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| RESEARCH ARTICLE

Development of a Mobile Application for Grid - Tied Solar Photovoltaic (PV) System Design for Residential Buildings

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| ABSTRACT
As digital technology is continually evolving and an increasing number of people from diverse backgrounds are spending more time on their mobile phones, building a mobile app for solar PV system design is beneficial for homeowners who wish to invest in solar energy as an alternative source of power for their appliances. The study aimed to develop a smartphone app for integrating solar photovoltaic systems in existing and new residential buildings. The software provides design on the rated capacity of the photovoltaic array, the size of the tie-inverter, the overall cost of the photovoltaic system, yearly savings, and return on investment. The software was created using solar radiance data, net-metering, and local government permitting requirements. The researcher collected 12 months of solar radiance data from five Dagupan City households before developing the app's design guidelines. The developed smartphone app was tested on residences with existing solar PV systems and compared to the real parameters of current solar PV systems. The results showed that the mobile app is a dependable tool for supporting residential clients in identifying suitable solar system sizes for their homes.

| KEYWORDS
Solar PV system, Net metering, Mobile app design, Grid-tied PV system, Solar radiance, Return on Investment (ROI)

| ARTICLE INFORMATION
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1. Introduction
The Philippines is dealing with an energy crisis since the Malampaya natural gas reserves are predicted to be drained by 2024, jeopardizing the country's aspirations to achieve energy independence by 2030. Both the UN Secretary-General and Amnesty International have stated that the Philippines is the most vulnerable to the climate issue, making a transition to renewables critical. The country has indigenous energy sources that are environmentally beneficial and can address climate change problems, including biomass, solar, wind, geothermal, ocean energy, and hydropower. The Renewable Act of 2008 was adopted to reduce the country's reliance on imported fossil fuels, with the goal of increasing renewable energy's part of the power generation mix to 35% by 2030 and 50% by 2040.

Solar PV systems have grown in popularity among commercial and industrial organizations in the Philippines, with three types of solar PV systems available: off-grid systems, grid-tied solar PV systems, and grid-interactive systems. Despite the growing popularity of solar panels, many homeowners are still hesitant to use them due to the high initial expenses, extended time return on investment, and concerns about the roof's ability to support the weight of solar panels. Solar energy, on the other hand, has economic potential, making it a significant option for enterprises. As a result, a strategy is required to demonstrate to homeowners that choosing solar is a major decision that may help them save money while also contributing to the country's transformation to renewable energy.

1.1 Statement of the Problem
The study focused on the integration of solar photovoltaic systems into existing and new residential buildings using mobile phones. It looked at creating software that runs on mobile devices (such as smartphones and tablets) and allows target people to engage with it effortlessly. The study was specifically guided by the following objectives:

1. To make the mobile application (or mobile app) user-friendly and capable of doing certain tasks, particularly collecting the following:
   a. Household's monthly energy consumption and electricity bill;
   b. The solar radiance of the region upon which the solar home project will be implemented;
   c. The rated capacity of the individual solar panel to be installed;

2. To make the mobile application capable of providing information related to the following:
   a. Number of solar panels and rated capacity of the PV array in kilowatts;
   b. The size of the tie-inverter;
   c. Cost of PV system;
   d. Annual savings and return on investment;
   e. Setting of language and monetary currency;
   f. Documentary requirements for:
      i. Applying for net-metering,
      ii. Electrical permits,
      iii. Single-line diagram and technical specifications of the solar PV.

3. To dry run the mobile app by trying it with houses installed with rooftop grid-tied solar PV systems and investigate the consistency of the result of the dry run with the actual performance of the existing solar PV system.

1.2 Hypothesis
Based on the foregoing, the researcher devised the null hypothesis, which states that "there is no significant difference between the results of the dry run and the actual size of the solar PV system installed on the selected residential buildings to be tested."

2. Review of Related Literature and Studies
2. 1 Related Literature
In comparison to nonrenewable energy sources, solar energy is considered a clean and sustainable source of energy (Solar NRG, 2022). The usage of solar photovoltaic (PV) systems as an alternative source of power is growing more widespread, with two types of solar PV systems being used: off-grid and on-grid (Khan, 2019). An off-grid PV system is not connected to the national grid and is designed for households and businesses, but a grid-tied PV system with a battery energy storage system is known as a hybrid grid-tied solar PV system (Almerini, 2023).

