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Development of a Solar Irradiance Estimation Method for Onboard PV System

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Photovoltaic Electric Vehicles (PVEVs) have potential to reduce emissions and charging needs, and recent advancements have improved their feasibility. However, their onboard PV systems suffer from shading by buildings and trees, unlike stationary systems. This study aims to clarify how diverse driving and weather conditions influence vehicle irradiance, which is the irradiance reaching the onboard PV system, and to develop a practical estimation method. Field tests were conducted in a shore route in Shonan Area, Kanagawa-ken (Fig.1), using a 2016-model Nissan Leaf to collect vehicle irradiance, fixed-point irradiance, and 360-degree semispherical photos across urban, suburban, and expressway routes. Analysis of the vehicle's electric consumption (EC) data, which was collected in past studies from 2019-2025, revealed that EV EC fluctuates significantly, ranging from 102 Wh/km in June to 122 Wh/km in January, and increasing by 39% when the ambient temperature drops to 4 degC. Accurately evaluating PVEV performance under such massive EC fluctuations makes it crucial to precisely estimate the onboard solar irradiance under diverse driving and weather conditions.

To quantitatively evaluate the shading effect, this study introduces the vehicle-to-fixed-point irradiance ratio (V/F) as a key indicator. V/F represents the proportion of solar irradiance received by the onboard PV compared to an unshaded fixed point, directly reflecting the degree of shading impact. Subsequent analysis of the solar irradiance data using this indicator revealed that shading distinctly affects the Normal Direct Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) components. The average shade height (β) calculated from spherical photos to quantify local shading characteristics was highest in urban residential areas (25.6 deg) and train stations (25.7 deg), and lowest on expressways (10.9 deg). Fig.2 shows the irradiance in urban residential areas under sunny conditions. When the solar height (α) is lower than β , DNI is blocked, causing vehicle irradiance to plummet from approximately 670 W/m² (fixed-point) to about 60 W/m². Thus, the α - β relationship determines the presence of DNI, leading to a significant V/F drop from 0.940 on expressways to 0.535 in residential areas (Fig.3). In contrast, Fig.4 illustrates the relationship between the V/F and shade height under cloudy conditions, where DHI is dominant. Within the same β range (10.9 deg to 25.6 deg), the V/F remains relatively high (0.85 to 0.96) and stable with a maximum fluctuation of only 0.11, indicating that an increase in β reduces the visible sky area, proportionally attenuating the DHI. Based on these findings, a vehicle irradiance estimation model was constructed (Fig.5). The model compares α with β for the DNI coefficient and integrates the visible sky area ratio for the DHI coefficient. Finally, Fig.6 compares the actual and estimated V/F to verify the model's accuracy. Under sunny conditions, the estimation error was 19.4% for urban residential areas (highest shading) and 6.1% for expressways (lowest shading). Under cloudy and rainy conditions, the estimation errors were maintained within the range of ±6.9%, confirming that the proposed model robustly predicts vehicle irradiance across diverse driving and weather conditions.

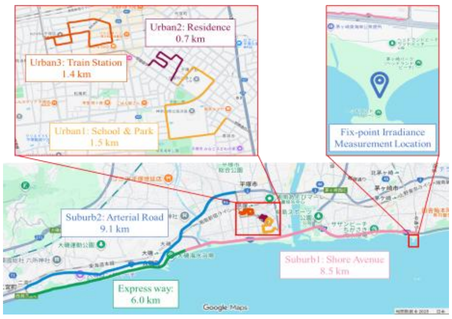

Fig.1, Route of field test

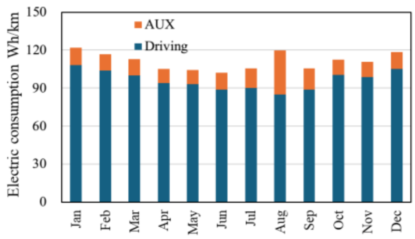

Fig.2, EC rate in every month

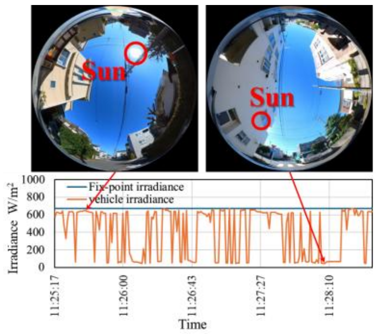

Fig.3, Fix-point and vehicle irradiance in residence (Clear)

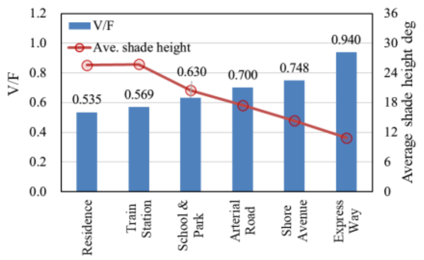

Fig.4, V/F in various driving conditions (Clear)

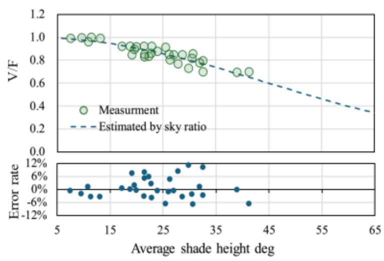

Fig.5, V/F varies by average shade height changes (Cloudy)

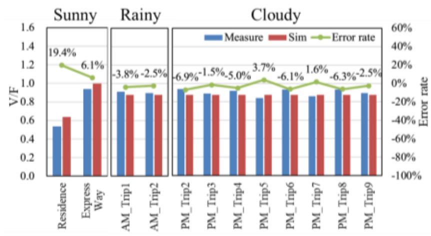

Fig.6, Comparison for actual and estimated V/F