Examination of Solar Power Generation Prediction Method by Estimating Snow Cover Condition on Solar Panel in Snowfall Area

Yoshito Nishita†, Yoshio Izui*, Keita Suzuki*, Daisuke Natsuume*, Hirokazu Tabata*

Abstract – Since introduction of Feed in Tariff (FIT), the amount of introduction of the solar power generation system in electric power consumer facilities such as homes and factories has been increasing in Japan. On the other hand, with the sequential end of FIT, the electricity generated by the solar power generation system must be consumed by the electricity consumers themselves. However, since the solar power generation volume is greatly affected by weather conditions. Then, in order to efficiently control the power storage device with respect to the amount of power supplied by solar power generation system, it is necessary to accurately predict the amount of solar power generation. In this research, in order to accurately predict the amount of solar power generation considering the influence of snow on the panel in areas with heavy snowfall such as snow on the panel, using meteorological data as input data, we will carry out comparative evaluation in various machine learning methods including deep learning.

Keywords: Renewable Energy Resources, Solar Power Prediction, Machine Learning, Snowfall Area

1. Introduction

For the purpose of low carbon and decarburization, in the field of electricity and energy, introduction of renewable energy including Photovoltaics (PV) power generation system is expanding [1]. In particular, PV power generation system production and introduction have continued to increase due to the background of aiming to achieve the new energy introduction target. Furthermore, in Japan, since the introduction of Feed in Tariff (FIT), the amount of electricity introduced in electricity consumer facilities such as homes and factories has been on the rise. On the other hand, as FIT will end in sequence from 2019, the electricity generated by the PV power generation system must be consumed by the electricity consumers themselves.

However, the amount of power generated by PV is greatly affected by weather conditions such as the amount of solar radiation and the temperature of the panel surface. It is often used in combination with a storage device. Also, in order to efficiently control a power storage device such as a storage battery according to the amount of power supplied by PV, it is necessary to accurately predict the amount of PV power generation. As a method for predicting the amount of PV power generation [2]-[8], there has been a type of method for predicting the amount of power generation based on the amount of solar radiation. However, in areas with heavy snowfall, there is snow on the panels. When the panel is completely covered with snow, the amount of power generation may be zero even in fine weather. Therefore, in snowy areas, it is difficult to predict the amount of power generation based only on the amount of solar radiation, and it is necessary to consider a method for predicting the amount of power generation in consideration of snowfall.

Against this background, we are studying the prediction of PV power generation considering the snow cover on the panel by utilizing "Community model demonstration experiment of renewable energy best mix" [9], [10] at Kanazawa Institute of Technology (KIT). Demonstration experiments are being conducted at the Hakusan-roku campus of the multiple campuses owned by KIT. The Hakusan-roku campus is located on the mountain side of Hakusan City, Ishikawa Prefecture, and there is a ski resort nearby, and snowfall is recorded every year.

In the previous research [1 1], we investigated and evaluated the accuracy of a deep learning method for predicting PV power generation using weather data, assuming that weather data was used, which was found to be related to PV power generation in the presence of snowfall. The results of the research showed that although the PV power generation could be predicted with a certain degree of accuracy, there were times when the accuracy dropped significantly. The reason for this is that most of the PV panels at customer facilities are installed on roofs, which are set at an angle to allow more sunlight to hit the panels, so that after

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a period of snowfall, the snow on the panels slides off due to rising temperatures and other factors, and even if snow remains on the ground, it can be used to predict the amount of PV power generated. It became clear that the snow cover at the observation point did not always coincide with the snow cover on the panel.

In this paper, to address the issue of predicting PV power generation considering accurate snow cover on PV panels, we used various methods to predict the percentage of panels covered with snow, or snow cover, based on images from monitoring cameras installed near the PV panels. In addition, we evaluated the accuracy of the PV power generation forecast using the predicted snow cover rate.

