REAL-TIME SHORT-TERM SOLAR FORECASTING FOR EFFICIENT LOAD-DEMAND MANAGEMENT FOR MICROGRIDS

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PROJECT OBJECTIVES

To create a wireless sensor network for solar photovoltaic (PV) data acquisition and subsequently implement a hybrid online prediction model for short-term solar irradiance forecasting with minimal data required from the sensor network.

To perform irradiance predictions to alert the system owner through the utilisation of historical and real-time data.

PROJECT SUMMARY

Accurate solar irradiance forecasting is crucial for PV system efficiency due to solar's intermittent nature. The team has developed a low-cost, low-power remote sensor-based data acquisition system for large-scale PV systems. We use Espressif Simple Protocol - Network of Wi-Fi (ESP-NOW) and Long Range Wide Area Network (LoRaWAN) protocols for data exchange. ESP-NOW handles short-range communication, while LoRaWAN handles long-range, low-power IoT communication.

Our self-power system monitors up to 12 voltage and temperature channels and 4 current, irradiance, ambient temperature, and humidity strings of PV panels. We employ 2.4GHz ESP-NOW for IoT node communication, with a transceiver node forwarding data via LoRaWAN. The system maintains a sub-3% sensor measurement error and averages an RSSI of -105dBm in non-line-of-sight conditions.

We collect offline and online feature data, with real-time environmental details as inputs for our online prediction model. Sensor data like panel temperature, ambient temperature and humidity, and irradiance feed into machine learning (ML) and deep learning (DL) models for single-variable (univariate) and multi-variable (multivariate) analysis. Well-trained model parameters and real-time data are used for online predictions, requiring careful parameter tuning.

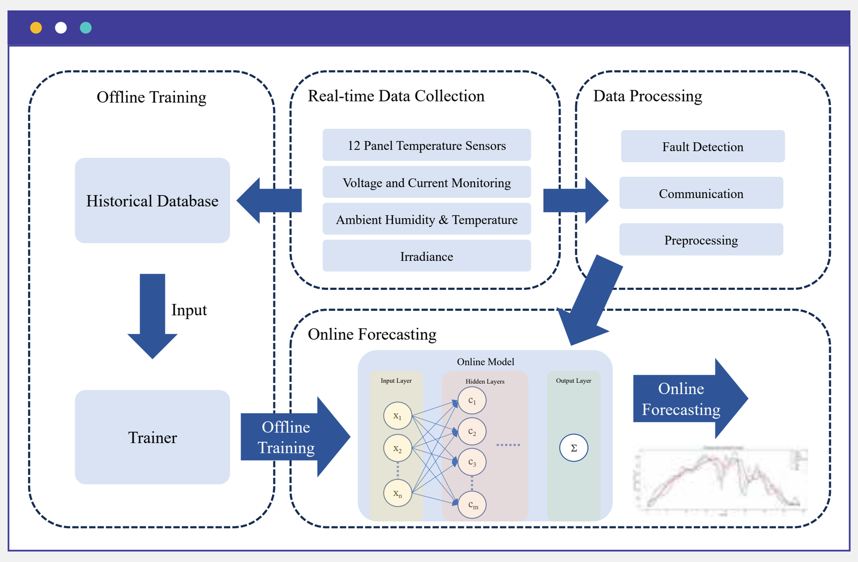
Initially, we performed univariate single-step irradiance forecasting using various algorithms. Long Short-Term Memory (LSTM) and Random Forest (RF) outperformed XGBoost, multilayer perceptron (MLP), and convolutional neural network (CNN). Notably, a lag between prediction and observation persisted in historical data-based forecasting. Subsequently, we introduced multivariate inputs and compared offline and online methods using time-series graphs.

The online approach outperformed offline predictions, correcting errors caused by real-time weather deviations. Our online LSTM-based model achieved the best accuracy with mean absolute error (MAE) of 20.97, root mean square error (RMSE) of 41.49, and R-squared (R^2) of 0.95.

We enhanced the online prediction model by incorporating time features to capture temporal patterns and seasonal fluctuations. These improvements facilitate accurate predictions.

In summary, the online method surpasses offline predictions, with a 25% RMSE improvement. These findings will be applied to the operation of the SIT Punggol campus microgrid, contributing to Singapore's transition to a greener, more resilient energy future.

Developed Online Prediction Framework



Numerical Comparison and Performance Improvement of Using the Developed Online Model

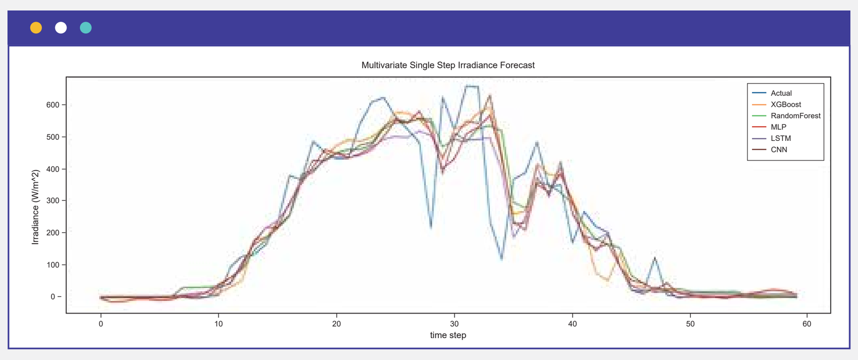
UNIVARIATE SINGLE STEP FORECAST RESULT

Method	XGBoost	Random Forest	MLP	LSTM	CNN
MAE	34.33	33.56	35.35	34.31	36.13
RMSE	70.8	71.38	71.36	70.57	75.16
R2	0.83	0.85	0.85	0.86	0.84

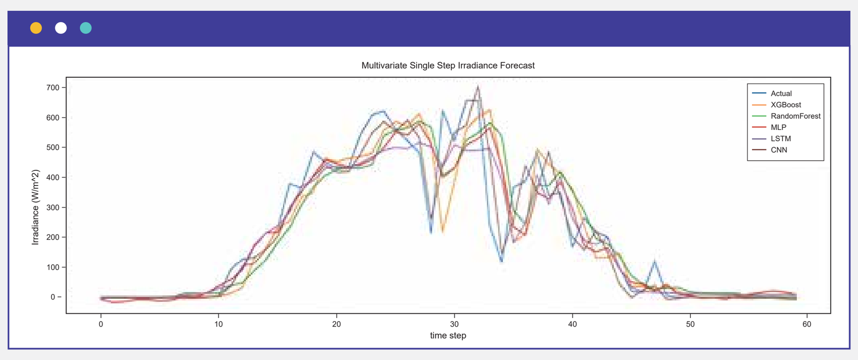
MULTIVARIATE SINGLE STEP FORECAST RESULT WITH AVERAGE PV PANEL TEMPERATURE, AMBIENT TEMPERATURE AND HUMIDITY

	Method	XGBoost	Random Forest	MLP	LSTM	CNN
Offline	MAE	38.25	31.05	42.53	41.88	42.4
	RMSE	77.99	59.35	80.51	82.07	81.40
	R2	0.79	0.9	0.81	0.81	0.77
Online	MAE	22.84	27.78	30.04	20.97	31.85
	RMSE	45.83	52.83	53.41	41.49	56.52
	R2	0.93	0.92	0.91	0.95	0.89

Offline Multivariate Single-step Prediction Result



Online Multivariate Single-step Prediction Result



PROJECT OUTCOMES

1. 1 complete hardware and software-based data acquisition system testbed.
2. 1 deep learning-based online prediction model.
3. 1 paper submitted to IEEE conference.