Solar PV systems can create power without harming the atmosphere with harmful gas (Skysteam Energy, 2022). The search for sustainable fuel sources is more important than ever because the greenhouse gases released by fossil fuels harm the environment, cause a climate crisis, and endanger human health (U.N., 2022). ASEAN member states are among those making attempts to transition to sustainable energy, notably solar energy, and have implemented various clean energy development initiatives (IEA, 2020; Sticher, 2021). Vietnam, Thailand, the Philippines, and Malaysia account for approximately 98% of the region's solar capacity, with Vietnam leading the way (Rodriguez, 2021; The ASEAN Post Team, 2023).

To achieve sustainability, the highest quality system components should be prioritized in solar PV system design and installation (Cabraal, 1995). In 2014, the Asian Development Bank (ADB) published a Handbook for Rooftop Solar Development in Asia that outlined the development of rooftop solar PV systems after documenting the results of several solar retrofit projects at its Headquarters to make its buildings more energy efficient (ISSD, 2012; ADB, 2014).

2.2 Related Studies
Solar photovoltaic (PV) systems are becoming more prevalent as a means of producing electricity. However, the efficacy of a solar PV system is determined by the amount of sunlight it receives, so when planning to install solar panels in residential buildings, it is critical to consider the collection of solar radiance data (Franklin, 2017). To guarantee that the system operates as efficiently as possible, one of the first stages should be to evaluate the property's daily sun irradiation. Solar irradiation is the amount of energy received from the sun per unit area, which varies by region. Thus, the sun radiance in Dagupan City, Ilocos Region, and Tarlac City, Central Luzon, varies (Global Sun Atlas 2.0, 2020).

The solar resource data map can be used to virtually analyze or compare the scale of a given region's PV power potential and compare it to other places in the Philippines. According to data, the solar energy potential of Pangasinan and Tarlac ranges from 5.0 to 5.5 kWh/m2/day (Macabebe et al., 2016). It is critical to understand how much radiation is required to generate the appropriate output power during daytime hours. This helps us to determine how many hours an area will receive the greatest sunlight. The system size must be determined using the local peak sun hours (PSH), which are calculated as 1 PSH= (1000 W/m2 sunlight)/hour (Franklin, 2017).

Solar radiance data must be acquired before designing an on-grid photovoltaic system, and the panel generation factor must be calculated based on this data and the irradiance value of the photovoltaic module at Standard Test Conditions (STC). The power output of solar panels is calculated using Kuchta's (2022) STC, which is at 25°C (77°F) and exposed to 1,000 watts per square meter (1 kW/m2) of solar irradiation when the air mass is at 1.5. The same equations were utilized in Ikoiwak et al.'s (2021) study, which attempted to build an on-grid photovoltaic system to tackle power supply shortfalls at the faculty of Engineering, Abuja campus, University of Port Harcourt.

It is also necessary to determine the load demand. The electrical load on a property might assist in determining the optimum size of solar panels. The DU's electricity bill can be used to compute daily electricity usage by dividing monthly consumption by 30 days. The capacity factor governs how frequently the virtual power plant runs for a particular period. It is calculated as a percentage by dividing the actual unit power output by the highest power output. In the Philippines, the capacity factor for simple solar PV applications is anticipated to be 16%. Finally, the size of the PV system must be estimated by dividing the daily kWh energy requirement by 24 hours multiplied by the solar PV system's 16% capacity factor. (Ariola & Lafrades, 2021).

The unbundled energy bill, mandated by the Electric Power Reform Act of 2002, is utilized and delivered by distribution utilities to consumers so that the latter can see the cost of each service they are paying for. Prior to adopting the unbundled bill, consumers had no idea how much they were paying for the following services: generation, transmission, system loss, taxes, subsidies, and distribution. The unbundled household power bill consists of 12 components.

Chowdhury and Bhatia's research on rooftop grid-tied solar home systems provided a detailed design calculation. They claim that using a solar capacity factor of 1.6%, the daily kilowatt-hour used can be estimated to determine the size of the PV system. Taylor-Parker also incorporated peak sun hours in the intended area by utilizing a sun hours chart to establish how many hours per day the sun delivers peak sunlight and locate the nearest solar energy source. He claims that the size of the required solar system may then be calculated.

