FEASIBILITY ANALYSIS OF PHOTOVOLTAIC ENERGY SOLUTIONS FOR MILITARY RADAR SYSTEMS

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DOI: 10.19062/2247-3173.2026.27.17

Abstract: *The integration of renewable energy sources into military radar systems presents both strategic advantages and significant technical challenges. Radar installations require a continuous and stable power supply, while photovoltaic (PV) systems are inherently influenced by environmental and operational factors that can significantly reduce energy production. This paper focuses on identifying and analyzing the main phenomena that affect the efficiency and reliability of photovoltaic systems used for powering radar installations. Key limiting factors such as solar irradiance variability, temperature increase, partial shading, surface contamination, and system losses are investigated, emphasizing their impact on energy output and operational stability. A practical case study is conducted based on the AN/FPS-117 long-range surveillance radar, with a typical average power consumption between 30 kW and 50 kW. The analysis evaluates the feasibility of a photovoltaic-based solution under realistic operating conditions, considering daily energy demand, peak power requirements, and the influence of adverse environmental conditions on system performance. The results indicate that although photovoltaic systems can improve energy autonomy, their performance is strongly dependent on environmental factors and proper system dimensioning. The study highlights the importance of accurately assessing limiting phenomena to ensure reliable operation of radar systems powered by renewable energy sources.*

Keywords: *photovoltaic systems, radar systems, AN/FPS-117, solar irradiance, energy losses, reliability, military applications*

1. INTRODUCTION

Modern military radar systems are critical components of defense infrastructure, requiring continuous and stable electrical power for reliable operation. Systems such as the AN/FPS-117 long-range surveillance radar operate permanently and depend on uninterrupted energy supply to maintain detection and tracking capabilities. Conventional power solutions, such as diesel generators or grid connections, present several limitations, including logistical vulnerability and dependence on fuel supply chains [8]. In this context, photovoltaic (PV) systems represent a potential alternative for increasing energy autonomy [2,10]. However, unlike conventional sources, photovoltaic systems are strongly influenced by environmental factors such as solar irradiance variability, temperature increase, partial shading, and surface contamination. These phenomena can significantly reduce energy production and affect system reliability. As illustrated in Fig. 1, variations in operating conditions may lead to fluctuations in power output, which are critical for radar applications requiring stable energy supply. This paper analyzes the main limiting factors affecting photovoltaic system performance and evaluates their impact through a case study based on the AN/FPS-117 radar, considering realistic operating conditions and energy requirements.

2. LIMITING FACTORS AFFECTING PV SYSTEM PERFORMANCE

Photovoltaic systems are strongly influenced by environmental and operational conditions, which can significantly reduce their energy output and affect system reliability. In military radar applications, where continuous and stable power is required, these limitations become critical. One of the most important factors is solar irradiance variability [1,11]. The amount of electrical energy generated is directly proportional to the incident of solar radiation, which varies throughout the day and is affected by weather conditions such as cloud cover or atmospheric attenuation. As a result, the power output of photovoltaic systems fluctuates. Temperature also plays a significant role in system performance. An increase in cell temperature leads to a decrease in conversion efficiency, typically between 0.3% and 0.5% per degree Celsius above standard conditions[3,7]. In high-temperature environments, this effect can cause substantial energy losses, even under high irradiance levels. Partial shading represents another critical limitation. Even small, shaded areas on a photovoltaic panel can reduce the output of the entire string, due to the series of connection of cells [6]. This phenomenon can lead to disproportionate power losses and may affect overall system stability. Surface contamination, such as dust, sand, or other particles, reduces the amount of solar radiation reaching the cells, decreasing energy production [7]. In harsh environments, such as desert or remote military locations, this effect can lead to significant long-term efficiency degradation if not properly managed. In addition to environmental factors, system losses must also be considered. These include losses in cables, inverters, and energy conversion processes, which can reduce the overall efficiency of the system by up to 20–30% [5,12]. The combined effect of these factors leads to variations in power output that must be carefully considered when designing photovoltaic systems for radar applications, where energy stability is essential for continuous operation.

3. IMPACT OF LIMITING FACTORS ON RADAR ENERGY DEMAND

The limiting factors presented above have a direct impact on the ability of photovoltaic systems to supply the energy required by radar installations. Unlike conventional loads, radar systems operate continuously and require a stable power input, making them highly sensitive to fluctuations in energy production.

In the case of systems such as the AN/FPS-117 radar, which typically operates with an average power consumption between 30 kW and 50 kW, even small variations in photovoltaic output can lead to significant energy deficits. These deficits become more pronounced under unfavorable conditions, such as reduced irradiance, high temperatures, or partial shading [9].

Therefore, to evaluate not only the nominal energy production of a photovoltaic system, but also its behavior under real operating conditions. The combined influence of environmental factors and system losses must be considered to ensure that the energy demand of the radar system can be met reliably.

Based on these considerations, the following section presents a case study focused on the energy requirements of the AN/FPS-117 radar and the feasibility of a photovoltaic solution under realistic conditions.

4. AN/FPS-117 RADAR ENERGY ANALYSIS

The feasibility of powering a military radar installation using photovoltaic systems is analyzed through a detailed case study based on the AN/FPS-117 long-range surveillance radar.

This radar operates continuously (24/7) and requires a stable power supply, with an average consumption between 30 kW and 50 kW, depending on operational mode and environmental conditions [9].

For this analysis, a nominal average power consumption of 40 kW is considered, along with peak demand conditions that may exceed 80–100 kW during transmission pulses. The continuous operation leads to a daily energy requirement defined as:

$$E_Z = P_{avg} \times t = 40 \times 24 = 960 kWh/day \tag{1}$$

This value represents the baseline energy demand, without accounting for system inefficiencies or additional auxiliary loads such as cooling systems, signal processing units, and communication equipment, which may increase total consumption by 10–20%.

