Test Procedure – Individual power resources minute ahead power consumption prediction by Convo-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 시스템	VPP시스템 순간 소비전력 예측 평균절대백분율 오차(MAPE)	%	-	≤13	≤10	16	16 (Ref. [3])	10	2차:자체 시험 3차:공인 시험성적서

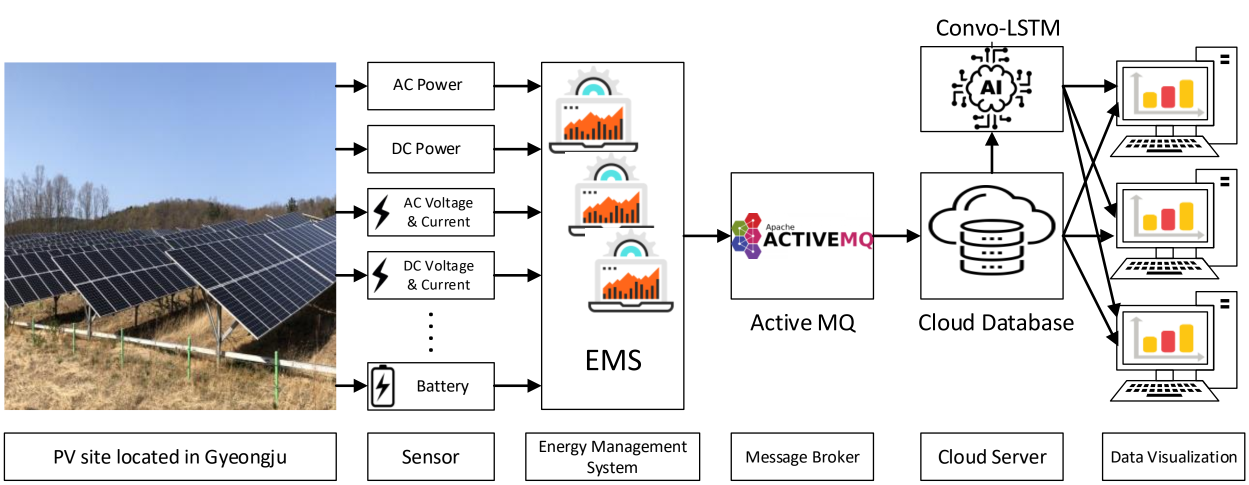
II. **Overall Architecture for Cloud Server**

• 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 Convolution long short-term memory (Convo-LSTM) over the data and predict minute ahead PV power consumption.



<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 consumption 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 minute ahead PV consumption using Convo-LSTM. The result of the prediction is shown on the monitor.

Test environment and test method on the cloud server:

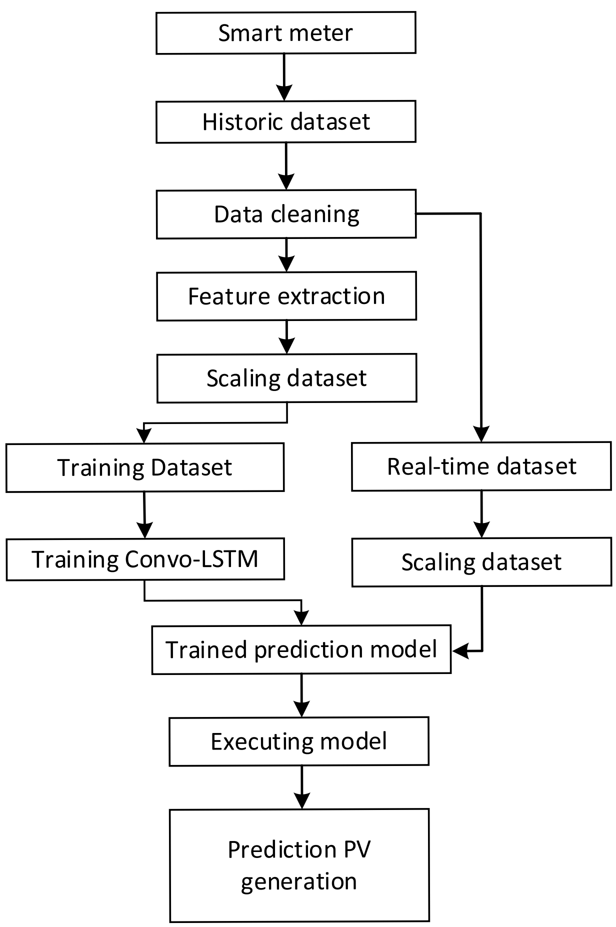
- The data from sensors were stored in a cloud database server for every minute.
- For the database, we will use PostgreSQL software because we did some tests using other database software and the result is PostgreSQL is the lightest and fastest among other database software.
- For testing and running the MSVM 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 Convo-LSTM model which will predict the real-time PV consumption 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 consumption in the system. Also, it will produce the mean error value of the prediction algorithm and print the forecasting result on the monitor.