2. Snow Cover Rate Prediction Method

The objective of this research is to predict the snow cover rate on the panel several hours in the future. In this comparative evaluation, the snow cover rate at dawn and subsequent hourly weather observations were used to predict the snow cover rate several hours ahead on an hourly basis, and the accuracy of the prediction was evaluated for each period. The predicting models were constructed using deep learning to predict snow cover rate. Various types of network models have been proposed, in this research, based on previous research [11], we constructed a deep neural network (DNN), a recurrent neural network (RNN), and a model that combines them, which are considered effective for predicting snow accumulation, and conducted snow cover rate predictions. Details of each network model are shown below.

2.1 The Network Model of Deep Neural Network (DNN)

The first method uses a deep neural network (DNN) to predict snow cover rate. The model of DNN used in this research is shown in Fig. 1. The input layer consists of snow cover rate, temperature, precipitation, and sunshine hours. The input data of the input layer differs depending on the snow cover rate to be predicted. Table 1 shows the relationship between the snow cover rate to be predicted and the input data. Fig. 2 shows the network model to be built when the predicted time of the snow cover rate is 8:00 am. As shown in Fig. 2, the snow cover rate at 7:00 am does not change, but the data at 7:00 am and 8:00 am are input for the temperature, precipitation, and sunshine hours. In this research, a learning model is constructed according to the time of the predicted snow cover rate. The snow cover rate at 7:00 am at dawn and each hourly weather data up to the time of day when the snow cover rate is to be predicted are used for the prediction, and the output layer consists of one unit: snow cover rate for each period. For the hidden layer,

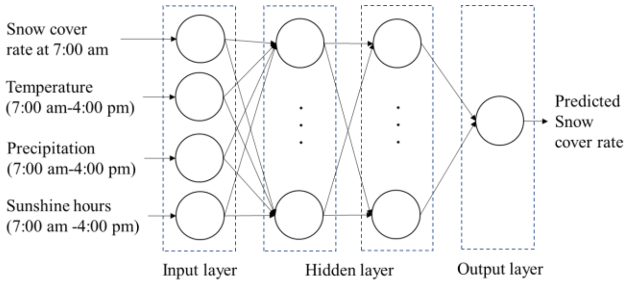

Fig. 1. Network model of DNN

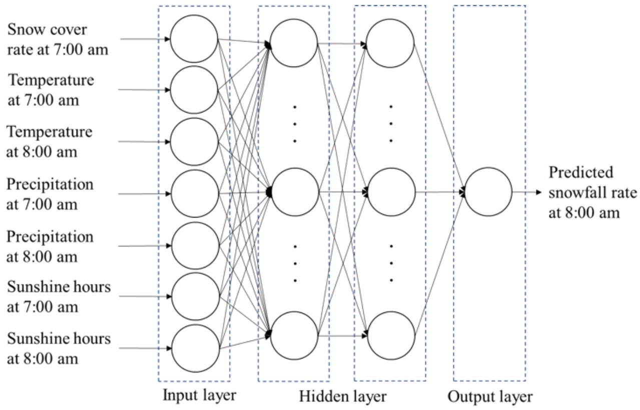

Fig. 2. Network model when the predicted time of snowfall rate is 8:00 am

the configuration with the best accuracy in the preliminary research was adopted, and a network with 8 layers and 14 units was constructed. ReLU (Rectified Linear Unit) was used as the activation function, the error back propagation method was used to construct the prediction model, and Adam was used as the optimization function.

2.2 The Network Model of Recurrent Neural Network (RNN)

The second method uses a recurrent neural network (RNN) to make predictions based on the snow cover rate over the past few days. RNN are network models that are good at capturing features of time series data. Snow cover changes gradually over time. Therefore, we attempted to predict using RNN, which are good at predicting time series data. Fig. 3 shows the RNN model. This time, LSTM (Long Short Term Memory) was used for the RNN network model. The model is constructed for each time in order to predict the snow cover rate at each time. In addition, as a prediction method using the constructed model, only the snow cover rate at 7:00 am is used as input data. Then, when predicting the snow cover rate after 9:00 am, the predicted value after 8:00 am is added as input data to calculate the predicted value at each time. Fig. 4 shows the Prediction of snow cover rate by RNN in this research.

