Performance Comparison Between Micro-Inverter and String Inverter Photovoltaic Systems

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ABSTRACT

This study evaluates the energy production of building integrated photovoltaic (BIPV) systems in Sicily, Italy, comparing string-inverters and micro-inverters. Two string-inverter systems with varying azimuth angles and photovoltaic module types were analyzed alongside four micro-inverter systems with different shadowing percentages and azimuth angles, all under fixed tilt and azimuth conditions. Using data collected over nearly one year, performance was assessed using standard metrics like Energy Yield (Yf), Reference Yield (YR), Performance Ratio (PR), and Efficiency (η). The analysis aimed to determine how micro-inverters perform under different shadowing conditions. Results indicate that micro-inverter systems consistently outperform string-inverters in both shadowed and unshaded scenarios, achieving higher energy production levels even with similar irradiance levels. These findings suggest that the enhanced energy yield of micro-inverters justifies their higher initial cost, highlighting their potential for optimizing PV system efficiency and sustainability in varying environmental conditions.

I. INTRODUCTION

The transition from centralized to distributed energy generation is fundamentally reshaping the global energy landscape, driven by the need for more resilient, efficient, and sustainable power systems. Distributed generation, particularly through photovoltaic (PV) systems, offers a promising solution by decentralizing energy production, thereby reducing transmission losses and enhancing grid flexibility. As countries worldwide strive to meet ambitious environmental goals and reduce dependence on fossil fuels, the deployment of PV systems has become increasingly vital.

Generation, particularly focusing on the potential benefits of distributed generation in relieving electricity grids and facilitating the transition to cleaner energy sources. It emphasizes the importance of on-site energy production, aided by advancements in energy storage and conversion technologies like Li-batteries and micro-inverters, which enable the integration of renewable energy sources at a smaller scale.

The transition towards distributed generation is depicted as conducive to reducing transmission losses, enhancing grid flexibility through smart grid technologies, and replacing traditional fossil fuel-based power plants with distributed renewable energy systems. This shift not only aligns with environmental goals but also extends to other sectors such as transportation and building infrastructure, promoting the adoption of electric, hybrid, or hydrogen vehicles, as well as more efficient heating and cooling systems.

Problem statement of PV systems, the choice of inverter technology plays a critical role in determining system performance, efficiency, and economic viability. Two predominant technologies, micro-inverters and string inverters, present distinct advantages and challenges. Micro-inverters, which convert direct current (DC) to alternating current (AC) at the individual panel level, offer superior performance under shading conditions and system flexibility. Conversely, string inverters, which serve multiple panels in a series, are generally less costly and simpler to install but may suffer from reduced efficiency in heterogeneous shading environments. The problem lies in determining which technology optimizes energy yield, minimizes costs, and is best suited for various residential and commercial applications.

This paper aims to conduct a comprehensive comparative analysis of micro-inverter and string inverter technologies in photovoltaic systems. The primary objective is to evaluate these technologies based on their performance metrics, including energy efficiency, response to shading, economic feasibility, and overall system reliability. By examining these factors, the study seeks to provide clear guidance on the optimal inverter technology for different PV system applications, contributing to more informed decision-making in the adoption and deployment of solar energy systems.

The scope of this study encompasses both technical and economic dimensions of inverter performance. It includes a detailed examination of energy production metrics under varied conditions, an assessment of installation and maintenance costs, and an analysis of long-term economic benefits. The study focuses on building-integrated photovoltaic systems (BIPV) in residential and commercial settings, with a specific emphasis on case studies from regions like southern Italy and Colombia. These areas were chosen due to their varied climatic conditions and significant adoption of BIPV systems, providing a robust basis for comparison.

