Test Procedure – Individual power resources next day power generation prediction by Bi-LSTM Model

I. **Yearly Requirements:**

주요 성능지표		단위	최종 개발목표			기술개발전 수준	※세계 최고수준 또는 수요처 요구수준	전체항목에서 차지하는 비중(%)	평가방법
			1차년도	2차년도	3차년도				
VPP 분산자원 예측 및 최적화	VPP시스템 순간 발전량예측 평균절대백분율 오차(MAPE)	%	-	≤12	≤10	15	20 (Ref. [2])	10	2차:자체 시험 3차:공인 시험성적서

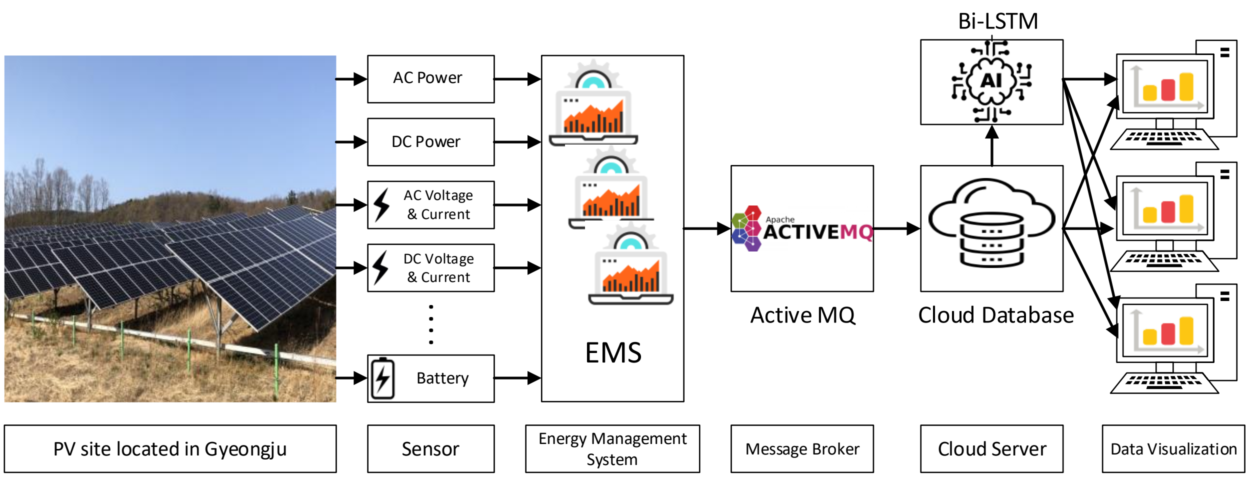
II. **Overall Architecture for Cloud Server**

• Step 1: Develop coding on the ActiveMQ platform side using Java.

• Step 2: ActiveMQ platform collects data from the all sensors and stores in PostgreSQL database.

• Step 3: Connect the python platform with data base system.

• Step 4: Apply Bi-directional long short-term memory (Bi-LSTM) over the data and predict next day PV power generation.



<Figure 1. Architecture for data acquisition from sensors to database system>

<Figure 1. Architecture for data acquisition from sensors to EMS>

$$D = (x_i, y_i)_{i=1}^{N}$$

Measurement procedure of collecting data and storing on the cloud server:

- All required sensors such as voltage sensor, current sensor, temperature sensor, and humidity sensor are connected to the energy management system (EMS) using TCP and Serial directly to the input module of EMS depending on each sensor connectivity.
- From the sensor, the PV generation data for each minute is calculated.
- The EMS collects all data from sensors continuously based on the sampling time of each sensor. Every minute, the EMS will transfer the collected data to the Cloud server using the MQTT protocol.
- To establish the MQTT connection between EMS and Cloud server, an internet connection is utilized.
- After receiving the data from EMS, the cloud server will store the data in its cloud database. In the cloud database, the data will be grouped into each type of data including the timestamp of the data. The database type that will be used is PostgreSQL.
- After that, the cloud server runs the AI algorithm for forecasting next-day PV generation using Bi-LSTM. The result of the prediction is shown on the monitor.

