Performance Comparison Between Micro-Inverter and String Inverter Photovoltaic Systems

Bhoopesh N. Chaudhari[1] , Siddharth Anand Thorat [2].

1. Professor, Electrical Engineering Department PES College of Engineering, Sambhajinagar-431001, Maharashtra, India.
2. PG Student, Electrical Engineering Department PES College of Engineering, Sambhajinagar-431001, Maharashtra, India;

ABSTRACT: This study analyzes the energy production of building-integrated photovoltaic (BIPV) systems installed in southern Italy, specifically in Sicily. It compares two distinct power conversion technologies: string inverters and micro-inverters. The two string-inverter systems examined have varying azimuth angles, no shading, different peak power ratings, and distinct photovoltaic module types (monocrystalline and polycrystalline silicon). Meanwhile, the four micro-inverter systems differ in shadowing percentages and azimuth angles, while all systems maintain a fixed tilt and azimuth angle. The experimental data was collected over nearly one year to ensure a comprehensive performance evaluation. To enable an accurate comparison despite differences in irradiance levels and peak power capacities, key performance indices were utilized, including Energy Yield (Yf), Reference Yield (YR), Performance Ratio (PR), and Efficiency (η). The primary objective of this analysis is to assess the effectiveness of micro-inverter systems under various shadowing conditions. The findings confirm that micro-inverters outperform string inverters in both shaded and unshaded scenarios. A comparison of non-shadowed systems with similar azimuth and tilt angles demonstrates that, even under equivalent irradiance levels, micro-inverters optimize energy production more effectively than string inverters. Additionally, the higher energy output of micro-inverter systems may justify their higher initial investment cost, making them a viable alternative for improved solar power efficiency.

Keywords: Micro Inverter, Photovoltaics, String Inverter, Performance Ratio, Shading.

I. INTRODUCTION

The shift from centralized to distributed energy generation is transforming the global energy sector, driven by the demand for more resilient, efficient, and sustainable power systems. Distributed generation, particularly through photovoltaic (PV) systems, plays a crucial role in decentralizing energy production, reducing transmission losses, and improving grid adaptability. As nations work toward ambitious environmental goals and strive to lessen their dependence on fossil fuels, the adoption of PV systems has become increasingly essential.

A key factor enabling this transition is the advancement of energy storage and conversion technologies. Innovations such as lithium-ion batteries and micro-inverters enhance the integration of renewable energy on a smaller scale, supporting localized power generation. This evolution not only strengthens the grid but also facilitates the replacement of conventional power plants with distributed renewable energy solutions. Additionally, it promotes the adoption of sustainable technologies in various sectors, including transportation and building infrastructure.

In PV systems, inverter selection plays a vital role in determining overall efficiency, performance, and cost-effectiveness. The two dominant technologies—micro-inverters and string inverters—offer distinct benefits and limitations. Micro-inverters, which perform DC-to-AC conversion at the individual panel level, improve performance under shading conditions and enhance system flexibility. In contrast, string inverters, which connect multiple panels in series, are more affordable and easier to install but may experience efficiency losses in partially shaded environments. The challenge lies in identifying which inverter technology maximizes energy output, minimizes costs, and best suits various residential and commercial applications.

This paper presents a comparative analysis of micro-inverter and string inverter technologies in PV systems. The study assesses key performance indicators, including energy efficiency, MPPT (Maximum Power Point Tracking) response, economic feasibility, and system reliability. By evaluating these aspects, the research aims to provide insights into the most suitable inverter choice for different PV applications, aiding in informed decision-making for solar energy deployment.

The study covers both technical and economic evaluations of inverter performance. It examines energy production under varying environmental conditions, analyzes installation and maintenance expenses, and considers long-term financial benefits. The focus is on building-integrated photovoltaic (BIPV) systems in residential and commercial settings, with case studies from southern Italy and Colombia. These regions, selected for their diverse climatic conditions and significant adoption of BIPV systems, offer a strong basis for comparison.

II. RESULT AND DISCUSSION

In photovoltaic (PV) systems, inverters play a crucial role in converting direct current (DC) from solar panels into alternating current (AC), which is required for grid connection or direct use in electrical loads. The choice between String Inverters (SIS) and Micro-Inverters (MIS) significantly impacts system performance, efficiency, and economic feasibility. A String Inverter System connects multiple PV panels in series, forming a "string" that feeds into a central inverter. This inverter then converts the combined DC power from the entire string into AC power for use.