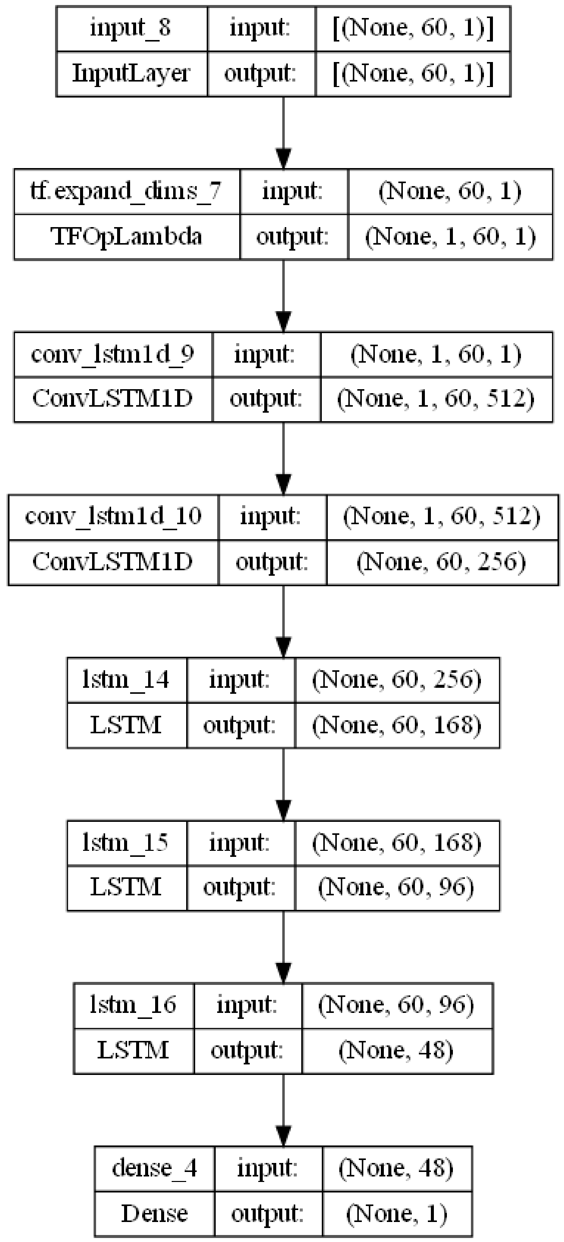
III. Requirements and test scenarios

a. 2nd Year Requirements

Key Performance Indicators	Unit	Requirements	Current Status
Mean Absolute Percentage Error	Percentage	≤13%	9.82 %



<Figure 3. Convo-LSTM workflow.>



<Figure 3. Convo-LSTM Architecture.>

b. Convo-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 Convo-LSTM model.
Step 6: To calculate the Mean Absolute Percentage Error of the system, we have applied this mathematical formula:

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

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

Step 7: Save the model.

c. Scenario:

(i) Average Absolute Percentage Error (MAPE) of VPP System Instantaneous Power Consumption Prediction: Minute-ahead

(ii) Edge E.PMS installed at individual PV sites measures actual data in real time using a solar power consumption system.

(iii) In addition, it measures and stores the power consumption of each power consumption source (Battery system, Aircon, etc.) of the demonstration site.

(iv) The error rate is verified by comparing the data measured in real time at the demonstration site with the data predicted by the analysis engine (ConvLSTM).

(v) The average absolute percentage error in predicting instantaneous power consumption of the VPP system receives input from the Edge E.PMS of individual PV sites and uses an algorithm (ConvLSTM) in the Embedded PC environment.

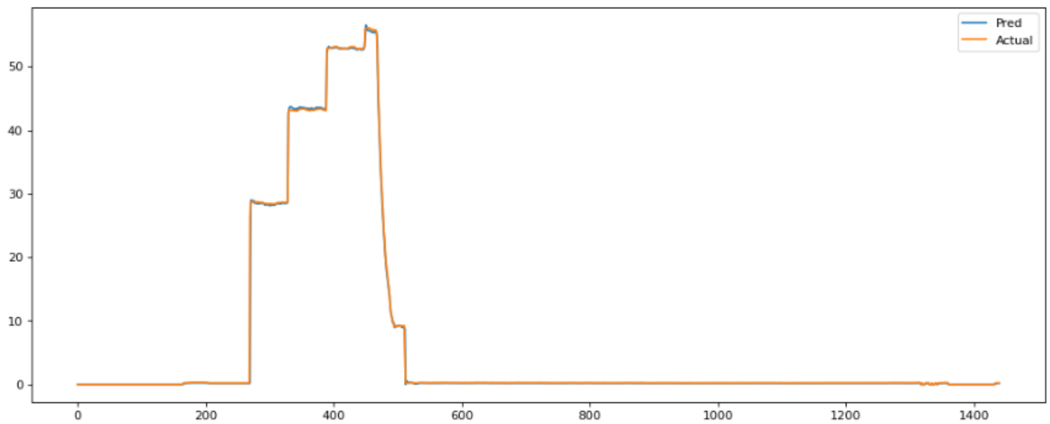
The procedure of system evaluation of the Convo-LSTM model:

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

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

c. Results and Discussion:

MSE: 0.5594
MAE: 0.0920
RMSE: 0.7479
MAPE: 9.8297
r2: 0.9976



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