 700	24	10.440
	0,12	0,36	12	0,14	Luxor 50W	3	3	269,01	165,44	OPzV150	6	936
	0,15	0,45	12	0,17	Luxor 50W	4	4	327,67	206,80	OPzV150	6	936

Source: own.

Table 3. Study 1 of costs of the main proposals (cont.).

Alternatives	Input current [A]	Output current [A]	Regulators	Quantity	Price Regulators [€]	Investors	Price investor [€]	Total price of the Alternative [€]	
1	88,1	50,625	PC1500B-6048D	2	303,00	Inversor SI 4,4 M-12	3.374	16.369,00	
2	225	70	PC1500B-6048D	4	606,00	Inversor SI 6,0 H-12	3.870	42.456,78	
3	56,46	60	PC1500B-6048D	1	151,50	Inversor SI 4,4 M-12	3.374	16.026,21	18.650,57
	9,72	10	ELECSUN2 10A 12/24V USB	1	29,68	NO	0	1.234,69	
	12,96	12,5	PRS 1515	1	74,00	Xpower 150	52	1.389,67	

Source: own.

Table 4. Study 2 of costs of the main proposals.

Alternatives	Load power [kW]	Daily consumption [kWh/day]	Nominal system voltage [V]	Minimum generator power [kW]	Panel reference	Quantity	Rows	Price panels [€]	Battery capacity [Ah]	Battery reference	Quantity	Price batteries [€]
1	2,43	7,29	48	2,76	KD245GH-2PB-KYOCERA	12	6	2.082,72	957,195378	OPzS Solar 985	24	8.712
2	3,78	11,34	48	4,29667519	CS6P-260P-SD 260W Poly BLK/WHT	17	1	3.558,44	1488,97059	OPzV1200	24	19.272
3	2,88	8,64	48	3,27	Q-Peak BLK G4.1 295W BLK/BLK	12	6	2.705,73	1134,45378	EnerSol T 1130	24	9.288
	0,12	0,36	12	0,14	Munchen 150P	1	1	199,00	165,441176	OPzV150	6	936
	0,15	0,45	12	0,17	Luxor 100M	2	1	162,00	206,801471	OPzV150	6	936

Source: own.

Table 5. Study 2 of costs of the main proposals (cont.).

Alternatives	Input current [A]	Output current [A]	Regulators	Quantity	Price Regulators [€]	Investors	Price investor [€]	Total price of the Alternative [€]	
1	13	70	VS 70	1	909,00	Inversor SI 4,4 M-12	3.374	15.077,72	
2	15	60	PC16-6015A	2	598,58	Inversor SI 6,0 H-12	3.870	27.299,02	
3	15	45	PC16-4515A	2	598,58	Inversor SI 4,4 M-12	3.374	15.966,31	18.769,31
	20	20	ML 2420	1	259,00	NO	0	1.394,00	
	20	20	ML 2420	1	259,00	Xpower 150	52	1.409,00	

Source: own.

When making the comparison between the first three alternatives it is notable that alternative 2 is the most expensive, this because the load is greater than that of the others, what requires greater system dimensioning, demanding a high storage capacity, which causes the cost to increase.

Add a regulator to the system, as in Study 2, has advantages that counteract the effect of decreasing the ease of operation of the system. The main advantage is that there is more possibility of a regulator adapting to the system requirements, considering that it will require supporting less input current. In the second option, configurations are presented in which the aforementioned was implemented, and despite using more regulators, the cost of the generation system presents a lower cost with the same consumption behavior.

Further, depending on the oversizing that has been obtained, the reliability increases when a different regulator corresponds to each group of panels, either for the series or parallel connection.

When comparing the two studies, is it possible to see that, if a balance is maintained between the prices of the components, it is possible to reduce the cost. This can be explained by analyzing the different alternatives, that allows to see the influence of the quantities of the devices in the price, which in the case of panels is conditioned by the total minimum power that the set of modules and the power of each equipment must have.

5. Conclusions

The relationship between complexity and cost is proportional, for this is necessary to design a system that meets the demand in a reliable way and that at the same time the cost is the minimum possible, giving priority to reliability over cost. This is achieved by maintaining a balance between the number of devices and the cost of them, considering the power required by the load and the nominal and operating values of the elements that make up the photovoltaic system.

For the design of the topologies, apart from the general distribution structure of the equipment sets, it is necessary to recognize how each set has its elements arranged, that is, the way they are connected, the panels between themselves, the batteries, the regulators and inverters.

To implement a photovoltaic system is necessary to keep in mind the type and the distance between the loads, in order to decide which topology to use. When the loads are very remote the third proposed topology, section 3.3, It allows to supply electric power to remote loads, because it has smalls systems according to the loads.

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