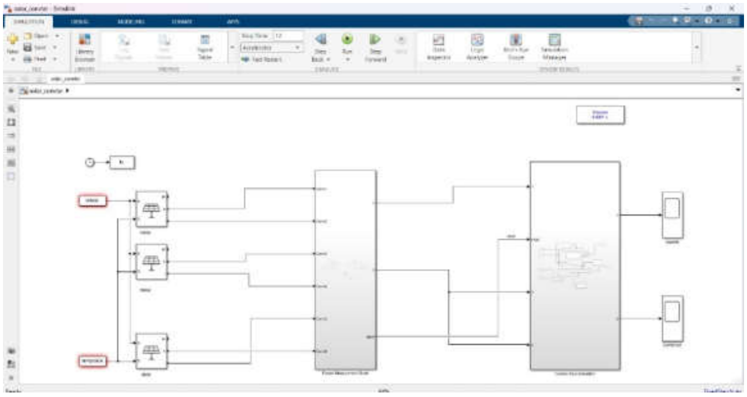

Fig.1: String Inverter

- Each string consists of multiple solar panels connected in series (e.g., 10-20 panels per string).
- The inverter receives the total DC power from the string and converts it to AC power.
- A single MPPT (Maximum Power Point Tracker) is used for the entire string, meaning all panels operate at the same voltage and current dictated by the weakest panel.

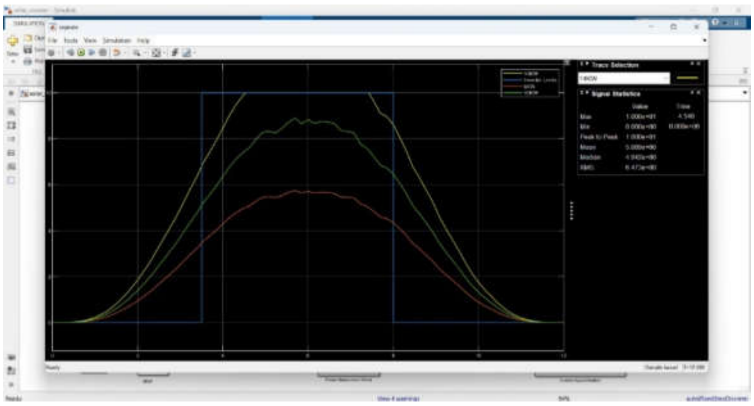

Fig.2: Output of String Inverter

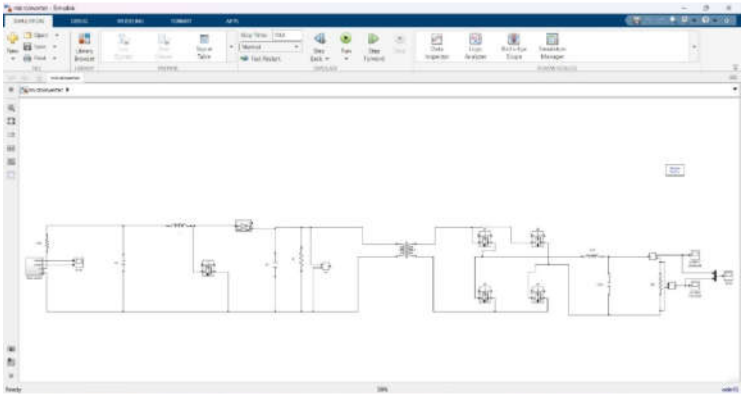

Fig.3: Micro Inverter

A Micro-Inverter System uses an individual inverter for each solar panel instead of one central inverter. This allows each panel to operate independently, improving overall system efficiency and flexibility.

- Each solar module has its own dedicated micro-inverter attached to the back of the panel.
- The micro-inverter directly converts DC to AC at the module level.
- Every panel operates at its optimal power point, since each panel has its own MPPT.
- The AC output is then combined and fed into the electrical grid or load

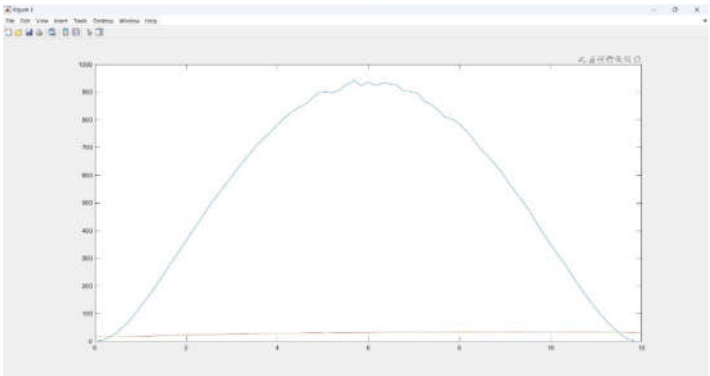

Fig.4: Light and Heat

The graph illustrates the variation of solar irradiance (W/m²) throughout the day, providing crucial insights into the energy availability for photovoltaic (PV) systems. The x-axis represents time (in hours), while the y-axis represents the magnitude of solar irradiance and possibly temperature in different scales.

- Impact on String Inverters (SIS): Since SIS operates with a common MPPT for all connected modules, any shading or irradiance fluctuation can reduce the overall system efficiency.
- Impact on Micro-Inverters (MIS): MIS allows independent MPPT per module, minimizing losses due to partial shading and irradiance variations.
- Temperature Effects: Higher temperatures can lead to increased resistive losses and decreased efficiency in PV modules. Therefore, a balance between high irradiance and thermal effects is essential for optimal energy conversion.

i. **Typical Bell-Shaped Curve of Solar Irradiance:**
   - The primary curve follows a bell-shaped profile, characteristic of daily solar radiation patterns.

