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ijerst.editor@gmail.com
editor@ijerst.com

Research Paper

OPTIMIZED SOLAR ENERGY SYSTEM MODELING FOR RESIDENTIAL APPLICATIONS USING PYTHON

Mr. Aravinda Swamy Konda
Assistant Professor
Dept. of EEE,
MRCET,Dulapalli
Secendrabad,Telangana,India
aravinddprec@gmail.com

Mr. Kanugula Aravind Kumar
Dept. of EEE
MRCET,Dulapalli
Secendrabad,Telangana,India
kanugulaaravindkumar@gmail.com

Mr.B. Sri Charan
Dept. of EEE
MRCET,Dulapalli
Secendrabad,Telangana,India
bsricharan01@gmail.com

Mr. B. ShivaRaj
Dept. of EEE
MRCET,Dulapalli
Secendrabad,Telangana,India
bhukyashiva1439@gmail.com

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Abstract—The growing demand for renewable energysolutions has led to an increased interest in solar energy systemsfor residential applications. This study focuses on the modeling of solar panel connections for home applications using Python.The primary objective is to design a single calculator to calculate all parameters of a solar energy system for a home like number of solar panels , their series parallel connection inverter , charge controller ratings, number of batteries connected in series and parallel connection. The results demonstrate the impactof different connection types on energy efficiency and offerinsights into selecting the most suitable configuration forsolic residential needs. This approach provides a cost-effective and flexible method for assessing solar panelperformance in home applications, ultimately supporting theadoption of sustainable energy solutions.

Keywords-- Solar Panels, Residential Energy, Series Connection, Parallel Connection, , Sustainable Energy, Solar system.

I.INTRODUCTION

The demand for ecologically friendly and sustainable energy sources is causing a revolution in the world's energy landscape. One of the most plentiful and sustainable energy sources, solar energy has become a practical way to deal with the problems of environmental deterioration and fossil fuel depletion. Solar photovoltaic (PV) systems are becoming more and more popular for residential use among the several solar energy harvesting technologies because of their low maintenance requirements and capacity to provide clean, renewable energy. Optimizing the performance and efficiency of these systems is becoming more and more crucial as the demand for home solar energy solutions keeps growing[4].

The connection between the solar panels is a critical component in optimizing the performance of a solar PV system. Solar panel connections are usually made in series, parallel, or hybrid arrangements; each has unique benefits and drawbacks. In a parallel design, the current grows but the voltage stays constant, whereas in a series arrangement, the voltage across the system rises but the current stays constant. Both configurations' components are combined in hybrid connections. The system's overall power output and efficiency, as well as its dependability in the face of changing environmental factors including solar radiation, temperature swings, and shading effects, are all impacted by the configuration decision. Designing effective residential solar power installations requires an understanding of how these elements affect solar system performance.

Although solar energy systems are becoming more and more popular, there are currently no all-inclusive

technologies available to forecast and maximize the performance of solar panel connections in home settings under actual circumstances. Numerous environmental conditions that can vary throughout the day and season have an impact on solar panel performance. The efficiency of the system is further complicated by elements like dust deposition on panels, shadowing from surrounding trees or buildings, and panel deterioration with time[10]. Modeling and simulation have become essential tools for examining how various solar panel layouts affect electricity generation in order to overcome these difficulties. The best effective setup for a certain set of circumstances can be found by simulating several scenarios.

The main goal of this paper is to develop a versatile, user-friendly tool that will help researchers, installers, and homeowners choose the best solar panel configuration for residential usage[11]. results of this study will advance our knowledge of solar panel performance, provide useful information for system design, and aid in directing the decision-making process around solar energy installations. In order to help worldwide efforts toward sustainability and lessen dependency on non-renewable energy sources, the research intends to encourage the wider use of solar energy by offering an affordable and easily accessible approach for optimizing solar power systems[3]. It is anticipated that the findings will help researchers, homeowners, and installers make well-informed decisions on the installation and upkeep of solar energy systems, thereby advancing the larger objective of supporting sustainable energy alternatives.



