Forecasting of Time Series of Wind and Solar Energy by Using AMeDAS Data

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Abstract: - The forecasting of time series of the wind and solar energy is necessary for the prevention from global warming. This paper explains the technique of time series forecast of the wind power energy and solar energy by using ten minutes intervals meteorological data obtained by AMeDAS(Automated Meteorological Data Acquisition System). We discuss an application of a neural network for forecasting to time series of wind velocity and solar energy. Furthermore, the pattern matching is used to choose the training data of the neural network. It is found from our investigations that forecasting accuracy of the time series of wind velocity and solar energy is improved by utilization the pattern matching of the weather map data.

Keywords: forecasting, wind velocity, solar energy, neural network, pattern matching, weather map, AMeDAS, wind power

1. Introduction

The utilization of the natural energy is necessary as an alternative energy of the fossil fuel to maintain a global environment. Many distributed power by using natural energy has been introduced into the electric power system. These distributed powers are installed in the place near the load. Therefore, the introductions of the photovoltaic and wind power generation are advanced by national policy for the global environment protection [1]-[5].

The energy density of wind power generation is the largest among natural energy generation. Japanese government has set the aim of introducing the wind power generation of 3,000 GW by 2010. On the other hand, the photovoltaic power generation is set up anywhere in the place where the sunshine is given. The fluctuation of the generation of wind and solar energy is larger than hydro-power generation and thermal power generation. The continental climate has comparatively been stabilized. Therefore, the forecasted values of wind velocity and solar energy in the continent are higher precision than the case of island[6][7].

However, in case of the island such as Japan, the weather is fluctuating sharply, and the forecasting of the natural energy is very difficult. Therefore, it is

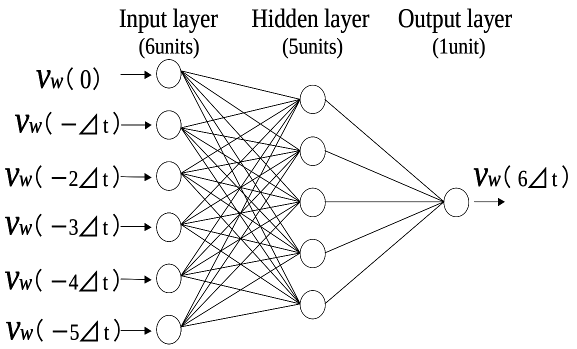

Fig. 1 Forecasting system of time series of wind velocity

difficult to utilize the wind power and solar power generation by system interconnection as a power directly[2]. The various researches have been carried out until now, because practical application is easy for the wind and solar power generation[3][8]-[11].

Then, by estimating the wind power and solar power generation quantity with good accuracy, the high-efficient utilization of the wind energy can be expected. In this study, the wind velocity and solar energy are forecasted by using neural network, and the pattern matching[12] of weather map data. The time series of the wind velocity and solar energy are forecasted by using the weather map and ten minutes intervals data of AMeDAS (Automated Meteorological Data Acquisition System)[13]. The Nagoya district in Central Japan is examined as a case study on the forecasting of the time series of wind power and solar energy.

2. Time series forecast of wind power

2.1 Configuration forecasting system

The neural network shown in Fig. 1 was used for the wind velocity forecasting. The input data to the neural network are six values of the wind velocity $w(-l\Delta t)$, (l=1,2,…5, Δt =10min.) The output layer has a single node. The output from the neural network is the forecasted wind velocity. The forecasted wind velocity derived as an output from the neural network at time t is recurrently reused as an input datum at each new forecasting step for time t+ t.

2.2 Training of Neural Network

The data for the training of the neural network is in August, 2005, and the day which gives wind velocity over effective 4m/s as a wind energy is used for the forecasting. We adopted the Nagoya meteorological observatory (above sea level 51m, grounds high 18m) as a site for forecasting of wind velocity. The training of the neural network was repeated using wind velocity data of the similar weather day extracted by the method of the pattern matching[12].

The forecasting at 9 o'clock of the forecast day was started using the forecasting system after the training of the neural network, and the wind velocity in the one hour ahead was forecasted in the 10 minute interval. The wind velocity observed at forecast site is in every 10 minutes.

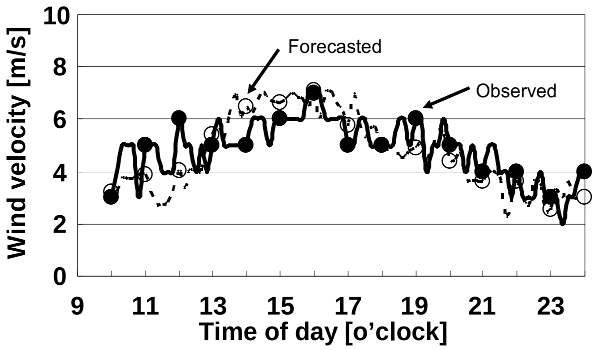

Fig.2 Time series of forecasted wind velocity (August 27, 2005)

Table 1. Error of forecasted time series of wind velocity

Day for forecast	Forecast error [m/s]
08.15.2005	1.1
08.18.2005	0.6
08.20.2005	1.0
08.21.2005	0.9
08.26.2005	0.9
08.27.2005	0.7
Average	0.9

2.3 Forecasted Results

An example of the forecasted results obtained by the above-mentioned method is shown in Fig. 2. In this figure, forecasted value and observed value are respectively shown in ○ and ● .