Table. 1. Input data in the snow cover rate at the predict target time

Input data	Snow cover rate at the predicted time								
	8:00 am	9:00 am	10:00 am	11:00 am	12:00 am	1:00 pm	2:00 pm	3:00 pm	4:00 pm
7:00 am	✓	✓	✓	✓	✓	✓	✓	✓	✓
8:00 am	✓	✓	✓	✓	✓	✓	✓	✓	✓
9:00 am		✓	✓	✓	✓	✓	✓	✓	✓
10:00 am			✓	✓	✓	✓	✓	✓	✓
11:00 am				✓	✓	✓	✓	✓	✓
12:00 pm					✓	✓	✓	✓	✓
1:00 pm						✓	✓	✓	✓
2:00 pm							✓	✓	✓
3:00 pm								✓	✓
4:00 pm									✓

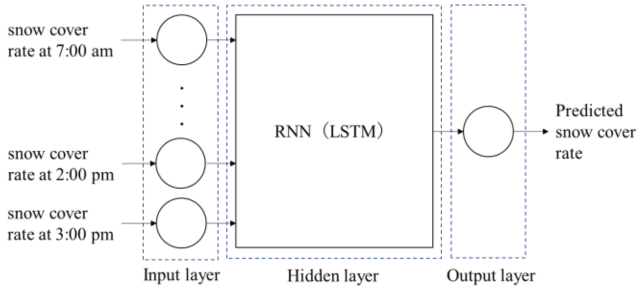

Fig. 3. Network model of RNN

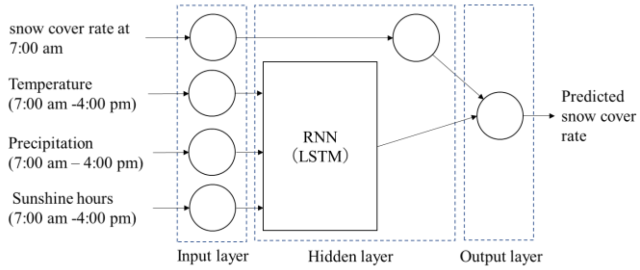

Fig. 5. Network model of Combining DNN and RNN

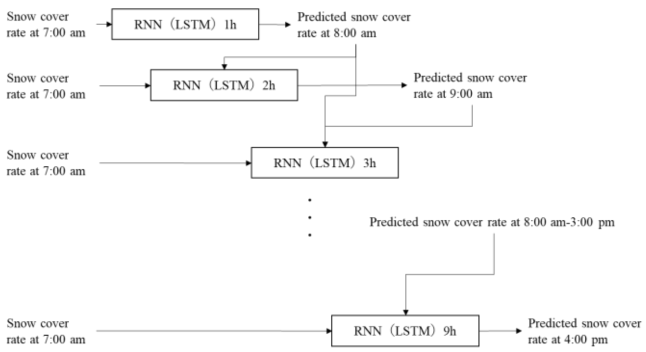

Fig. 4. Prediction of snow cover rate by RNN in this research

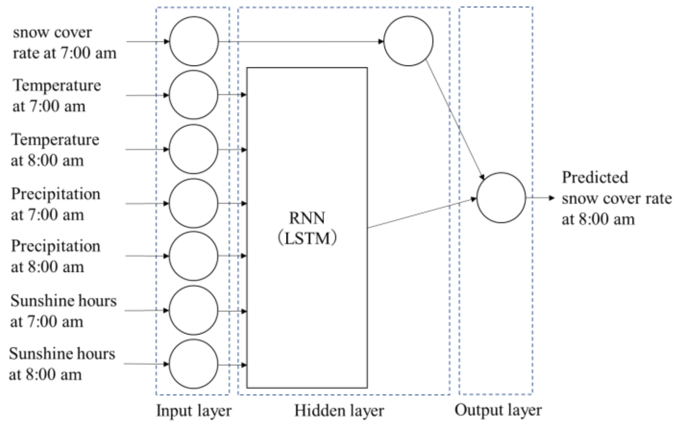

Fig. 6. Network model when the predicted time of snowfall rate is 8:00 a.m.