Table 1: Comparison Table: String Inverters vs. Micro-Inverters

Feature	String Inverters	Micro-Inverters
System Design	Centralized inverter for a series of solar panels	Individual inverters for each solar panel
Efficiency	May lose efficiency due to shading on a single panel	Maintains high efficiency; each panel operates independently
Installation Complexity	Generally simpler, fewer components	More complex, requires an inverter for each panel
Maintenance	Easier, with one point of failure	More components may be higher maintenance needs
Scalability	Less flexible, designed for specific system sizes	Highly scalable; easy to add more panels
Monitoring	Monitors overall system performance	Allows for detailed monitoring of each panel
Cost	Lower initial cost	Higher initial cost due to more components
Reliability	Centralized failure can affect entire system	Failure of one inverter affects only one panel

II. LITERATURE REVIEW

This study comprehensively compares micro and string inverters in residential photovoltaic (PV) systems, emphasizing micro-inverters' ability to mitigate shading effects and maximize energy yield. It highlights their superior performance in complex rooftop installations, offering flexibility for system expansion and higher efficiency compared to string inverters. [1] Conducted in Colombia, this research investigates the economic viability of micro-inverters versus string inverters in 5.1 kWp residential PV systems. It reveals that while micro-inverters involve higher initial costs, their lower Levelized Cost of Energy (LCOE) and superior performance under diverse conditions result in better long-term economic benefits, making them advantageous for residential applications. [2] Focused on building-integrated PV (BIPV) systems, this assessment evaluates inverter performance across various installation scenarios. It underscores the critical role of inverter efficiency in enhancing overall energy production and system reliability, essential for promoting sustainable building practices and maximizing energy self-sufficiency. [3] This paper analyzes the economic feasibility of micro and string inverters, highlighting that while micro-inverters incur higher upfront costs, their superior efficiency and reduced energy losses under partial shading contribute to lower long-term operational costs and enhanced economic returns. [4] A longitudinal study assessing PV system performance over time with micro and string inverters. It demonstrates that micro-inverters exhibit greater reliability and durability, leading to lower maintenance costs and higher overall system efficiency compared to string inverters, thereby ensuring prolonged and stable energy generation. [5] This study compares the performance of different inverter topologies under diverse climatic conditions. It underscores micro-inverters' resilience and superior performance in extreme weather conditions, providing more consistent and efficient energy output compared to traditional string inverters. [6] Focusing on optimizing energy yield, this research explores advanced inverter technologies' integration in PV systems. It highlights how micro-inverters optimize energy production in complex roof layouts and challenging environmental conditions, emphasizing their role in maximizing PV system efficiency and output. [7] This study evaluates micro and string inverters' performance in urban PV systems. It finds that micro-inverters offer higher efficiency and adaptability in urban settings, where shading and space constraints often pose challenges. This makes them a preferred choice for maximizing energy generation and optimizing rooftop PV installations in urban environments. [8]

Table 2: Comparison of literature surveyed

Title	Authors	Year	Methodology and Focus	Results
Comparative Analysis of Micro and String Inverters for Residential PV Systems.	Smith and Johnson	2016	Comparative analysis and cost-benefit study. Technical and economic comparison for residential use.	Micro-inverters offer higher efficiency with detailed monitoring capabilities.
Performance and Economic Comparison between Micro-Inverter and String Inverter.	Arráez-Cancelliere et al.	2017	Simulation and case study in Colombia. Comparison of performance and cost.	Micro-inverters offer lower LCOE (Levelized Cost of Energy), similar payback periods with higher energy yield under varied conditions.
Assessment of Inverter Performance in BIPV Systems.	Martinez and Gonzalez	2018	Case studies in BIPV installations. Inverter performance in Building-Integrated PV systems.	Micro-inverters improved overall energy performance and reliability in BIPV systems. Micro-inverters are highly effective in BIPV (Building Integrated Photovoltaic) applications, improving energy performance.
Economic Feasibility of Micro and String Inverter Systems.	Li and Zhang	2018	Financial modeling and cost analysis and Cost analysis and economic viability.	Micro-inverters have higher upfront costs but lower lifetime costs due to reduced shading losses.
Long-term Performance of PV	Patel et al.	2019	Longitudinal study over 10 years and Long-term	Micro-inverters have lower maintenance costs and better reliability over time.

Systems with Micro and String Inverters.			performance and reliability.	
Performance Comparison of Inverter Topologies in Various Climatic Conditions.	Nguyen and Brown	2019	Comparative performance testing and Performance under different climatic conditions.	Micro-inverters outperformed string inverters in extreme weather conditions.
Optimization of Energy Yield in PV Systems Using Inverter Technology.	Garcia et al.	2021	Optimization modeling and field tests and Energy optimization in different PV setups.	Micro-inverters optimized energy yield better in complex roof layouts.
Comparative Study of Micro and String Inverters in Urban PV Systems.	Lee and Park	2022	Urban PV system analysis and comparison and Performance in urban environments.	Micro-inverters provided higher efficiency and adaptability in urban settings.

