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ENERGY STORAGE USING SUPERCAPACITORS IN A PHOTOVOLTAIC INSTALLATION FOR A HOUSE IN THE RURAL AREA

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Abstract: At present, supercapacitors are being the subject of exhaustive research as a new type of alternative storage device to batteries, due to the advantages they present with respect to batteries, among these are high energy power, instantaneous charge, and discharge and at the same time stability after long cycles of use. The objective is to demonstrate the usefulness of supercapacitors as storage systems in isolated photovoltaic systems. The bibliographic review was used as a methodology that helped to search for the necessary information to compare supercapacitors as storage systems with respect to batteries, as well as experimental and field work. The design resulted in a storage source with supercapacitors, using an isolated photovoltaic system as a generation source to supply a home in the rural area, a field study was carried out for the load and demand analysis with which the data required to carry out the design of the storage system was obtained, in addition a prototype of smaller scale was developed to perform different tests, it was concluded that the supercapacitors are a viable alternative Energy in the isolated photovoltaic facilities that could be used in areas of difficult access to the electricity network.

INTRODUCTION

The implementation of supercapacitors (SC) as energy storage within a photovoltaic system arises from the existing problem in the deficit of electricity supply in difficult-to-access areas of the country.

Battery-based storage systems present a danger to the environment, which is why this system has corrosive, reactive, explosive, toxic and flammable capacities; they are also made by electrochemical compounds; in turn, supercapacitors have the advantage of being more environmentally friendly because they store energy in the form of electrostatic charges.

In this period, the reduction of greenhouse gas emissions must be achieved, so that the global temperature does not increase as expected, this can be limited with the only realistic option available, which is a considerable expansion of renewable energy and efficiency solutions, (IPCC, 2023), (Olade, 2021).

The use of photovoltaic energy is ideal due to the geographical location of Ecuador, where the polar oscillation of the planet has little effect on the climate and the sunlight that reaches the surface with high efficiency throughout the year (Castelo, 2015).

The strong energy dependence on oil has an impact on the access and quality of electricity in the rural territories of Ecuador, especially in the province of Manabí, where there are problems with the quality of the energy that is currently supplied in rural areas (Rodríguez, 2018).

According to the study carried out by the Ecuadorian Institute of Statistics and Censuses (INEC), by the end of 2021, 37% of households in Ecuador do not have access to this basic service and most of it prevails in rural areas, this shows that in the last four years there has been a minimal increase in service coverage in the country, despite the large investments made in the electricity sector (Primicias, 2022, p. 1).

Access to quality electricity services represents a key element in the fight against poverty, marginalization, unsanitary conditions, illiteracy, and the well-being of people. Therefore, it is necessary, in order to promote efficiency in production processes and effectiveness in public service, to create the right conditions to have developed communities that avoid migration in traditional environments (Rodríguez, 2018).

As energy demand increases, new technologies or devices are sought to generate and store energy in the most efficient way possible, which is why different types of systems and components have been developed and implemented, which have come to replace those currently used in order to obtain better energy use (Guachamín, 2017).

The fuel cell, due to its ability to convert chemical energy into electrical energy, where its fuel is hydrogen capable of providing more energy per unit of mass than any other known fuel, 33 kWh per kg (Guachamín, 2017).

Due to the need to store energy, different devices have been developed to do so, directly (supercapacitors) or indirectly, in recent years the use of supercapacitors has been of great importance due to their greater storage capacity compared to a common capacitor, in addition to supporting high current values, they present a great advantage over batteries in terms of their useful life and charging time, because they are able to manage charging quickly, this being one of their most notable advantages over other components (Guachamín, 2017).

MATERIALS AND METHODS

A bibliographic and field research was carried out to carry out the studies of load and demand of the community and to be able to manipulate the data with greater security in carrying out the design of the system, the quantitative, participatory method, the latter allows active intervention in decision-making by those who are linked to the project. The survey directed to the people who live in the Naranjal site of the Abdón Calderón parish of the city of Portoviejo was used as a technique.

For the calculation of the sample, equation 1 was used, for a known population (Hernández, Fernández & Baptista, 2014).

$$n = \frac{NWITH^2PQ}{It\ is^2(N-1)+WITH^2\ PQ} \quad (1)$$

Where:

N→ Population

n→ Sample size (30)

P→ Probability of success, or expected proportion (0.05)

Q→ Probability of failure (=.95)

e→Margin of error (0.5)

Z→ Confidence level (1.96)

ANALYSIS AND DISCUSSION OF RESULTS

An energy storage system is a device used to accumulate energy for later use, either in the short or long term, intensively or in a sustained manner over time (Guisado, 2016), its development must contribute to sustainable development where the contribution to CO reduction must be considered.$_2$, without forgetting the gray energy consumed by the construction of the storage system itself (François, 2021, p. 15).