2.3 The Network Model of Combining DNN and RNN

The third method uses a model that combines DNN and RNN. The model is shown in Fig. 5. The input data of the input layer in the combined model is the same as that of DNN, and it depends on the time of the predicted snowfall rate. Fig. 6 shows the network model when the predicted time of the snow cover rate is 8:00 am. The snow cover rate at 7:00 am at dawn, the snow cover rate up to one hour before the snow cover rate is predicted, and each weather data is used to predict the snow cover rate.

3. Evaluation Experiment

In this chapter, the snow cover rate is predicted by network models described in the previous chapter. It also predicts PV power generation based on the predicted snow cover rate.

3.1 Experimental Conditions

In this research, the weather data that is available free of charge is used to predict the amount of electricity generated. The reason for this is that this research targets the predicting of power generation from PV panels installed in a single facility, and the use of paid meteorological data are considered to be cost-effective

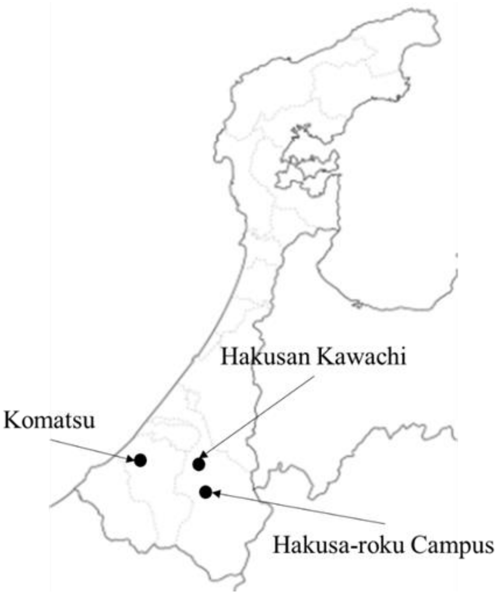

Fig. 7. Location of each weather data observation point

when the effect of PV power generation on a single electricity consumer is taken into account. In recent years, representative data that can be used easily and free of charge in Japan include data provided by the Japan Meteorological Agency (JMA) [12] and data provided by OpenWeatherMap [13]. The JMA and OpenWeatherMap differ in the data measurement points they provide, with the JMA's observation point closest to the Hakusan-roku campus, the location of this demonstration experiment, being Hakusan Kawachi and OpenWeatherMap's being Komatsu City, with Hakusan Kawachi being closer to the demonstration site. The JMA data was used for this experiment because it is closer to the location of the experiment. The relationship between the location of the experiment site and the observation points is shown in Fig. 7. Also, we used data on temperature (average temperature), sunshine hours, and precipitation from the JMA's data. Since the objective of this research is to predict PV power generation in snowfall areas, taking into account the effect of snow on PV panels, the period covered by the predict is from 8:00 am to 4:00 pm in February 2020, the time of snowfall at the location of the demonstration experiment. Data from December 2020 to February 2021 was used to construct the forecast model. Table 2 shows the PV specifications used in this demonstration experiment. Note that the total amount of electricity generated in a day is calculated based on measured values.

3.2 Show Cover Rate Prediction Results

The predicting results of each method are shown in Fig. 8 for DNN, Fig. 9 for RNN and Fig. 10 for Combined model. The evaluation method used was to calculate the absolute error between the actual and predicted values for each hour and evaluate the results using the mean absolute error for the day. As shown in Fig. 8, the accuracy of the snow cover

Table 2. PV spec.