Test environment and test method on the cloud server:

- The data from sensors were stored in a cloud database server for every minute.
- For the database, we will use PostgreSQL software because we did some tests using other database software and the result is PostgreSQL is the lightest and fastest among other database software.
- For testing and running the Bi-LSTM software, we use work station with 64 GB of memory and Intel(R) Core(TM) i9-9820X CPU @ 3.30GHz 3.31GHz processors will be using the Windows Operating System.
- To run the AI algorithm, we use the most recent version of the Python programming language. We also use a few Python libraries to support AI algorithm development, such as Tensorflow, Numpy, Scikit Learn, Pandas, and Matplotlib.

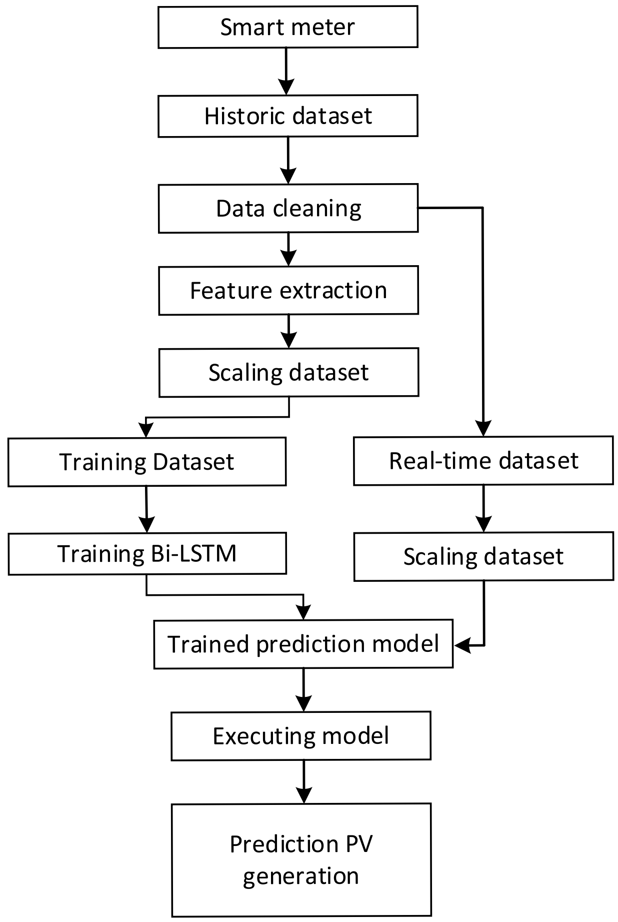
- Periodically, the system will do an AI training process using recent data received in the database. The training process will result in a trained AI model that will be used for the testing process (explained in Figure 3).
- Then, the new data will be loaded on the trained Bi-LSTM model which will predict the real-time PV generation of the PV power station.
- The testing program will be in Python executable .exe file format. The cloud server will execute the .exe file to predict the energy generation in the system. Also, it will produce the mean error value of the prediction algorithm and print the forecasting result on the monitor.

III. Requirements and test scenarios

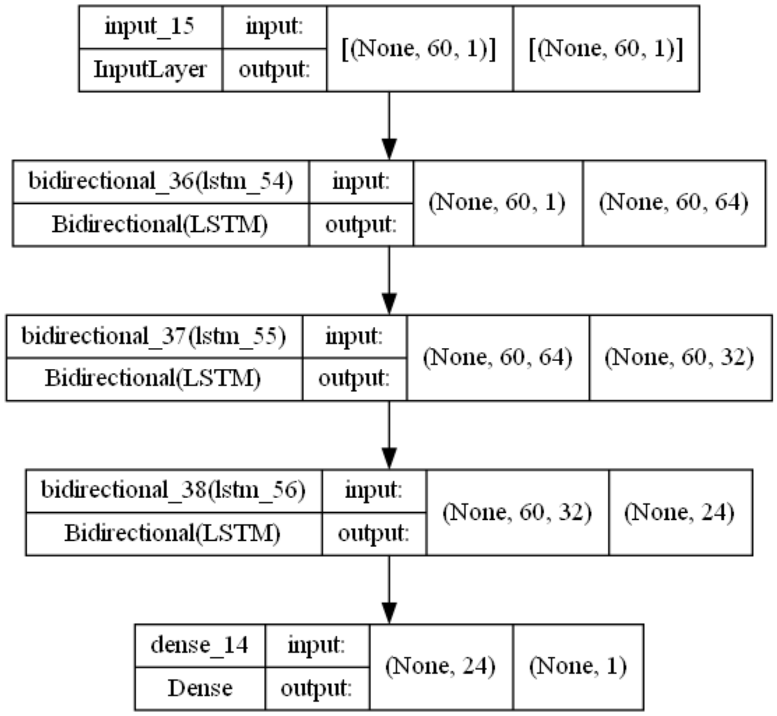
a. 2nd Year Requirements

Key Performance Indicators	**Unit**	**Requirements**	**Current Status**
Mean Error	Percentage	≤12%	9.3618 %

