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Design of a hybrid photovoltaic system for a gable roof at the La Suiza Farm mini-industry

Diseño de un sistema fotovoltaico híbrido a dos aguas para la minindustria Finca La Suiza

Ivelisse Almanza Fundora[1*], Francisco García Reina[1], Rigoberto Antonio Perez Reyes[1], Oscar Brown Manrique[1] and Maiquel López Silva[2]

[1]*Universidad de Ciego de Ávila Máximo Gómez Báez (UNICA), Ciego de Ávila, Cuba.*
E-mail: pancho@unica.cu, rigobertopr@unica.cu, obrown@unica.cu
[2]*Universidad Católica Sedes Sapientiae, Lima, Perú. E-mail: mlopezs@ucss.edu.pe*

[*]Author for correspondence: Ivelisse Almanza Fundora, e-mail: ivelisse@unica.cu

ABSTRACT: The instability of the electrical grid in rural areas of Cuba affects the productivity of small industries, increasing costs and dependence on fossil fuels. Grid-connected photovoltaic systems offer an alternative, although their generation concentrated at midday does not always match consumption profiles. The objective of this research is to design a hybrid photovoltaic system with a dual-pitch roof structure (east and west orientations) to optimize daily generation and guarantee the electricity supply for the mini-industry "Finca La Suiza" in Ciego de Ávila. A load analysis was performed, and the PV generator was sized with 40 DSM-380MP panels (15.2 kWp), considering the local average solar irradiance of 5.28 kWh/m²/day and an inclination of 24°. A hybrid inverter, the SMA Sunny Tripower 15000TL-10, was selected. The dual-pitch roof structure design was modeled to distribute generation and compare its performance with a traditional South-facing configuration. The system generates a net energy of 59.43 kWh/day, exceeding the critical consumption of the industry. The dual-pitch structure showed a flatter and more extended generation profile, reducing the midday peak by 25% and shifting 15-20% of production toward the morning and afternoon. This improves the match with demand and reduces injection during peak hours. The hybrid inverter ensures operational continuity during grid failures. The design represents a viable solution for the Cuban context, optimizing the use of solar radiation and favoring integration with the local grid.
Keywords: Energy Saving, Hybrid Inverter, Rural Solar Energy.

RESUMEN: La inestabilidad de la red eléctrica en zonas rurales de Cuba afecta la productividad de las pequeñas industrias, incrementando costos y dependencia de combustibles fósiles. Los sistemas fotovoltaicos conectados a red ofrecen una alternativa, aunque su generación concentrada al mediodía no siempre coincide con los perfiles de consumo. El objetivo de esta investigación es diseñar un sistema fotovoltaico híbrido con estructura a dos aguas (orientaciones este y oeste) para optimizar la generación diaria y garantizar el suministro eléctrico de la minindustria "Finca La Suiza" en Ciego de Ávila. Se realizó un análisis de carga y se dimensionó el generador FV con 40 paneles DSM-380MP (15,2 kWp), considerando la irradiación solar local de 5.28 kWh/m²/día y una inclinación de 24°. Se seleccionó un inversor híbrido SMA Sunny Tripower 15000TL-10. El diseño de la estructura a dos aguas se modeló para distribuir la generación y comparar su desempeño con una configuración Sur tradicional. El sistema genera una energía neta de 59.43 kWh/día, superando el consumo crítico de la industria. La estructura a dos aguas mostró un perfil de generación más plano y extendido, reduciendo el pico del mediodía en 25% y desplazando entre 15-20% de la producción hacia la mañana y la tarde. Esto mejora la coincidencia con la demanda y reduce la inyección en horas centrales. El inversor híbrido asegura continuidad operativa durante fallos de la red. El diseño representa una solución el contexto cubano, optimizando el uso de la radiación solar y favoreciendo la integración con la red local.
Palabras clave: ahorro energético, energía solar rural, inversor híbrido.

INTRODUCTION

The transition towards a sustainable energy matrix is a global and national imperative. In Cuba, the Policy for the prospective development of renewable energy sources and energy efficiency sets the goal of generating 24% of electricity from renewable sources by 2030 (Gaceta Oficial de la República de Cuba, 2019). This objective is particularly relevant in the rural productive sector, where the instability of the National Electric System (SEN) translates into interruptions that affect the value chain, increase operational costs due to the use of diesel generators, and limit local economic development (Salazar-Quevedo et al., 2025).