Machinery and tools	Spec
Rated output	1,760W
Daily power generation (max)	11,800Wh

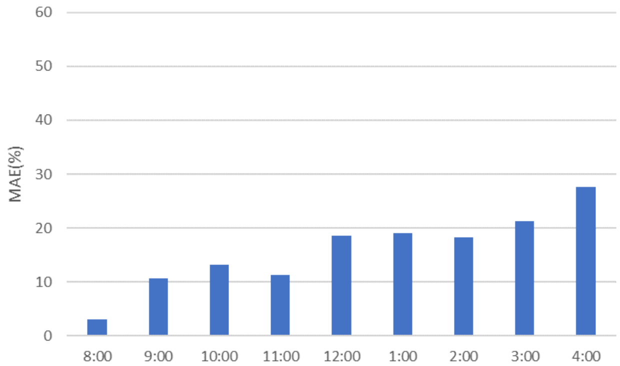

Fig. 8. Predicting results of DNN

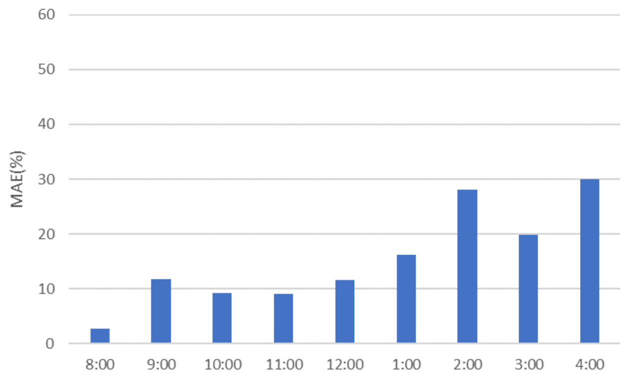

Fig. 9. Predicting results of RNN

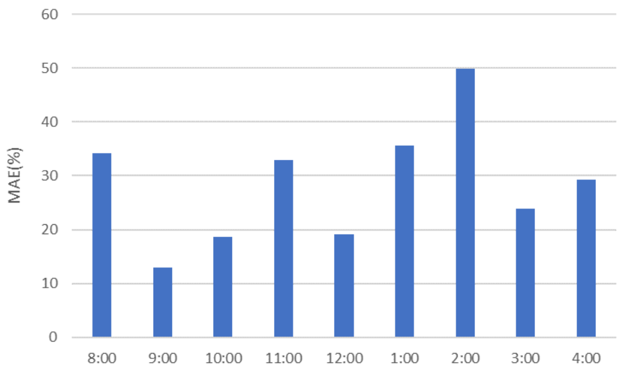

Fig. 10. Predicting results of Combined model

rate predicted using the DNN decreased over time, even with weather information from 7:00 am to 3:00 pm, and the mean absolute error of the predict was about 15% until 11:00 am, while the mean absolute error of the 16:00 prediction was 27.6%, In contrast to our initial assumption that RNN, which are known to be better at capturing the characteristics of time-series data, would be better at capturing changes in snow cover than DNN, there was no clear improvement in the accuracy of snow cover rate predicting using DNN. In terms of overall mean absolute error, the difference between DNN and RNN was minimal, at 15.7% and 15.4%, respectively. Fig.8 shows the results of the prediction evaluation by the combined model. Fig.10 shows that when comparing the predict results by the combined model, when compared to the prediction results using the DNN, the combined model is more accurate than the DNN at later times, such as from 3:00 p.m. to 4:00 p.m. However, the mean absolute error of all patterns using the combined model is larger than that of the prediction results using the DNN.