Figure 1 shows the parameters of a storage system, these mainly respond to its life cycle and the functions it must fulfill.

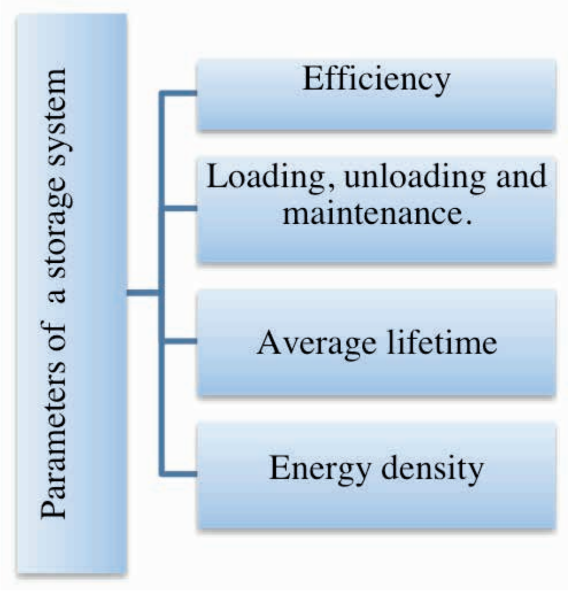

Figure 1. Parameters of a storage system.

There are different storage technologies such as: Hydroelectric pumping, compressed air, thermal storage, supercapacitors, flywheels, batteries, hydrogen fuel cells (BBVA, 2021), each of them has its specific application, for example for large-scale storage (reversible hydroelectric (pumped) and thermal storage) that is used with GW scales; storage in networks and in generation assets (cells and batteries, capacitors, superconductors and flywheels) where MW scales are used; end-user level storage (batteries, superconductors, and flywheels) used with kW.

To store the energy generated with photovoltaic systems during the day to be used in hours when there is sun, storage in Molinero batteries (2021) is used, these are devices that serve as electric energy accumulators through electrochemical procedures. The battery or cell is a device that allows to store electricity. There are different types of batteries, this depending on the chemistry used inside, among them are those of lead and acid are the most used, they are composed of lead dioxide (PbO_2) in the cathode and spongy lead in the anode Padilla, 2020). They are used more in uninterruptible storage systems (UPS) and in vehicle starting, they have disadvantages that are very heavy, their energy density is quite limited (30-50Wh/kg), they do not allow fast charging and their life is also limited (Molinero, 2021).

There are others such as nickel-cadmium, nickel-metal hydride, lithium ion, the latter are the most current, are used in portable devices (mobile phones, cameras), electric vehicles, renewable energy, have the advantages of having a high energy density (75-200 Wh/kg), they have a high voltage level for each cell of approximately 3.3V, but their useful life ranges from 2 to 5 years, they are quite expensive compared to other technologies, and they are still in full development (Molinero, 2021).

STORAGE WITH SUPERCAPACITORS

Supercapacitors are devices which have characteristics of capacitors and batteries, these are made up of sheets of activated carbon, a special electrolyte, and a separator. They work through electrolytic reactions. The positive electrode-electrolyte interface and the other at the negative electrode-electrolyte interface (Chamorro, 2020). these store energy directly as an electrostatic charge due to the formation of the so-called electrochemical double layer at the electrode/electrolyte interface (electrostatic/non-faradic) Fernández (2021).

The main characteristics of supercapacitors is that they allow an approximate capacity of up to 100,000 F, they handle limited voltages of 2.5 - 2.8V, high power density and low energy power density stand out, their useful life is greater than 10 years and they have around 95% efficiency (Chamorro, 2020).

Supercapacitors, also called supercapacitors, are devices that store energy with high power density, unlike conventional capacitors. They are made up of two electrodes (one positive and one negative) with a small separation between them and a porous separator in between, immersed in an electrolyte (Hurtado, 2021).

Supercapacitors can be charged and discharged in very short periods of time, of the order of seconds or less, which makes them especially appropriate to respond to short-term supply interruptions" (Colmenar, 2015, p. 35).

The operation of supercapacitors is based on electric fields where ions accumulate, and mass is not transferred. The difference with batteries is that they have superior performance, since batteries generate energy by chemical reactions (Rodríguez, 2020).

DEMAND FACTOR STUDY

For the design calculations, the lighting of the house was consideredwith a load of 100 Watts (W), for outlets a load of 200 W: A load of 200 W should be considered for each outlet outlet and special loads of around 1,500 W proposed by (Lara, 2015).