The following equations were used by the researcher for the system calculations of the developed mobile application:

a. Photovoltaic Component Sizing

The daily solar radiation for the location in which the PV plant is sited is divided by the irradiance value of the photovoltaic module at STC.

$$Panel\ Generation\ Factor = \frac{Daily\ Solar\ Radiation\ of Location}{Irradiance\ of\ PV\ at\ STC}$$

The entire PV panel energy required is multiplied by the system losses compensation factor, which is 1.3.

$$Total\ PV\ Module\ Energy\ Required = Energy\ Consumption * Energy\ Lost\ in\ the\ System$$

b. PV System Module Sizing

The total watt peak rating required to operate the PV modules was first estimated to size the PV modules. According to the Formula:

$$PPV = \frac{Ed}{PSH * \eta\mathrm{CR} * \eta\mathrm{inv}}$$

Where:

Ed = daily energy consumption of the faculty in kWH/day

PSH = peak sunshine hours (hrs/day)

$\eta\mathrm{CR}$ = charge regulator efficiency

$\eta\mathrm{inv}$ = inverter efficiency

The formula was simplified into the equation below for simplicity:

$$Total\ watt\ peak\ of\ PV\ modules = \frac{Energy\ PV\ modules}{Panel\ Generation\ Factor}$$

To calculate the capacity utilization factor, they used the following equation:

$$CUF = \frac{EAC.a}{\text{PPVrated} * 24 * 365} * 100$$

Where:
CUF = Capacity Utilization Factor
EAC.a = the annual ac energy output, kWh.
PPVrated = the rated PV power, kWh.
The capacity factor for a grid connected PV system is also represented by the following:

$$CUF = \frac{Peak\ sun\ hours/day}{24\ h/day}$$

After calculating the number of solar panels, measuring the required area is undertaken by multiplying the total modules by the module area. The product is then divided by 0.7, as shown below.

$$Total\ Area = \frac{Total\ Modules * Module\ Area}{0.7}$$

The researcher found two approaches for calculating the return on investment. The study paper of Kaur, H. & Kaur, I (2019) introduced the formula for computing the payback period as

$$Payback\ Period = \frac{cost\ of\ project}{annual\ cash\ inflows}$$

On the other hand, Croatian researchers, namely, Bosnjakovic, Cikic & Zlatunic, presented in their paper the formula for determining the simple payback period (SPP) was used to computing the ROI as

$$SPP = \frac{cost\ of\ investment}{anuual\ profit}$$

Other critical aspects for developing a smartphone app for creating a solar house project include net metering, which is a component of the Renewable Energy Act of 2008. According to Verzola (2015), net metering is defined as "the DU gives a peso credit for the excess electricity received equal to the DU's blended generation cost, excluding other generation adjustments, and deducts the credits earned from the customer's electric bill."

3. Methodology

Prior to creating the smartphone app, the researcher discovered several homes with solar PV systems and net metering with the help of the electric distribution utilities serving the two areas for his research. In connection with this, he visited some of these houses and explained the purpose of his research to gauge their interest in taking part. They agreed to take part in the study after being persuaded by the researcher. With nine households agreeing to participate, data on their average monthly electricity use and cost savings were successfully gathered. In order to collect a year's worth of solar radiance data, the researcher collected data from five residents over the course of 12 months. The researcher gathered the inhabitants' harvest between June 2021 and June 2022.

The next step was to research different website development techniques for the mobile application. A process developed by Team Invonto (2021) was eventually discovered, indicating that the first step in the process is to plan the tasks the mobile app will perform, such as simulating a grid-tied solar PV system for residential buildings, estimating the interest rate of return, and other tasks deemed necessary to satisfy the users. In order to ensure that the contents of the pages will fit the user's screen, the layouts for the App pages were created. The work done to accomplish the first two goals focuses on creating a set of guidelines for users to follow in order to carry out the intended actions inside the mobile app.

The researcher then tested the mobile app on homes with existing solar PV systems and compared the results to the actual parameters of the tested existing solar PV systems. The researcher discovered several residences with solar PV systems with net-metering with the help of the electric distribution utilities serving Dagupan City and Tarlac City. The goal is to validate the mobile app's performance by comparing the results of the dry run test to the actual parameters of the solar PV system examined.

3.1 Research Design

The study's research method was action research. Lewin (1947) defined action research as a three-step spiral process that comprises (1) fact-finding, planning, (2) acting, and discovering information about the effects of actions. It is an experimental activity that optimizes a solution in the development of software to produce the best design of a solar PV system.