3.3 PV Power Generation Prediction Results

In the previous chapter, snow cover rates were predicted by three different network models. As a result, the snow cover rate predictions using DNN resulted in the lowest mean absolute error. In this chapter, we compared and evaluated the predicted value calculated by the PV power generation prediction method in the previous research [11] and the predicted PV power generation using the snow cover rate predicted in this research. Fig. 11 shows the network model used for the PV power generation prediction method in the previous research. In addition, Fig. 12 shows the network model used when predicting the amount of PV power generation using the snow cover rate predicted in this research.

the predicted snow cover rate is used to predict the PV power generation considering the snow cover. The network model used to predict PV power generation is shown in Fig.12. The details of the PV power generation predicting method that takes snow cover rate into account are described below.

The predict of PV power generation that takes snow cover rate is described. In this research, PV power generation that takes snow cover rate is predicted by multiplying the PV power generation predicted without taking snow cover into account (predicted by DNN using only sunshine hours) by the snow cover rate estimated in this research. The mathematical formula for the predicted PV power generation considering snow cover is shown below.

$$Pv = \left(1.0 - \frac{rate_{snow}}{100.0}\right) \cdot Pv_{without\_snow} \quad (1)$$

where Pv is the predicted PV power generation considering snow cover, $rate_{snow}$ is the average snow cover rate, and $Pv_{without\_snow}$ is the predicted PV power generation before considering snow cover. In this case, since the target of the predict is the total PV power generation for one day, the

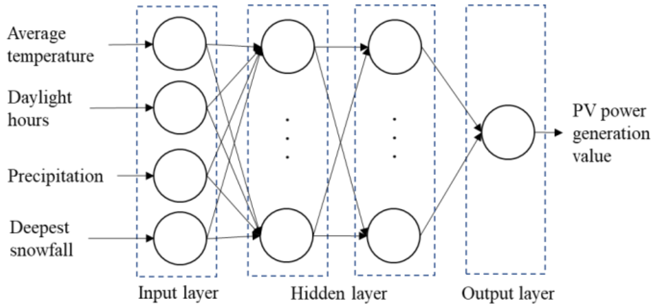

Fig. 11. Network model for PV power generation prediction

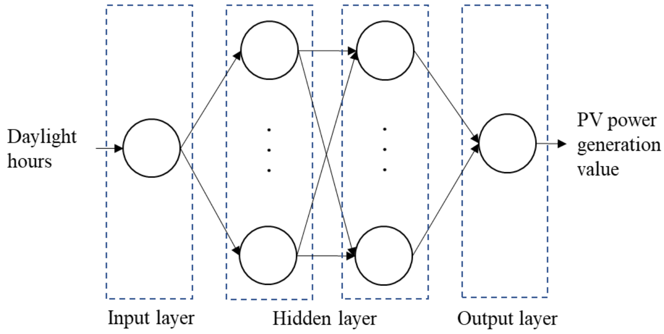

Fig. 12. Network model for PV power generation prediction

Table 3. MAE

Previous res earch [11]	DNN	RNN	Combined model
1727.57Wh	912.26 Wh	890.41 Wh	1077.79 Wh

snow cover rate is calculated by the weighted average of the predicted hourly snow cover rates from sunrise to sunset (8:00 am to 4:00 pm in this case) and multiplying the average by the predicted PV power generation without considering the snow cover rate. The following table shows the number of the weight of the weighted average was set so that the weight increases toward 12:00 and decreases after 12:00. The reason for this is that the intensity of solar radiation, which affects PV power generation, increases as the sun rises and decreases as the sun sets.

A comparison of the PV power generation prediction and actual values is shown in Fig. 13, Fig. 14, Fig. 15, Fig. 16. The mean absolute error values for each method are shown in Table 3. As shown in Fig.13, Fig.14, Fig.15, Fig.16 and Table 3, the results of the method of predicting PV power generation using the predicted value of snow cover rate examined in this research were better than those of the method of predicting PV power generation using meteorological data in the previous research. Therefore, it can be said that the method examined in this study is effective as a method for grasping the state of snow cover on the panel.