Fig.1.1: Typical solar panel

Solar panels, also known as photovoltaic (PV) panels, are devices designed to capture sunlight and convert it into electrical energy. They are a crucial component of solar energy systems and are widely used in residential, commercial, and industrial applications to harness the power of the sun. Solar panels work based on the principle of the photovoltaic effect, where certain materials can generate an electric current when exposed to light. This technology has seen rapid development and adoption over the past few decades, making solar energy a leading renewable energy source[9].

Many smaller units known as solar cells, which are usually constructed of semiconductor materials like silicon, make up a conventional solar panel. Photons from the light are absorbed by the semiconductor material when sunlight strikes the solar cell's surface[4]. The material's electrons are excited by this energy, which moves them and produces an electric current. The photovoltaic effect is the name given to this process. Each solar cell produces direct current (DC), which can be stored in batteries or transformed into alternating current (AC) for usage in residences and commercial buildings via an inverter[1].

There are two main types of solar panels: monocrystalline and polycrystalline and the construction and application of both are:

- **Monocrystalline Solar Panels:** These are made from a single continuous crystal structure, which allows for higher efficiency and better performance under low-light conditions. They are generally more expensive than polycrystalline panels but offer better space efficiency and are more durable[8].
- **Polycrystalline Solar Panels:** These are made from silicon crystals that are melted together. They are generally less expensive than monocrystalline panels but also have slightly lower efficiency. However, they still offer significant energy production, making them an affordable option for many residential and commercial installations[6].

Another type of solar panel gaining popularity is thin-film solar panels. These are made from layers of photovoltaic materials deposited on a substrate, which can be flexible, lightweight, and cheaper to produce. However, they are typically less efficient than silicon-based panels and are more commonly used in large-scale installations or in applications where weight and flexibility are important.

The efficiency of a solar panel refers to the percentage of

sunlight it can convert into usable electricity. Most commercial solar panels have an efficiency rating between 15% and 22%. Several factors affect the efficiency of solar panels, including the angle and orientation of the panel, shading, the temperature of the environment, and the quality of the materials used[11].

In addition to residential and commercial applications, solar panels are increasingly being used in solar farms to generate large-scale electricity. As technology advances and production costs decrease, solar panels are becoming more accessible to a broader range of consumers, providing an environmentally friendly and cost-effective solution for reducing dependence on fossil fuels[3].

One of the key benefits of solar panels is their environmental impact. Solar power is a clean energy source, meaning it produces no greenhouse gas emissions or pollutants during operation. By utilizing solar panels, households and businesses can reduce their carbon footprint and contribute to the global effort to mitigate climate change.

Overall, solar panels represent an innovative and reliable technology for tapping into renewable energy. As efficiency improves and costs continue to decrease, solar panels are expected to play an even larger role in meeting global energy needs while promoting sustainability[11]&[13].

1.1 Objectives of the paper

The main objectives of this paper, focused on modelling solar panel connections for home applications using Python, are as follows:

The primary objective is to design a calculator to calculate all parameters of a solar energy system for a home, including the number of solar panels and their series-parallel connection, inverter, charge controller ratings, and the number of batteries with their connection configurations using Python.

The results demonstrate the impact of different connection types on energy efficiency and provide insights into selecting the most suitable configuration for specific residential needs. This approach offers a cost-effective and flexible method for assessing solar panel performance in home applications, ultimately supporting the adoption of sustainable energy solutions[2].

II. METHODOLOGY

A systematic technique that combines theoretical concepts with useful simulations is used in the Python methodology for modelling solar panel connections for residential applications. The process starts with a thorough literature review to comprehend the fundamental ideas of solar photovoltaic (PV) systems, the various configurations of solar panel connections (series, parallel, and hybrid), and the variables that affect solar panel performance, including temperature, shading, and solar irradiance. Important factors including solar irradiance (measured in W/m²), panel efficiency, temperature effects on efficiency, and shading effects on the system's energy output are all identified with the aid of the literature review. This

stage lays the groundwork for creating a simulation model that faithfully captures how solar panels behave in actual situations[9].