The photovoltaic system must therefore be dimensioned not only to meet the average energy demand but also to compensate for system losses and environmental variability. The required installed photovoltaic power is estimated using:

$$P_{pv} = \frac{E_z}{PSH \times FP} \tag{2}$$

Where PSH represents Peak Sun Hours and FP is the performance factor [10], accounting for losses in cables, inverter efficiency, temperature effects, and dust accumulation. Assuming realistic operating conditions with PSH = 4.5–5 h/day and FP = 0.70–0.75, the required installed power becomes:

$$P_{pv} \approx \frac{960}{5 \times 0.72} \approx 267 kW \tag{3}$$

This value represents the theoretical requirement under near-optimal conditions. However, in real environments, the system must be oversized to compensate for performance degradation. Considering a safety factor of 1.3–1.5, the adjusted installed power becomes:

$$P_{pv,real} \approx 350 - 400 kW \tag{4}$$

Using photovoltaic panels rated at 450 W, the total number of panels required is estimated between:

$$N = \frac{350000}{450} \approx 780 \; to \; N = \frac{400000}{450} \approx 890 \; panels \tag{5}$$

The system performance is further affected by environmental factors analyzed in Section 2. A reduction in solar irradiance due to cloud cover may lead to a 20–40% decrease in energy production. Additionally, high operating temperatures can reduce panel efficiency by 10–15%, while partial shading and dust accumulation may introduce further losses of 5–20%. Under unfavorable conditions, the cumulative effect of these factors can reduce total energy output by more than 50%, resulting in an effective daily production of approximately 450–500 kWh.

Compared to the required 960 kWh/day, this leads to a significant energy deficit, making it impossible for the system to sustain continuous radar operation without additional support. Another critical aspect is the mismatch between energy production and consumption profiles.

Photovoltaic systems generate energy only during daylight hours, while radar systems operate continuously. This temporal mismatch introduces additional challenges, requiring either energy buffering or hybrid configurations to ensure uninterrupted operation. The analysis demonstrates that while photovoltaic systems can contribute significantly to reducing dependency on conventional energy sources, their standalone use is limited by environmental variability and operational constraints. Therefore, accurate system sizing and realistic performance evaluation are essential for ensuring reliability in critical military applications.

5. DISCUSSION

The results of the case study highlight both the potential and the limitations of using photovoltaic systems for powering military radar installations. While the theoretical analysis indicates that photovoltaic systems can cover the average daily energy demand, real operating conditions introduce significant uncertainties that affect system reliability.

One of the main challenge is the strong dependence on environmental conditions [2,10]. Variations in solar irradiance, combined with temperature effects and partial shading, can significantly reduce energy production. As shown in the previous section, under unfavorable conditions, total energy output may decrease by more than 50%, leading to substantial energy deficits. Another critical issue is the mismatch between energy generation and consumption profiles. Photovoltaic systems produce energy only during daylight hours, whereas radar systems operate continuously. This discrepancy makes it difficult to ensure a stable and uninterrupted power supply using photovoltaic systems alone. The presence of peak power demands, specific to radar operation, adds an additional layer of complexity. Although the average consumption is relatively constant, short-term power peaks cannot be directly supported by photovoltaic generation, which depends on instantaneous solar conditions.

These aspects indicate that photovoltaic systems, when used as standalone solutions, may not be sufficient to guarantee continuous operation of critical systems such as radar installations. However, they can significantly reduce the dependency on conventional energy sources when integrated into a broader energy strategy. The implementation of photovoltaic systems in military applications must be based on realistic performance assessments, considering environmental variability, system losses, and operational constraints. Proper system dimensioning and risk evaluation are essential to ensure that the energy supply remains reliable under all operating conditions.

Although utility-scale photovoltaic systems require considerable installation surfaces, the available operational land and support infrastructure within the radiolocation unit perimeter are sufficient to accommodate the proposed photovoltaic installation. Consequently, the spatial requirements associated with the deployment of renewable energy infrastructure do not represent a major constraint for this category of military application.

The proposed photovoltaic system is intended primarily as a supplementary energy solution for peacetime operation and routine military activity, with the objective of reducing dependence on conventional power sources and improving overall energy resilience.

Under combat or high-readiness operational conditions, mission continuity and radar operational availability take precedence over energy-efficiency considerations, while the primary power supply remains ensured through conventional military energy systems. In addition, long-range radar installations are typically deployed as fixed strategic assets with predefined operational locations that can already be identified through satellite reconnaissance, electromagnetic surveillance, or intelligence analysis. Therefore, the integration of photovoltaic infrastructure is not expected to produce a significant increase in the operational detectability or vulnerability of the radiolocation site.

6. CONCLUSIONS

This paper analyzed the feasibility of using photovoltaic systems for powering military radar installations, with a focus on the AN/FPS-117 radar. The study highlighted that, although photovoltaic systems can theoretically meet the average energy demand, their performance is strongly influenced by environmental and operational factors. The analysis of limiting phenomena such as solar irradiance variability, temperature effects, partial shading, and system losses demonstrated that real energy production can be significantly lower than theoretical estimates. Under unfavorable conditions, the resulting energy deficit may compromise the continuous operation required by radar systems. The mismatch between intermittent energy generation and continuous power demand represents a major limitation of standalone photovoltaic systems. This aspect, combined with peak power requirements, further reduces the reliability of such solutions when used independently. Photovoltaic systems can contribute to increasing energy autonomy and reducing dependence on conventional energy sources, their implementation in critical military applications requires careful system design, realistic performance evaluation, and consideration of operational constraints.

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