Integration of solar radiation nowcasting models into a real-time modular weather station architecture

SolarPACES

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1. Introduction

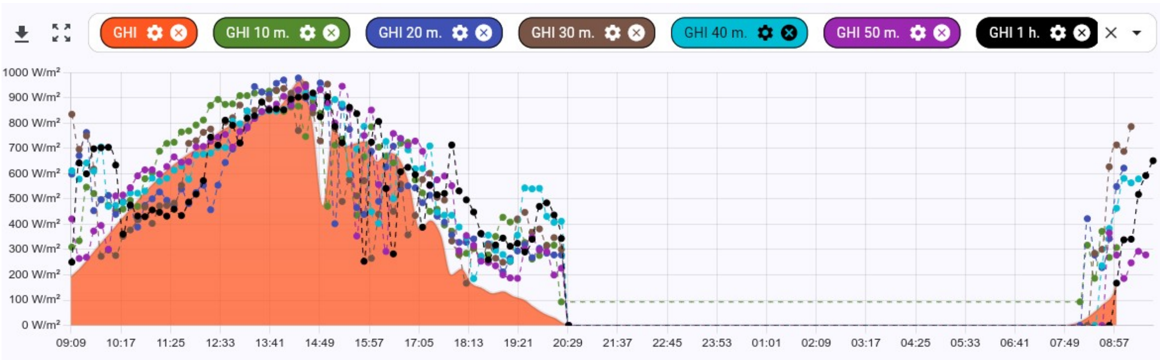
Accurate solar radiation forecasting is crucial for optimizing the performance of solar energy systems, enhancing energy management strategies. Nowcasting, which involves short-term forecasting, typically within minutes to a few hours, plays a pivotal role in real-time decision-making for solar power plants, microgrids, and other renewable energy applications. The integration of solar radiation nowcasting models into weather station software can significantly enhance the capabilities of energy forecasting tools by providing near-instantaneous updates. Recent advancements in machine learning and ground-based sensor networks have improved the accuracy of solar radiation nowcasting models. However, effective deployment of these models in real-world applications requires a robust, modular, and real-time computational framework. Traditional weather station software often lacks the flexibility to incorporate advanced features, such as Application Programming Interface (API) support [1] and dynamically incorporate diverse nowcasting models, limiting its adaptability to varying climatic conditions and user requirements. This work integrates state-of-the-art solar radiation nowcasting models into a real-time, modular weather station architecture.

2. Methodology

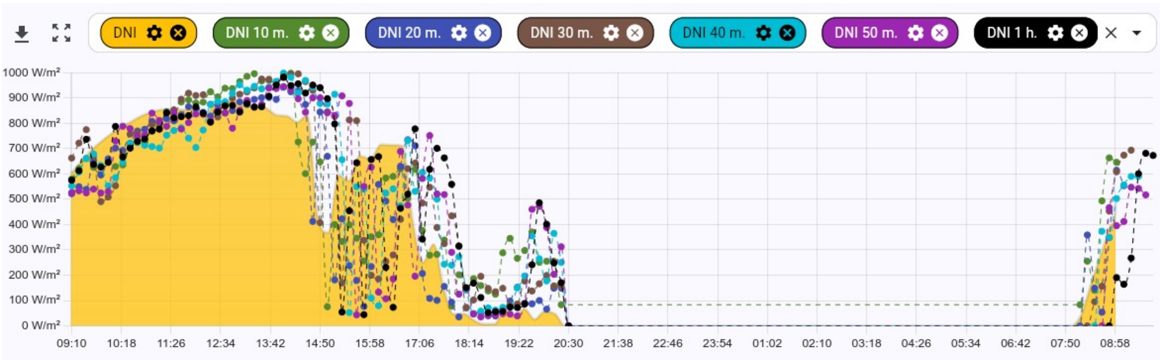
The underlying software architecture [2] adopts a microservices-based design, offering flexibility, modularity, and independent development and maintenance of components. Each service runs in its own container, improving security and stability. Users can easily customize or extend functionalities by adding or replacing modules without affecting the whole system. Microservices can be distributed across servers with load balancers to optimize traffic and prevent bottlenecks. The weather station infrastructure also integrates a nowcasting microservice designed to provide short-term forecasts of Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI). The prediction models were developed using data collected from the north CESA-I weather station at the Plataforma Solar de Almería (PSA). To account for seasonal variations, the dataset was segmented into three key periods: summer solstice, winter solstice, and equinoxes. Each period was further classified into clear and cloudy days using the clarity index. This classification resulted in six distinct study cases.

3. Results

Initial experiments [3] evaluated various regression techniques, including linear regression, decision tree regressors (fine, medium, and coarse), Support Vector Machines (SVM), and Random Forest (RF). Later, Artificial Neural Networks (ANNs) were employed, specifically using the Nonlinear Autoregressive with Exogenous Input (NARX) architecture. Training was conducted using three algorithms: Levenberg-Marquardt (LM), Bayesian Regularization (BR), and Scaled Conjugate Gradient (SCG). Model performance was optimized by tuning hyperparameters, particularly the number of neurons in the hidden layer. For each study case, the dataset was divided into training (70%), validation (20%), and testing (10%) subsets. Evaluation metrics included Normalized Root Mean Square Error (NRMSE), Mean Absolute Error (MAE), and the Correlation Coefficient (R). Although all regression models yielded acceptable performance, RF consistently outperformed other regression approaches. ANNs, particularly those trained using the LM algorithm, delivered the highest accuracy. The most accurate models achieved an NRMSE of 2.8% under clear winter solstice conditions, while the least accurate case, clear equinox day, reached an NRMSE of 6.2%. Prediction accuracy for cloudy days was generally lower due to higher atmospheric variability and limited available data. The presented software architecture is currently used to collect, store, and provide information from various weather stations at PSA. Figure 1 displays the dashboard featuring real-time measured GHI and DNI, along with past and future nowcasting predictions. These predictions are provided at 10-minute intervals, extending up to one hour.



a) GHI nowcasting



b) DNI nowcasting

Fig. 1: *Dashboard showing real-time and forecasted GHI and DNI values at 10-minute intervals*

References

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