Define the mathematical models that will replicate the behaviour of solar panels in various configurations after the important parameters have been determined. When solar panels are joined end to end in series, the overall voltage is raised while the current stays constant. On the other hand, when panels are linked side by side in a parallel connection, the total current rises while the voltage stays the same. To balance current and voltage, a hybrid setup uses both parallel and series connections. The power created by the system is determined using the formula $P = V \times IP$, where P is the power output, V is the voltage, and I is the current. These configurations have a direct impact on the electrical output [6].

Comparing the power output of various configurations while taking cost, effectiveness, and installation simplicity into account is part of this. Based on their location and environmental circumstances, the results will be used to advise solar contractors and homeowners on the best solar panel arrangement. The process results in an extensive report that provides useful advice on how to best plan and maximize solar power installations for residential use. This study intends to enhance the efficiency and affordability of household solar energy systems by modelling and evaluating various connection arrangements [8].

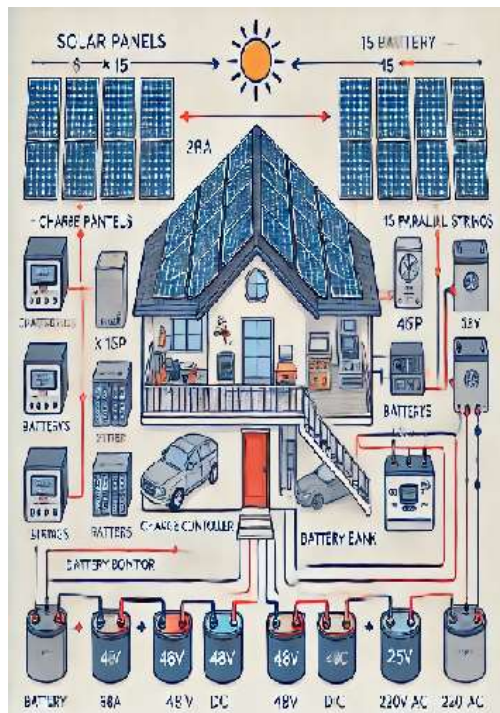


Fig.1.2:Block diagram

This diagram shows how a solar power system connects to a house. Solar panels capture sunlight and convert it into electricity. The electricity first passes through a DC MCB

(circuit breaker) to protect the system from overcurrent or short circuits. A charge controller then regulates the power and safely charges the batteries, which store energy for use at night or during low sunlight. The stored energy is sent to a solar inverter, which converts the DC power from the batteries into AC power, making it suitable for home appliances. The electricity then flows through a power distribution panel, which sends it to different parts of the house. This system helps reduce electricity bills, provides backup power, and promotes clean, renewable energy[7].

A step-by-step methodology is calculated through the following flow chart. The below flow chart represents the step-by-step procedure.

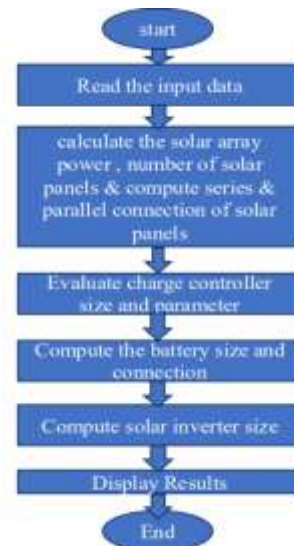


Fig.1.3:Flow Chart

Modeling solar panel connections for home appliances using Python involves simulating the entire energy system, from solar power generation to battery storage and supply to appliances. Below is a step-by-step methodology for modeling solar panel connections for home appliances using Python[13]:

Step 1: Read the Input Data

To design a solar power system, the following input parameters must be gathered:

1. Power Demand (Total load in watts)
2. Number of Backup Hours & Average Daily Usage
3. Number of Sunlight Hours (Peak Sun Hours per day)
4. System Efficiency (Efficiency of solar panel parameters)
5. Standard DC Voltage of Battery (Usually 12V, 24V, or 48V)
6. Number of backup Days (Days the system should run without sunlight)

7. Depth of Discharge (DOD) of the Battery (Usually 50% for lead-acid batteries)

This systematic approach ensures an efficient and well-sized solar power system.