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Solar photovoltaic (PV) energy stands out as one of the most suitable solutions for the Cuban context, given its high average solar irradiation (approximately 5 kWh/m²/day) and the constant decrease in technology costs (IRENA, 2022). Grid-connected PV installations in the industrial sector, whether rooftop or ground-mounted, have been widely studied internationally, demonstrating benefits in economic savings, carbon footprint reduction, and supply reliability improvement (Saxena et al., 2021; Sharma and Kolhe, 2025).

In Cuba, research and application of PV systems have evolved from off-grid systems towards large-scale solar parks and self-consumption systems. Studies such as those by García-Reina et al. (2019) have documented the potential and deployment of PV parks in the province of Ciego de Ávila; however, national scientific literature lacks detailed analyses of hybrid PV applications (grid-connected with backup capability) for small rural industries, a critical link for local development (Álvarez-Villagómez and Concha-Ramírez, 2025). These systems require not only generating energy but also guaranteeing an uninterrupted supply given frequent grid failures.

A technical aspect even less explored in the local context is the optimization of the generation profile. Traditional configurations, with all panels facing geographic south at a fixed tilt, produce a pronounced energy peak at midday (Díaz-Santos et al., 2018). This profile may not coincide with the load curve of a mini-industry, which may have constant demands or peaks at different times, and can saturate the injection capacity of weak grids. Design strategies such as splitting arrays into east and west orientations ("dual-pitch") allow for flattening the generation curve, shifting part of the production to morning and afternoon hours, thus improving generation-consumption synchronization and grid integration (Gamarra et al., 2021; Minuto et al., 2024).

Therefore, a research gap is identified in the application and evaluation of hybrid PV systems with optimized generation configurations (such as dual-pitch structures) for the specific context of Cuban rural mini-industries, where grid intermittency and consumption profiles are determining factors.

This study contributes to the scientific community and professional practice as follows: it presents a comprehensive design methodology for a hybrid PV system adapted to the conditions of a Cuban rural mini-industry; it proposes and conceptually analyzes the impact of a dual-pitch structure as an innovation to optimize the generation profile; and it quantifies the potential energy and environmental benefits of the solution. The objective of this research is to design a hybrid photovoltaic system with a dual-pitch structure that guarantees and optimizes the electricity supply for the mini-industry "Finca La Suiza" in Ciego de Ávila, Cuba.

MATERIALS AND METHODS

The study was developed as an engineering design project based on a real case study. The local development project is located at Finca La Suiza with coordinates 21.94945° N, 78.74005° W, Ciego de Ávila municipality. The methodology followed a structured process in the following stages: The solar resource was determined based on the average daily horizontal solar irradiance for the Ceballos area of 5.28 kWh/m²/day, corrected for the tilt angle of the generator plane.

The electrical demand was determined from an inventory and operating schedule of all electrical equipment in the mini-industry, which allowed calculating the daily required power by applying a simultaneity coefficient to reflect the incomplete temporal overlap of loads:

$$P_N = \left[\sum (P_U . N_E . H_T)\right] . C_S \tag{1}$$

Where P_N is the daily required power (kWh), P_U is the unit power (kW), N_E is the number of equipment, H_T is the daily operating hours, and C_S is the simultaneity coefficient (0.70).

The polycrystalline panel DSM-380MP (380 Wp) was chosen, with a module efficiency of 19%, power warranty of 80% at 25 years, and electrical parameters suitable for tropical climate (nominal cell operating temperature, NOCT of 45±2°C).

The daily energy generated by the system was determined considering local peak sun hours of 4.60 h/day and an initial global performance ratio of 0.85, which includes losses due to temperature, soiling, wiring, and inverter efficiency. The number of panels (N_p) was calculated from the rectified required power; subsequent iterations were performed until the daily generated energy was equal to or greater than the daily required power. The following equations were used:

$$E_{gd} = Pp_s .\ HPS . PR \tag{2}$$

$$N_p = \frac{P_{nr}}{Pp_p \cdot \eta} \tag{3}$$

Where E_{gd} is the daily energy generated by the system (kWh/day), Pp_s is the peak power of the system (kWp), Pp_p is the peak power of the panel (kWp), HPS are the peak sun hours (h), PR is the Performance Ratio or global performance factor, P_{nr} is the rectified required power (kW), η is the safety factor (20%).