HOUSING CLASSIFICATION

The types of dwellings were considered to be able to consider the maximum demand of each one, since they present differentloads, and therefore different demand factors, which differ according to the construction area, table 1 shows the types of housing according to the ministry of urban development (Ministerio de Desarrollo Urbano y Vivienda, 2018).

Type of houses	Construction area (m^2)	Minimum Numbering of Circuits	
		Lightning	power outlet
Small	A < 80	1	1
Median	80 < A < 200	2	2
Medium Large	201 < A < 300	3	3
Big	301 < A > 400	4	4
Special	A > 400	1 per 100m² or fraction 100 m²	1 per 100m² or fraction 100 m²

Table 1. Classification of dwellings according to construction area

Ministry of Urban Development and Housing (2018, p. 7)

For the calculation of the installed load, a house was selected in the Naranjal site of the Abdón Calderón parish shown in figure 2.

Figure 2 Housing used as an object of study in

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the "El Naranjal" site of the Abdón Calderón parish.

Table 2 shows the special loads of the house.

Electric equipment	Average Power (W)
Electric shower	3500
Electric oven	3000
Electric kitchen	6000
electric water heater	8000
Air-conditioning	2500
Electric heater	3000
electric vehicle charger	7500

Table 2. Special charges in the proposed home

Source: Ministry of Urban Development and Housing (2018, p. 8)

For the design of the system, the circuits must be independent of lighting, outlets, special loads and have the following characteristics: LThe conductors of feeders and circuits must be sized to support a current of not less than 125% of the maximum load current to be served; each circuit must have its own neutral or grounded conductor and its own protection, no circuit must share services between floors or different levels of the house (Ministerio de Desarrollo Urbano y Vivienda, 2018).

The community was inquired into how the electrical service behaved, obtaining the results shown in figure 3.

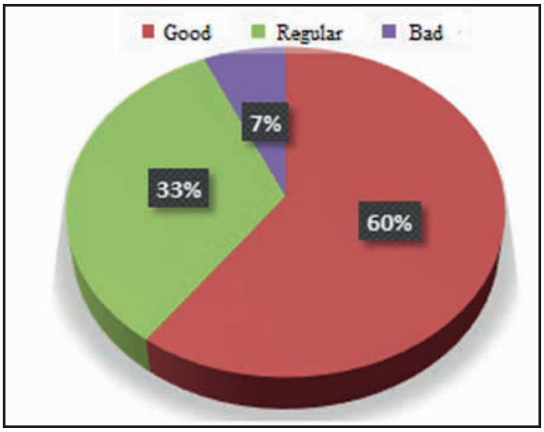

Figure 3. Status of electrical service

From a sample of 30 people surveyed, 60% responded good, 33% responded regular and 7% responded poor, noting that there was no response of excellent status, despite the fact that between fair and bad they are below those who responded good. It is good to point out that according to the answers, only in some houses there were light flickers.

One of the noted difficulties was related to power outages and recovery time, the results are shown in figure 4.

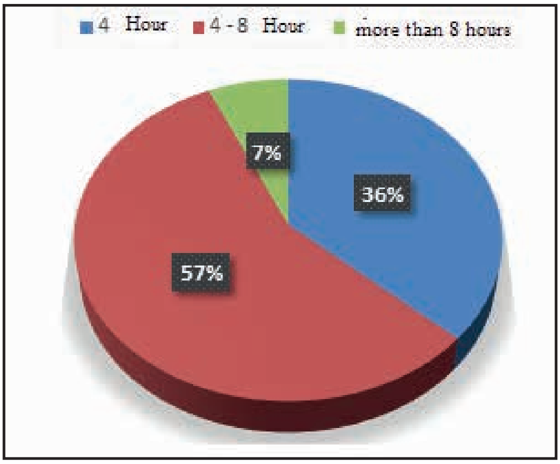

Figure 4. Percentage and time of power outage

As you can see, the largest number of people responded that the longest power cut time was 8 hours and the shortest time was 4 hours, this means that it is a considerable time to cause stress problems in the affected population.

Most of the people surveyed know the advantages that photovoltaic systems have to maintain the stability of the electrical service, so 67% of them consider it a viable alternative to have a quality service in rural areas; In addition, 83% agreed that batteries can be replaced by superconductors, they also considered that the implementation of supercapacitors can contribute positively to rural electrification. 97% of them considered that by using supercapacitors as energy storage, a more efficient system can be obtained in rural areas.