Step 2: Calculate the Array Power

$$1. \text{ Solar power output} = \frac{\text{load demand} \times \text{operating hours}}{\text{peak hours} \times \text{system efficiency}}$$

$$2. \text{ Number of solar panels} = \frac{\text{solar output power}}{\text{each panel power}}$$

parallel connection of solar panels:

$$(i) \text{ Number of panels connected in series} = \frac{\text{standard battery voltage}}{\text{each panel voltage}}$$

$$(ii) \text{ Number of panels in parallel strings} = \frac{\text{total number of panels}}{\text{number of panels in series}}$$

Step 3: Charge Controller size

$$i) \text{ Charge controller rating} = \text{safety margin} \times \text{rated current}$$

$$ii) \text{ Rated current} = \frac{\text{solar array power} \times \text{safety factor}}{\text{solar array voltage}}$$

If solar array voltage is more than battery voltage, the solar array voltage is reduced to battery voltage by charge controller.

Step 4: Battery size and capacity

$$\text{Battery capacity} = \frac{\text{solar output power} \times \text{autonomy days}}{\text{standard battery voltage} \times \text{DOD}}$$

$$\text{Battery connection: Number of batteries in series string} = \frac{\text{standard battery voltage}}{\text{each battery voltage}}$$

$$\text{Number of parallel strings} = \frac{\text{Battery capacity}}{\text{Each string battery capacity}}$$

Step 5: Inverter power rating

The inverter power rating should be higher than the load power to handle surges and ensure a long lifespan. A safety margin of 25% is typically considered.

$$\text{Inverter Power} = \text{Load demand} \times 1.25$$

$$\text{Inverter input voltage} = \text{Standard battery voltage}$$

$$\text{Inverter output voltage} = 1\text{-ph load voltage}$$

Step 6: Display Results

After completing all calculations, the final results should be displayed, including:

1. Solar Array Size
2. Number of Panels Connected in Series & Parallel
3. Charge Controller Size
4. Battery Size and Series & Parallel Connection Details
5. Inverter Power Rating

III. RESULTS & DISCUSSION

The output represents the design of a solar power system based on the given inputs:

Inputs Provided:

1. **Solar System Demand:** 4 kW (This is the power requirement of the system)
2. **Backup Hours:** 3 (The system should provide power for 6 hours when sunlight is not available)
3. **Operating Hours:** 6 (This means the solar system is expected to provide 4 kW of power for 6 hours per day using the energy directly from the solar panels).
4. **Peak Sun Hours:** 7 (The number of effective sunlight hours per day for charging)
5. **Solar Panel Voltage:** 35 (This means each individual solar panel has an output voltage of 35 volts)
6. **Solar Panel Wattage:** 135W (This means each individual solar panel can generate 135 watts of power)
7. **Each Battery Voltage:** 24V (This means a single battery operates at 24 volts)
8. **Each Battery Storage:** 100Ah (This means a single battery can provide 100 ampere-hours (Ah) of electrical energy at its rated voltage (24V))
9. **Battery Depth of Discharge (DoD):** 0.8(80%) (This means that only 80% of the total battery capacity can be used before recharging. The remaining 20% of the battery's charge is reserved to prevent damage and extend battery life).

Output

```
Enter Solar System Demand (kW): 4
Enter Number of Backup Hours: 3
Enter Number of operating Hours: 6
Enter Peak Sun Hours: 7
Enter Solar Panel Voltage in volts: 35
Enter Solar Panel Wattage in Watts: 135
Enter the Each battery Voltage in Volts: 24
Enter the each battery storage in Ah: 100
Enter the battery dod from 0.1 to 0.9: 0.8
```

=== Solar System Design Summary ===

```
Total Panels: 30.0
Panel Configuration: 2.0S x 15.0P
Charge Controller rating: 90A, 48V MPPT
Total Batteries: 8.0
Battery Configuration: 2.0S x 4.0P
Inverter: 5.0kW, 48V DC to 230V AC
```

Fig.1.4: Program Output

The output represents the design of a solar power system based on the given inputs:

Inputs Provided:

10. **Solar System Demand:** 4 kW (This is the power requirement of the system)
11. **Backup Hours:** 3 (The system should provide power for 6 hours when sunlight is not available)
12. **Operating Hours:** 6 (This means the solar system is expected to provide 4 kW of power for 6 hours per day using the energy directly from the solar panels).
13. **Peak Sun Hours:** 7 (The number of effective sunlight hours per day for charging)
14. **Solar Panel Voltage:** 35 (This means each individual solar panel has an output voltage of 35 volts)
15. **Solar Panel Wattage:** 135W (This means each individual solar panel can generate 135 watts of power)
16. **Each Battery Voltage:** 24V (This means a single battery operates at 24 volts)
17. **Each Battery Storage:** 100Ah (This means a single battery can provide 100 ampere-hours (Ah) of electrical energy at its rated voltage (24V))
18. **Battery Depth of Discharge (DoD):** 0.8(80%) (This means that only 80% of the total battery capacity can be used before recharging. The remaining 20% of the battery's charge is reserved to prevent damage and extend battery life).

Solar System Design Summary:

1. **Total Panels:** 30
 - The number of solar panels needed to meet the power requirement.
2. **Panel Configuration:** 2S × 15P
 - This means the panels are arranged in 2 Series (S) and 15 Parallel (P) combinations.
 - Series (S) increases the voltage, while Parallel (P) increases the current.
3. **Charge Controller:** 90A, 48V MPPT
 - 90A is the required current capacity of the charge controller.
 - 48V MPPT (Maximum Power Point Tracking) ensures efficient power conversion.
4. **Total Batteries:** 316
 - The total number of batteries required for storing backup power.
5. **Battery Configuration:** 2S × 4P
 - 2S (Series) means 2 batteries are connected in series to increase the voltage.
 - 4P (Parallel) means 4 such series sets are connected in parallel to increase capacity.
6. **Inverter:** 5.0 kW, 48V DC to 230V AC

- The inverter converts 48V DC (from batteries) to 230V AC (for home appliances).
- The 5.0 kW rating matches the system demand.

3.1 What This Means:

- The system is designed to generate and store enough power to run a 3 kW load for 6 hours, using solar panels, a charge controller, batteries, and an inverter.
- The solar panels charge the batteries during the 8 peak sun hours so they can supply power when needed.
- The battery bank stores energy to ensure continuous power supply even when the sun is not shining.

IV. CONCLUSION

This paper effectively illustrates how to use Python to model solar panel connections for residential applications. The system efficiently identifies the ideal arrangement of solar panels, batteries, charge controllers, and inverters by combining important parameters including power demand, backup length, peak sun hours, and component specifications. The design process is streamlined by the computational approach, which guarantees effective energy generation, storage, and use. The findings offer a well-organized system design that includes the necessary number of solar panels, their series-parallel configuration, battery bank setup, and inverter choice. This approach improves precision, minimizes laborious computations, and enables prompt adjustments in response to varying energy needs.

This paper helps to promote sustainable energy alternatives for household usage by using Python for solar system modeling. The approach is a useful tool for engineers, solar energy specialists, and homeowners since it may be further expanded to maximize cost, efficiency, and real-time monitoring. To improve decision-making for solar power system installations, future developments could incorporate cost analysis, real-time weather data integration, and graphical visualizations.

V. FUTURE SCOPE

There are numerous ways in which this paper could be improved to facilitate and increase the efficiency of solar system design. Real-time weather data can be added in the future to increase accuracy and provide consumers a better understanding of how weather and sunshine impact power generation. Incorporating cost estimation enables customers to determine the overall cost of solar system installation and

evaluate several options to select the most economical and effective configuration. It is possible to create an intuitive interface that would allow anyone, including those without technical expertise, to enter their energy requirements and receive suggestions for the optimal solar system design. Additionally, graphs and charts can be included to clearly display energy consumption, battery storage, and power generation. Adding smart monitoring devices to the system, which enables users to track battery health and solar panel performance in real-time, is another significant enhancement. If maintenance or repairs are required, users can be informed automatically.

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