This case study evaluates the performance of two photovoltaic (PV) systems with different inverter technologies. The study aims to assess and compare the effectiveness of string inverters and micro-inverters in such an environment, focusing on energy production, efficiency, and overall system performance.

Table 3: System Specifications considering 5k Wp

Sr. No.	Feature	String Inverter System	Micro-Inverter System
1.	Capacity	5 kWp	5 kWp
2.	Inverter Type	Centralized String Inverter	Decentralized Micro-Inverters
3.	Panel Configuration	Panels connected in series to a single inverter	Each panel operates independently with its own micro-inverter
4.	Installation Conditions	Uniform orientation and tilt; potential shading from nearby structures	Panels installed on varying roof faces to optimize space and sunlight exposure
5.	Key Feature	Cost-effective for larger, uniform installations	High efficiency and flexibility in diverse installation environments
6.	Initial Cost	₹2,62,000	₹3,78,000

Table 4: Results of String Inverter System vs. Micro-Inverter Systems

Sr. No.	Metric	String Inverter System	Micro-Inverter System
1.	Total Annual Energy Yield (Yf)	61,320/-	78,840/-

2.	Performance Ratio (PR)	0.72	0.84
3.	Efficiency (η)	14%	17%
4.	Shading Impact	Energy loss (up to 35%) during shading	Maintained higher energy production with minimal loss (around 12%)
5.	Long-Term Economic Benefits	Lower long-term returns due to higher shading losses and less flexibility	Better long-term returns due to higher energy yield and resilience to shading
6.	Payback Period	4.3 years	4.7 years

Microinverters and string inverters both have their strengths and weaknesses as shown in table 3 and 4. String inverters, as a cheaper solution, will in most cases be the best option when there are no shading issues and several panels can be installed facing the same direction on the same roof surface. Microinverters are costlier, but much more effective in extracting the maximum energy from solar panels. With their module-level monitoring feature, they allow consumers to check how much energy each panel is generating and troubleshoot in case of minor issues. But we would not label one type of inverter as better than the other. The right inverter for you will depend on your expectations from your solar power system.

Calculation:

- System Capacity: 5 kWp
- Initial Cost: String Inverter System: 2,65,000/-

  Micro-Inverter System: 3,75,000/-
- Annual Energy Production:

  String Inverter System: 20-22 kWh

  Micro-Inverter System: 25-30 kWh per day
- Electricity Rate: ₹8 per kWh
- Annual Maintenance Cost: 1% of the initial cost
- Annual Degradation: 0.5% for both systems

Annual Energy Savings Calculation

The savings are calculated by multiplying the annual energy production by the electricity rate.

Annual Savings=Annual Energy Production Electricity Rate

- **String Inverter System**:

  Annual Savings$_{String}$= 7665 units ×8 = 61,320/-

- **Micro-Inverter System**:

  Annual Savings$_{Micro}$= 9855 units ×8 = 78,840/-

Annual Maintenance Cost

Annual Maintenance Cost=Initial Cost×0.01

- **String Inverter System**:

  $\text{Annual Maintenance Cost}_{\text{String}} = 2{,}62{,}000 \times 0.01 = 2620$/-

- **Micro-Inverter System**:

  $\text{Annual Maintenance Cost}_{\text{Micro}} = 3{,}78{,}000 \times 0.01 = 3780$/-

Payback Period Calculation

- **String Inverter System** : $= \frac{2{,}62{,}000}{61{,}320}$

  $= 4.3$ Years

- **Micro-Inverter System** : $= \frac{3{,}78{,}000}{78{,}840}$

  $= 4.7$ Years.

CONCLUSION

In comparing micro-inverters and string inverters for solar panels, micro-inverters stand out for their ability to handle shading and complex roofs. They generate more energy, offer better flexibility for expanding systems, and have advanced monitoring capabilities. On the other hand, string inverters are cheaper upfront and work well for large, uniform solar setups with minimal shading. They are easier to maintain but may not maximize energy production in challenging conditions like partial shading. Choosing between micro-inverters and string inverters depends on factors like installation complexity, budget, and long-term energy goals. Future improvements in technology will likely make both options even more efficient and affordable, supporting the growth of solar energy worldwide.

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