DESIGN OF A STORAGE SOURCE WITH SUPERCAPACITORS

To design the isolated photovoltaic system, a load and demand study of the selected home was carried out. For the load and demand study, the highest maximum power was taken, which was in the order of 3447 Watts and the total energy consumed at 5,506 kWh.

SOLAR PANEL CALCULATION

To carry out the calculation of the solar panel, we proceed with the study of the demand, which is placed a protection factor that will be a constant of 1.25, the demand is calculated using equation 2.

DEMAND

$$D = Cd \ x \ Fp \tag{2}$$

Where:

D→Demand

Cd→Average daily charge

Fp→Protection factor

Obtaining a demand for 4875 *Wh*

Equation 3 was used to calculate the photovoltaic power.

$$Pf = \frac{D}{HSP} \tag{3}$$

Where:

Pf→Photovoltaic power

D→Demand (4875 Wh)

HSP→Hora solar pico (4,82)

It was obtained that the photovoltaic power is 1011W.

Figure 5 shows the average annual solar radiation at the selected site.

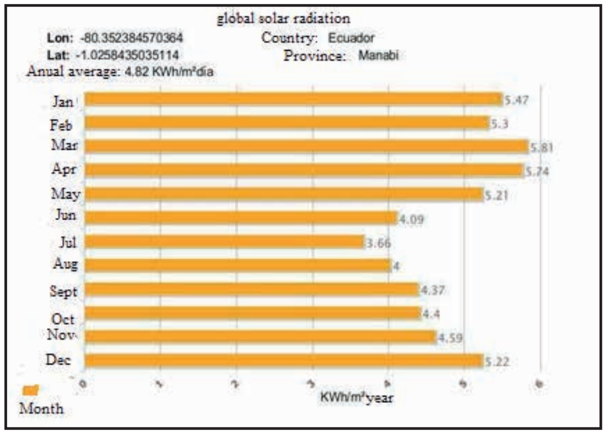

Figure 5. Annual solar radiation at the selected site

*Source:*http://geoportal.utm.edu.ec/

The number of solar panels that the photovoltaic system will have is calculated, based on the fact that the nominal power of the system must be less than 1500 and a voltage of 12 V, taking into account this, equation 4 is used to calculate the number of panels.

$$N°p = \frac{Pf}{Pmp} \tag{4}$$

Where:

N°p→Number of panels

Pf→Photovoltaic power (1011W)

Pmp→Photovoltaic module power(200W)

It was obtained that 5 photovoltaic modules from 200 W to 12 V must be used.

SOLAR INVERTER CALCULATION

Equation 5 is used to calculate the inverter.

$$W = Pt * Fp \tag{5}$$

Where:

IN→Inverter power

Pt→Potencia total (3447 W)

Fp→Protection factor (1.25)

It was obtained that the power of the inverter is 4308 W, with these results we proceeded to select a 5000W inverter that works at 12V.

CONTROLLER CALCULATION

To carry out the calculation of the photovoltaic controller, the short-circuit current is taken into account and equation 6 is used.

$$IMP = Isc * N°p \tag{6}$$

Where:
IMP→ Controller current
Isc→ Module short-circuit current
N°p→ Number of solar panels

With the controller current determined, a controller will be selected that is consistent with the result obtained. It is also recommended for 72-cell panels to choose MPPT-type controllers. For which a 60 Amp 12V MPPT controller is selected.

STORAGE SYSTEM CALCULATION

For the design of the storage system with supercapacitors and solar panel to feed a house in the rural area, the installed load, simultaneity factor, utilization factor, power factor and the study of housing demand have been considered.

The studies carried out in the house determined that its monthly demand was of the order of 27,357 kWh, an average daily demand of 3.90 kWh and a monthly energy consumed of the order of 109,430 kWh.

For the design of the storage system, the highest average daily load point will be taken, which is 3.9 kWh, in addition to the time of use (10 h), energy consumed in 1 hour (390 Wh), supply voltage (120 V), current (cos cos φ 3.25 A), power factor (0.92) and frequency (60 Hz).

CALCULATION OF THE CURRENT FOR THE STORAGE SOURCE

Equation 6 was used to calculate the current.

$$I = \frac{P}{IN} \times cos\ cos\ f \tag{6}$$

Where:
I→Corriente
V→Tensión (120)

$$cos\ cos\ f(0.92)$$

It was obtained that the current is 3.35 A required in 1 hour

SUPERCAPACITOR BANK CALCULATION

Taking into consideration that the average energy consumed by the home is 390Wh, the supercapacitor with the codeC27100000SR of 2.7V – 100000F that has the following characteristics:

- Normal current of 28 Amps (A)
- Maximum continuous current 150 Amps (A)
- Maximum peak current 200 Amps (A)
- 60 watt-hours (w/h) stored energy

The voltage considered for the storage source is 16.2 volts (V), so it is required to place 6 supercapacitors in series of 2.7 V as indicated in figure 6, resulting in a capacity of 16667 Farads (F) and 16.2 Volts (V).

