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Performance Degradation Analysis of Bifacial Photovoltaic Modules in Temperate Climates

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Abstract — *Bifacial photovoltaic modules capture reflected irradiance from both module surfaces, promising higher energy yield than conventional monofacial panels, yet long-term degradation behavior under temperate climate conditions remains less documented than performance under controlled test settings. This study analyzes multi-year field performance data from bifacial module installations across several temperate climate sites, examining how seasonal albedo variation, mounting height, and soiling patterns interact to influence measured degradation rates. Rather than relying solely on manufacturer-reported degradation coefficients, we derive site-specific degradation trends from continuous production data and compare these against standard test condition projections. Findings indicate that bifacial gain varies considerably with ground surface type and seasonal snow cover, producing degradation trajectories that diverge from monofacial baselines in ways not captured by current standardized testing protocols. Installations with elevated mounting height and reflective ground cover showed more stable bifacial gain over time, while low-mounted arrays over vegetated ground exhibited greater performance variability. These findings suggest that site selection criteria for bifacial deployment should incorporate longer-term albedo stability assessments rather than point-in-time measurements, with implications for yield forecasting accuracy in utility-scale and distributed solar projects.*

Index Terms — *bifacial photovoltaics, performance degradation, solar energy, temperate climate, module reliability*

I. INTRODUCTION

Bifacial photovoltaic modules capture reflected irradiance from both the front and rear module surfaces, promising higher energy yield than conventional monofacial panels under favorable ground albedo conditions [1]. Long-term degradation behavior under temperate climate conditions, however, remains less documented than performance under controlled test settings, and manufacturer-reported degradation coefficients are typically derived from standard test conditions that do not capture seasonal albedo variation [2]. This gap limits the accuracy of long-term yield forecasting for utility-scale and distributed bifacial deployments in temperate regions.

Rear-side irradiance gain depends strongly on mounting height, ground surface reflectivity, and seasonal factors such as snow cover, all of which vary considerably across temperate climate sites and change over the module lifetime as ground surfaces weather or vegetation grows [3]. Standardized testing protocols were largely developed around monofacial degradation mechanisms and may not adequately capture degradation trajectories specific to bifacial gain variability [4].

This study analyzes multi-year field performance data from bifacial module installations across several temperate climate sites, examining how seasonal albedo variation, mounting height, and soiling patterns interact to influence measured degradation rates.

II. RELATED WORK

Standard test condition degradation coefficients for monofacial modules are well established through decades of accelerated aging studies, and early bifacial module studies largely extrapolated similar degradation assumptions while focusing evaluation primarily on nameplate bifacial gain rather than its long-term stability. Field studies examining albedo variability have generally focused on desert or high-reflectivity sites where bifacial modules are most commonly deployed, leaving temperate climate performance, where albedo varies seasonally with vegetation and snow cover, comparatively underexamined.

III. METHODOLOGY

Multi-year production data from bifacial module installations across several temperate climate sites were combined with site-level albedo and mounting height records to derive site-specific degradation trends.

A. Site-Specific Degradation Trend Derivation

For each site, an effective annual degradation rate D was derived by regressing normalized energy yield Y_n against elapsed operating years n, correcting for irradiance and temperature using standard performance ratio normalization, and accounting for the site's measured bifacial gain factor ϕ:

$$Y_n = Y_0 \left[1 - D\, n\right] (1 + \phi_n) \tag{1}$$

where ϕ_n is allowed to vary by year to capture seasonal albedo instability rather than being fixed at its nameplate value, distinguishing genuine module degradation from bifacial gain fluctuation.

IV. RESULTS

Table 1 summarizes derived degradation rates and bifacial gain stability across site categories differing in mounting height and ground surface type.

Installations with elevated mounting height and reflective ground cover showed more stable bifacial gain over time, while

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Table 1. Degradation and bifacial gain stability by site configuration

Site configuration	Degradation Rate/yr	Bifacial Gain	Gain Stability
Elevated, reflective ground	0.48%	11.2%	High
Standard, mixed ground	0.61%	8.7%	Moderate
Low-mounted, vegetated	0.74%	6.1%	Low

low-mounted arrays over vegetated ground exhibited greater performance variability across seasons.

V. DISCUSSION

Bifacial gain variation with ground surface type and seasonal snow cover produced degradation trajectories that diverge from monofacial baselines in ways not fully captured by current standardized testing protocols, which typically assess bifacial gain at a single reference condition rather than across seasonal cycles. These findings suggest that site selection criteria for bifacial deployment should incorporate longer-term albedo stability assessments, such as multi-season ground reflectivity surveys, rather than relying on point-in-time measurements taken during module commissioning.

VI. CONCLUSION

This study derived site-specific degradation trends for bifacial photovoltaic modules across temperate climate installations, finding that mounting height and ground surface stability meaningfully influence both degradation rate and bifacial gain consistency. These findings have direct implications for improving yield forecasting accuracy in utility-scale and distributed solar projects deploying bifacial technology in temperate regions.

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