The mobile was created after a thorough review of the literature and research on PV System programs and data, specifically the solar radiance of target sites. The mobile application, which was free to download, was made accessible via the Google Play Store or app store. Online evaluations would be performed to validate the solar PV system size result from the mobile application.

3.2 Respondents and Locale of the Study

The research was carried out in two areas of Luzon: Dagupan City and Tarlac City. These cities were chosen because they are highly urbanized, as indicated by numerous business facilities, universities, hospitals, and big populations. The study assumed that the characteristics of these two cities were the explanation for the high number of households having rooftop grid-tied solar PV systems. From these two cities, nine respondents with existing solar PV installations were chosen.

3.3 Data Gathering Process

Data collection procedures included using a survey method to collect monthly energy consumption and solar radiance data, conducting face-to-face interviews with participants to discuss the purpose of the study and make them feel comfortable participating, extracting information from websites, and testing the completed project.

3.3a Collection of Solar Radiance Data

Since there is no direct data on solar radiance, the researchers used the following formula to calculate the average solar radiance data per KWH in Dagupan City:

$$Radiance\ per\ kwh = \frac{\frac{Monthly\ GenerationOutput}{30\ days}}{system\ capacity}$$

The following equation was used with each system to calculate the total average of all systems.

$$Average\ Radiance\ per\ kwh = \frac{total\ radiance\ per\ kwh}{12\ months}$$

3.3b Testing of the mobile application on residential buildings

The researcher used nine samples of residential buildings with actual solar PV systems in Dagupan City and Tarlac City to test the mobile app on buildings that had already been fitted with rooftop solar PV systems and compare the results of the trial with the real-world performance of the solar PV system. The real system size of each of these nine samples was compared to the mobile app design. Following data collection, the researcher computed the mean value of the actual design and the mean value of the mobile app design. The t-test statistical method was then used to determine whether there was a statistically significant difference between the two values.

4. Findings of the Study

The following were the findings from the study:

Based on the solar radiance data acquired from the pre-installed Grid - linked PV systems of the five Dagupan residents, the gathered solar radiance is 4.3KWH. The information acquired made it easy for the researcher to build and develop a mobile application for consumers interested in installing a Grid-tied PV system.

The smartphone application was developed using solar radiance data collected from the five Dagupan City residents' pre-installed Grid-tied PV systems. The Solar PV smartphone app was created to assist residential customers in Dagupan City and the surrounding towns and cities in calculating the optimal design for a solar rooftop PV system. It required user input of KWHR usage, in addition to panel wattage and position, to generate suitable KW capacity. Based on this information, an ideal design was developed for the respondents, indicating the system size, inverter size, number of panels, system cost, and ROI (return on investment).

The results revealed that there was no statistically significant change in the size of the solar PV system between the actual setup and the mobile application. This demonstrates that the mobile application is a dependable tool for assisting residential clients in determining the appropriate solar system size for their homes.

At the end of this thesis, it can be argued that the mobile application successfully achieved the expected outcome for the grid-connected PV system. The results demonstrated how successfully and efficiently the application works. As a result, the model developed can be utilized to undertake further research and studies on the grid-connected PV system and its components, allowing for the creation of more advanced and effective hardware architectures, control algorithms, and protection techniques. Finally, the developed mobile application met the primary, fundamental goals of this project.

4.1 Conclusion

The following conclusions were drawn from the study's findings: (1) The acquired solar radiance data is 4.3KWH based on the solar radiance data gathered from the pre-installed Grid-tied PV systems of the five Dagupan residents. (2) The grid-connected PV system achieved the anticipated outcome as a result of the mobile application. The results demonstrated how successfully and efficiently the application works. This demonstrates that the mobile application is a dependable tool for assisting residential clients in determining the appropriate solar system size for their homes. (3) The results revealed that there was no statistically significant change in the size of the solar PV system between the actual setup and the mobile application.

4.2 Recommendations

Based on the findings and conclusions, the researcher recommends the following: (1) Validate the simulation results with some real-world trials. (2) Using the established model, conduct comparison studies of alternative hardware structures and control techniques. (3) Using the developed model, do system fault analysis research. (4) Before designing the system, more detailed information is required, such as the electrical arrangement, the potential mechanical load the building can support, mounting structure dimensions, and protection and disconnect switches. (5) The LGU should launch an information campaign to promote grid-connected solar PV systems, which are rarely deployed in the study region because most homeowners prefer off-grid systems.

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