For the site's latitude, a fixed tilt of 24° relative to the horizontal was selected, which maximizes annual energy capture in Cuba (Potes and Proaño, 2020). Instead of a single south orientation, the "Dual-Pitch" configuration was used: the PV field was divided into two sub-arrays of equal power: a) East Sub-array with an azimuthal orientation of +90° (East) which captures predominantly morning radiation, and b) West Sub-array with an azimuthal orientation of -90° (West) which captures predominantly afternoon radiation.

The hourly generation profile for each orientation was modeled using power (%) and time (h) data and compared with the typical south-oriented profile (Padrón-Suárez et al., 2021). The percentage power was obtained by multiplying the daily required power by one hundred and dividing it by the maximum daily required power. The profile was represented using the typical profile template technique in Excel to relate power to time based on the panel's orientation.

The Balance of System (BOS) encompasses all components of a solar installation except the solar panels; therefore, it includes the elements that allow a photovoltaic system to function correctly:

A hybrid inverter SMA Sunny Tripower 15000TL-10 (15 kVA) was selected, with two independent maximum power point trackers (MPPT), one for each sub-array (East/West). Its characteristics (MPP voltage range: 150-800 VDC, maximum input current) are compatible with the designed strings. Its hybrid mode allows operation connected to the grid with surplus injection, and maintenance of critical loads in island mode (with optional batteries) during grid failures.

Conductors for direct current and alternating current were sized according to standard NC-ISO-60228, verifying voltage drop (<1.5%) and current-carrying capacity. Protections against overvoltages, circuit breakers, and residual-current devices were included in accordance with the Cuban Low Voltage Electro-Technical Regulations.

The annual energy generation was calculated using the specific yield for Cuba. The following equation was used:

$$E_{anual} = Pp_S \cdot Y_f \tag{4}$$

Where E_{annual} is the annual energy generated (kWh/year), Y_f is the specific yield (1400 kWh/kWp/year).

The environmental impact associated with fossil fuel savings and CO_2 emission reductions was estimated using standard conversion factors:

$$A_{comb} = E_{anual} \cdot F_{acf} \tag{5}$$

$$R_{CO2} = E_{anual} \cdot F_{rem} \tag{6}$$

Where A_{comb} is the fossil fuel savings (t fuel/year), R_{CO2} is the CO_2 emission reduction (t CO_2/year), F_{acf} is the fossil fuel savings factor (0.000086 t/kWh), F_{rem} is the CO_2 emission reduction factor (0.00075 t CO_2/kWh).

RESULTS AND DISCUSSION

Table 1 shows the load survey, which revealed significant and diversified energy consumption. The daily required power was 528.43 kWh, equivalent to an average power of approximately 22 kW over 24 hours. This value justifies the need for an on-site generation system.

The sizing led to the installation of 40 DSM-380MP panels, configured in 4 strings of 10 panels in series each. Two strings will be connected to MPPT1 (East sub-array) and two to MPPT2 (West sub-array). The total peak power of the system is 15.20 kWp.

Figure 1 shows the comparison of the simulated generation profile for a clear day for three configurations (traditional South, East, and West), where the Y-axis represents the relative power of the installed capacity (%) and the X-axis the hour of the day. The "Dual-Pitch" configuration (sum of East and West profiles) produces a notably flatter generation curve.

The simulation shows that the South-oriented system concentrates over 70% of its maximum generation between 10:00 and 14:00 hours. In contrast, the "Dual-Pitch" system starts significant generation earlier (thanks to the East sub-array) and maintains it later (thanks to the West sub-array). The absolute peak is reduced by approximately 25%, and between 15-20% of the total generation is shifted to the periods of 8:00-10:00 and 16:00-18:00. This result is consistent with the findings of Álvarez-García (2024), who reported a significant reduction in peak grid injection in facilities of the Villa Clara Dairy Products Company, Cuba, with similar designs.

This flattened profile is particularly beneficial for the mini-industry under study, whose load is relatively constant during the day due to cold room operation and has peaks from the use of motors in specific processes (mills, pasteurizer) that may not coincide with midday. Minuto et al. (2024) highlight that this strategy improves the instantaneous self-consumption rate, reducing grid injection/consumption cycles and relieving stress on local transformers and lines, a critical factor in weak rural grids like Cuba's.