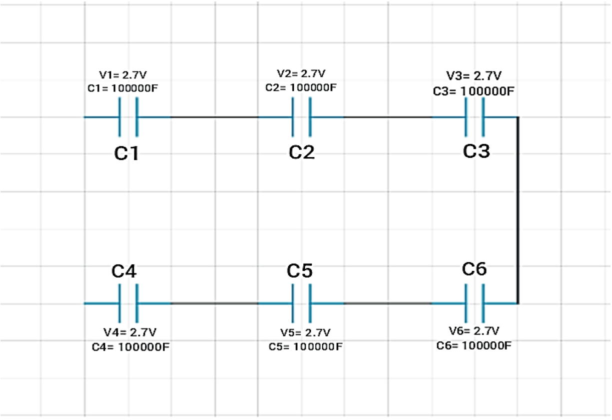

Figure 6. Bank of supercapacitors

Fuente: Electric Circuit Studio

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$$C = \frac{1}{\frac{1}{C1}+\frac{1}{C2}+\frac{1}{C3}+\frac{1}{C4}+\frac{1}{C5}+\frac{1}{C6}}$$

$$C = 16667\ F$$

SUPERCAPACITOR BANK SELECTION

With the results obtained, it is observed that there is a capacity of 16667 F, so it was decided to select a bank of supercapacitors that has the following characteristics:

- Maximum charging voltage 13.5V
- Internal resistance of ≤ 4.5m Ohm
- Maximum continuous current 40 Amps (A)
- Maximum peak current 60 Amps (A)
- Stored energy of 225watts/horas (W/h).

Currently, supercapacitor manufacturers offer banks of 7000F at 16.2V with charge stabilizers ready to be used in wind turbine or solar panel systems.

It has been considered to use 8 data banks for the storage source. GHT 12V 7000F Moudle connected in parallel with a capacity of 56000 F and 13.5V, which guarantees power supply for approximately 5 consecutive hours at full load without solar energy.

IMPLEMENTATION OF A STORAGE PROTOTYPE WITH SUPERCAPACITORS AND SOLAR PANEL.

After the development of the surveys to the community of "Naranjal", belonging to the Calderón Parish of the Canton of Portoviejo, it was obtained that there is little knowledge about renewable energy and storage systems with supercapacitors, so it was decided to implement a prototype that includes solar panel, regulator, inverter and supercapacitors in order to evaluate and publicize the advantages of generating solar energy and storing it in a bank of supercapacitors.

It was possible to demonstrate that the use of these energy storage systems can be very useful due to its useful life and the benefits that it brings to the environment, it can be noted that this technology aims to promote more research on storage systems in energy accumulation systems.

Figure 7 shows the bank of capacitors used for the tests.

Figure 7. Supercapacitors used for the tests.

Source: https://tiendamia.com/ec

ASSEMBLY OF THE PROTOTYPE.

It was decided to build a 45*45*17 module in RH material to house the elements it contains: solar panel, inverter, controller, and supercapacitors in which the circuitry is included to activate and deactivate a load (LED spotlight) as detailed in figure 8.

Figure 8. Built prototype

This prototype serves as a teaching, learning and research tool for future professionals at the Technical University of Manabí.

CONCLUSIONS

Supercapacitors are a device that can replace batteries as energy storage sources for isolated photovoltaic systems, these devices theoretically have faster charge and discharge cycles which are ideal for withstanding high voltage surges, they have a low internal resistance which allows them to offer greater instantaneous power, they are more environmentally friendly since they store electrical energy in the form of electrostatic charges.

When carrying out the design of the storage system with supercapacitors and solar panel, it was concluded that these devices have a capacity of up to 100,000 F, but their voltage reaches 2.7V, with these characteristics the design was made for a house in the rural area, for which the average energy consumed was calculated, for which the storage system will be covering approximately 5 hours without solar energy at full load.

A prototype was built to understand and evaluate the operation of supercapacitors as an alternative storage source to batteries in an isolated photovoltaic system, six 500F supercapacitors at 2.7V connected in series were used, giving us a bank of 83.3F at 16.2V; a 200W solar panel, a 6000W inverter and a 100A controller and a 3W Led bulb was used as a load, which serves as a teaching, learning and research tool for future professionals in the electrical engineering career at UTM.

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