Model Name	KPI Metric	Target value 1st Year	Target value 2nd Year	Target value 3rd Year
Bi-LSTM	MAPE	-	≤12%	≤10%



<Figure 3. Bi-LSTM workflow.>



<Figure 3. Bi-LSTM Architecture.>

b. Bi-LSTM model design and development:
Step 1: Receive data through the database.
Step 2: Select the feature.
Step 3: Cleaning the raw data
Step 4: Scaling and resampling the featured data.
Step 5: Trained the Bi-LSTM model.
Step 6: To calculate the Mean Absolute Percentage Error of the system, we have applied this mathematical formula:

$$MAPE = \frac{\sum_{t=1}^{n} \frac{|\mathrm{A}_t - F_t|}{\mathrm{A}_t} x100\%}{n}$$

Where, A_t= Actual value of PV generation, F_t= Forecasted value of PV generation, and n= Number of data sample

Step 7: Save the model.

c. Scenario:
(i) Average Absolute Percentage Error (MAPE) of VPP System Instantaneous Generation Forecast: Minute-ahead

(ii) Raw data received from every sensor is stored in Edge E.PMS Local DB in real time.
(iii) Remotely access the Edge E.PMS Local DB on site.
(iv) It is measured in real time at the demonstration site (PV 100kW of Ansan Power Plant and PV 100kW/Battery 300kWh of Gyeongju Seomyeon PV-linked ESS Power Plant).
(v) Prediction is made using an analysis engine (BiLSTM) on the received raw data.
(vi) Verify the error rate by comparing predicted data and measured data. The average absolute percentage error of VPP system instantaneous power generation prediction receives input from the Edge E.PMS of each PV site and uses the algorithm (Bi-LSTM) in the Embedded PC environment

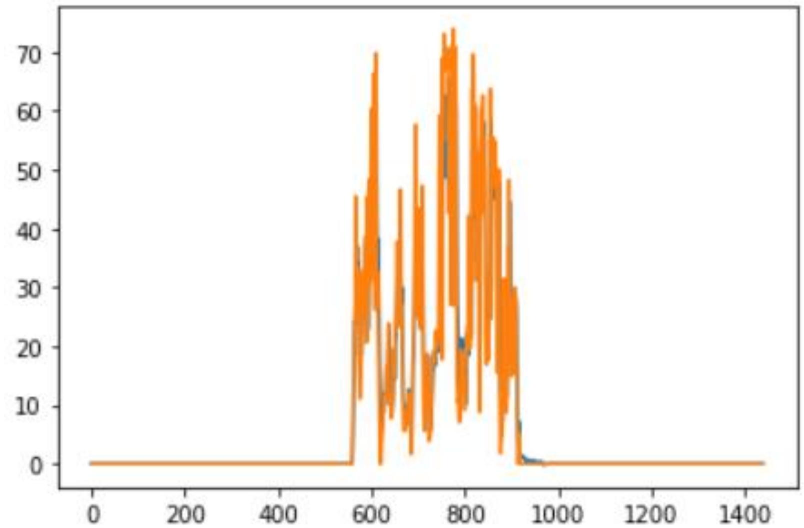
The procedure of system evaluation of the Bi-LSTM model:

Step 1: Prepare the collective power resource generation raw test data of PV generation of one month from the database.
Step 2: Cleaning and scaling the test data.
Step 3: Loaded the data in Bi-LSTM saved model to determine the minute ahead PV energy prediction.
Step 4: Measure Mean Absolute Percentage Error from the actual and predicted values.
Step 5: Shows the forecasting results of the Bi-LSTM algorithm.

The working procedure has been shown in Figure 3 and 4.

c. Results and Discussion:

MSE: 16.6598
MAE: 0.9641
RMSE: 4.0816
MAPE: 9.3618
r2: 0.9548



<Figure 5. Real time implementation results of Bi-LSTM on cloud server. >