5. Conclusion

In this paper, in order to predict the photovoltaic power generation in the snow-covered area in consideration of the snow cover of the panel, we examined the method of predicting the snow cover rate, which is the ratio of the snow cover that covers the panel. The snow cover was predicted using DNN, RNN and a model combining these models. Then, we evaluated the accuracy of PV power generation predictions using the snow cover rate predictions from the three methods. As a result, we confirmed that the method accuracy of the predicted PV power generation was better than that of the conventional method that does not take snow cover into account, and that the snow cover on the panel can be reflected in the PV power generation prediction by using the snow cover rate. We will continue analyzing and examining methods to improve accuracy.

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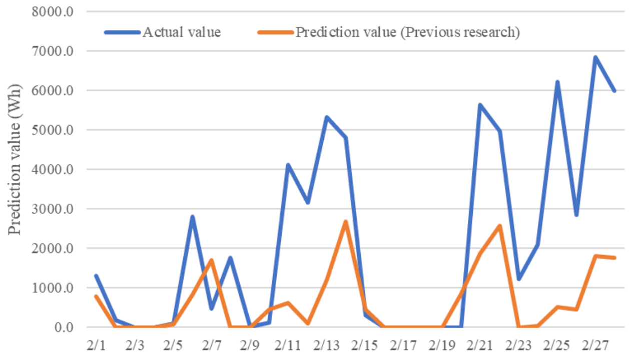

Fig. 13. Network model for PV power generation prediction

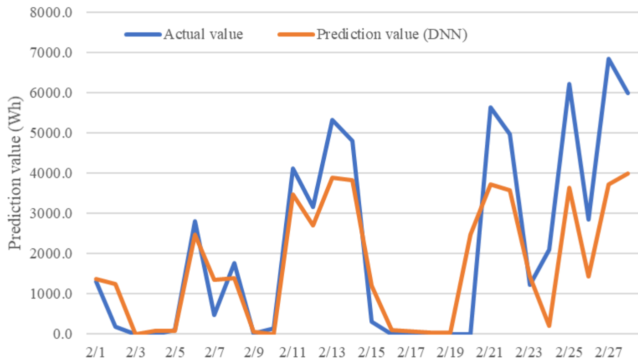

Fig. 14. Network model for PV power generation prediction

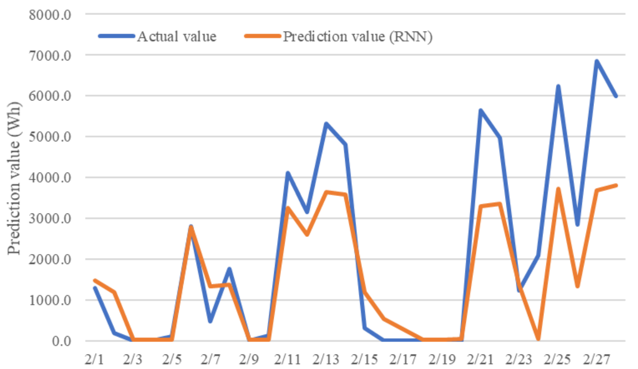

Fig. 15. Network model for PV power generation prediction

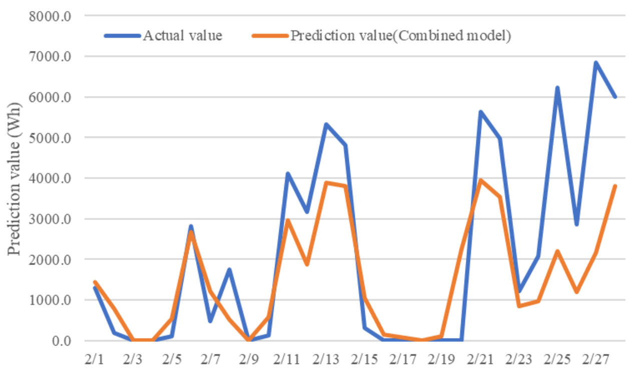

Fig. 16. Network model for PV power generation prediction

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