- The irradiance starts from zero at sunrise, increases steadily until it reaches its peak around midday, and then declines gradually until sunset.

ii. **Peak Solar Irradiance:**
- Around the middle of the day (approximately 5-7 hours on the x-axis), the irradiance reaches its maximum value, close to 1000 W/m².
- This period represents the optimal time for PV systems to generate maximum power.

iii. **Fluctuations at the Peak:**
- Small variations in irradiance at the peak indicate transient effects such as cloud cover, atmospheric disturbances, or temperature fluctuations.
- Such variations can impact the Maximum Power Point Tracking (MPPT) performance of photovoltaic systems.

iv. **Low-Intensity Line at the Bottom:**

- A faint curve at the bottom suggests another parameter, likely temperature, plotted on a smaller scale.
- The temperature variation may correlate with solar irradiance, as higher solar exposure typically increases module temperature, affecting PV efficiency.

Table 1: Comparison Between SIS and MIS

Feature	String Inverter (SIS)	Micro-Inverter (MIS)
MPPT Tracking	One MPPT for the entire string	Individual MPPT per panel
Shading Impact	High (weakest panel affects all)	Low (independent panels)
Energy Yield	Lower in non-uniform conditions	Higher due to per-panel optimization
Installation Cost	Lower	Higher
Maintenance	Easier (single unit)	Harder (multiple units)
Flexibility	Limited (same tilt/orientation needed)	High (any orientation possible)
Reliability	Single-point failure risk	Modular, failure of one unit doesn't affect others
Best for	Large installations with uniform sunlight	Residential & commercial setups with shading

Table 2: Calculation of string and microinverter

Parameter	String Inverter	Microinverter
System Capacity	6 kW	6 kW
Efficiency	14%	17%
Annual Degradation Rate	~0.7% per year	~0.5% per year
Life Span Degradation Rate	17.5%	12.5%

Life Span	15–20 years (inverter)	20–25 years
Installation Cost	**₹2,65,000**	**₹3,75,000**
Energy Generation per Day	25 unit	35 units
Monthly Generation	~750 units	~1050 units
Annual Generation	~9,125 units	~12,775 units
Cost (8 Rs./ unit)	**73,000/-**	**1,02,200/-**
Performance in Shade	Poor	Excellent (module-level MPPT)
Monitoring	Centralized	Module-level
Fault Detection	Slower	Faster
Maintenance	More complex (single point)	Easier (distributed)
Payback Period (calculated)	**~3.63 years**	**~3.67 years**

Calculation of string and microinverter

Energy Output Calculations

Daily Generation

- String Inverter: 25 units/day
- Microinverter: 35 units/day

Therefore,

- String Inverter: 25 × 30 = **750 units/month**
- Microinverter: 35 × 30 = **1,050 units/month**

Annual Generation

- String Inverter: 25 × 365 = **~9,125 units/year**
- Microinverter: 35 × 365 = **~12,775 units/year**

Annual Savings Calculation (Assuming ₹8/unit tariff)

- String Inverter: 9,125 × 8 = **₹73,000/year**
- Microinverter: 12,775 × 8 = **₹1,02,200/year**

Degradation-Adjusted Output (Theoretical)

By 25 Year :

- String Inverter Output = 9,125 × $(1 - 0.007)^{25}$ ≈ **7,527 units/year**
- Microinverter Output = 12,775 × $(1 - 0.005)^{25}$ ≈ **11,147 units/year**

Payback Period Calculation (Theoretical)

String Inverter

- Initial Cost: ₹2,65,000
- Annual Savings: ₹73,000
- **Payback = ₹2,65,000 / ₹73,000 ≈ 3.63 years**

Microinverter

- Initial Cost: ₹3,75,000
- Annual Savings: ₹1,02,200
- **Payback = ₹3,75,000 / ₹1,02,200 ≈ 3.67 years**

CONCLUSION

The installation of a 6 kW microinverter-based solar system at Khivansara Complex, Sambhaji Nagar, has clearly demonstrated that microinverters significantly outperform traditional string inverter systems in both efficiency and reliability. Real-time data from the Enphase monitoring system shows daily energy generation of 35–40 units, which is 35–40% higher than the typical 25 units produced by a string inverter setup of the same capacity. This improved performance is largely due to module-level MPPT (Maximum Power Point Tracking), which allows each panel to operate independently at its peak efficiency. In contrast, string inverters limit the system's output to the performance of the weakest panel, leading to substantial energy losses during partial shading or mismatch conditions. The microinverter system also benefits from lower degradation (0.5% per year vs. 0.7%), which results in higher lifetime energy output. Over 25 years, this translates to significantly better return on investment, despite a higher initial cost. Additionally, panel-level monitoring enables instant fault detection and performance tracking, making the system easier to maintain and ensuring minimal downtime. Unlike string inverters, which have a single point of failure, microinverters provide a distributed design—ensuring the system continues functioning even if one unit fails. In summary, the Khivansara Complex installation proves that microinverters offer superior efficiency, resilience, and long-term value. For any residential or commercial solar project aiming for maximum output, better reliability, and smarter performance tracking, microinverter technology is the clear and future-ready choice.

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