Table 1. Electrical load analysis of the mini-industry Finca La Suiza.

Equipment	Quantity	Unit Power (kW)	Time (h/día)	Consumption (kWh)
Cold Room.	1	6,00	24	144,00
Induction Vats.	2	15,00	4	120,00
Pasteurizer.	1	36,00	2	72,00
Mills.	5	16,50	5	82,50
Turbines.	4	3,00	8	96,00
Others (computers, pump, etc.)	7	Variable	Variable	62,93
Total (without simultaneity)		140,29		754,90
Total (with simultaneity)		-		528,43

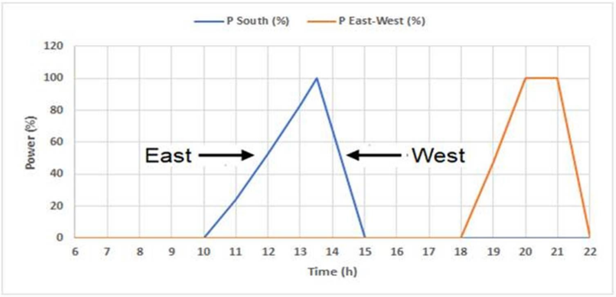

Figure 1. Simulated hourly generation profile of the PV system for different orientations.

The estimated annual energy generation using a conservative value for Cuba of 1400 kWh/kWp/year was 21,280.00 kWh/year. This equates to a net average daily generation of 58.30 kWh/day, which was lower than the total daily consumption (528.00 kWh); but it covers the critical daytime demand and displaces a substantial percentage of grid consumption. On sunny days, the system is expected to cover 100% of the demand during daylight hours, injecting surplus energy into the National Electric System.

The strategic value of this result lies in its temporal displacement capacity. Power generation is concentrated during the hours of highest daytime activity, and during this period, the solar energy is instantly self-consumed, covering a substantial portion of the critical demand and reducing the draw from the national grid. This self-consumption represents a net displacement of approximately 58 kWh/day, equivalent to 11% of total consumption. This translates into direct economic savings and contributes to the stability of the national electrical system by reducing the load during peak hours.

The environmental impacts were significant with a fossil fuel saving of 1.83 tons of fuel/year and a CO_2 emission reduction of 15.96 tons of CO_2/year. These values, although derived from a medium-sized system, when multiplied by the potential replication in hundreds of mini-industries, underline the tangible contribution of this technology to Cuba's decarbonization commitments. The fuel saving is a direct contribution to national energy security, a central objective of Cuban energy policy (Gaceta Oficial de la República de Cuba, 2019).

The selection of the SMA Sunny Tripower 15000TL-10 inverter with two MPPTs allows optimal management of the two sub-arrays with different orientations, maximizing the energy captured in each one independently of shading or irradiance differences (Díaz-Santos et al., 2018). Its hybrid capability solves the central problem identified (grid instability). While the grid is present, the system operates in efficient injection/self-consumption mode. In case of an outage, the inverter, coupled with a battery bank (future dimension), can form an "electrical island" to power priority loads, preventing production stoppage. This functionality, still little implemented in the Cuban industrial sector, is key to increasing energy adaptation at the micro level (Álvarez-Villagómez and Concha-Ramírez, 2025).

CONCLUSIONS

The study achieved the conceptual design and evaluation of a hybrid photovoltaic system with an innovative dual-pitch roof structure configuration for the "Finca La Suiza" small-scale industry.

The system sized at 15.20 kWp is technically viable and capable of generating an estimated annual energy of 21,280.00 kWh, covering the critical daytime demand and contributing significantly to the industry's energy balance.

The dual-pitch configuration (East and West orientations) is an effective strategy for optimizing the generation profile in the Cuban context. The simulation demonstrated that it flattens the production curve, reduces the midday peak by approximately 25%, and shifts between 15-20% of generation to morning and afternoon hours, improving the match with industrial consumption profiles and reducing stress on the weak local grid.

The integration of a hybrid inverter provides the necessary robustness to operate in an unstable grid environment, ensuring operational continuity through its island mode capability, which directly addresses the objective of securing the supply.

The project provides concrete environmental benefits, estimating savings of 1.83 tons of fossil fuel and mitigation of 15.96 tons of CO_2 annually.

The research should be extended to include system monitoring, model validation, and an evaluation of its impact on rural electrical grid stability.

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