From this figure, it is confirmed that the forecasted value is close to the observed one. In order to

Table 2.Windmill generator specification.

Windmill type	The horizontal axis propeller type
Braid diameter	20m
Rated power	50kW
Rated wind velocity	12m/s
Cut-in wind velocity	2m/s
Cut-out wind velocity	15m/s

quantitatively compare the prediction result, the instantaneous value error of the forecasted values *E*rrw is estimated by using the following equation:

$$Errw = \frac{\sum_{i=1}^{n} \left| v_{fi} - v_{oi} \right|}{N} \text{ [m/s]} \qquad (1)$$

where *N* is number of forecasted values, v_{fi} and v_{oi} are the forecasted and observed values of the wind velocity , respectively.

The error of the forecasted values obtained by the (1) is shown in Table 1. In the table, the forecasted and observed values of the average wind velocity are also shown together. According to the table, the maximum value of the forecasted error of wind velocity is 1.1m/s, and the average one is 0.9 m/s. It is confirmed that forecasted values of the velocity of the wind are obtained with about 1 m/s error.

2.4 Simulation of windmill generation

The simulation of the windmill generation is executed by using the forecasted result of the wind velocity obtained in the previous section. The model of the wind power generator is used as shown in Table 2.

The wind energy *P* [W] is given in the following equation.

$$P_w = \frac{1}{2} \times r \times A \times v^3 \times h \times 10^{-5} \qquad (2)$$

where *v* is wind velocity [m/s], ρ is air density [kg/m^3] and *A* is wind receiving area [m^2]. As the values of ρ and A, 1.293 kg/m^3 and 1 m^2 are used, respectively. The generation efficiency η of the wind mill is assumed by 30%. Using the forecasted result in the previous section, the wind energy obtained by (2) is calculated as forecasted value. The simulated results of the windmill generation are shown in Fig 3. This result is in larger error than Fig 2, because of that the generation power is in proportion to the cube of the wind velocity.

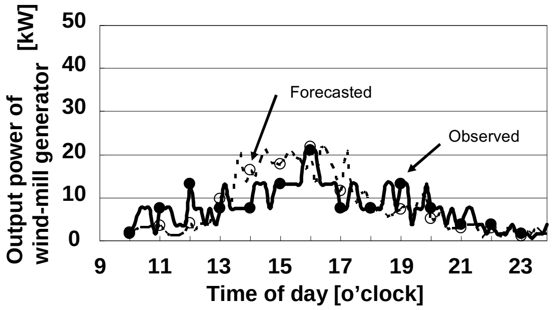

Fig. 3. Time series forecast of wind power energy. (August 27.2005)

Table 3. Error of Time series forecast of wind power energy.

Day for forecast	Forecast error [kW]
08.15.2005	6.5
08.18.2005	1.9
08.20.2005	2.8
08.21.2005	3.0
08.26.2005	6.3
08.27.2005	3.6
Average	4.0

As well as equation (1), the instantaneous value error of the forecasted ones *Errpw* is estimated by using the following equation:

$$Errpw = \frac{\sum_{i=1}^{n} \left| P_{fi} - P_{oi} \right|}{N} \text{ [kW]} \qquad (3)$$

where *N* is number of forecasted values, P_{fi} and P_{oi} are the forecasted and observed values of the wind power, respectively.

The errors of the forecasted values are shown in Table 3. As shown these errors, the maximum is 6.5kW and the average is 4.0kW. These errors are affected on the error of wind velocity as shown in the Table 1.

3. Time series forecast of solar power

3.1 Sunshine duration and solar energy

The future system in which the introduction of photovoltaic power generation spread was assumed. It

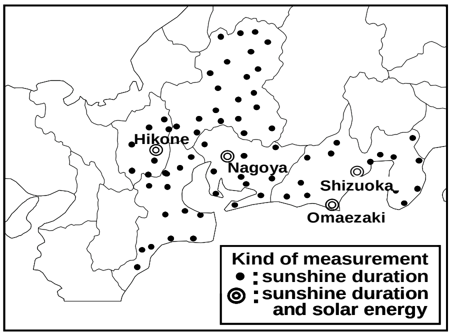

Fig.4 Point of measurement of sunshine duration and solar energy

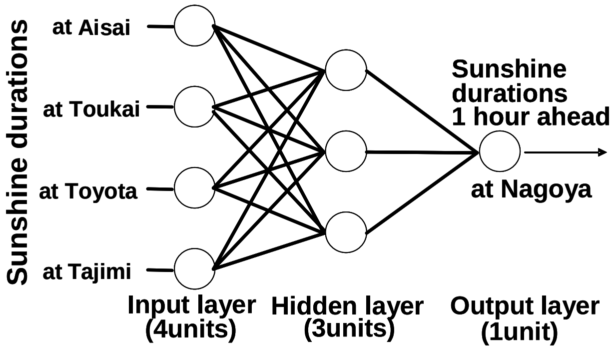

Fig.6 Time series forecast system of sunshine duration

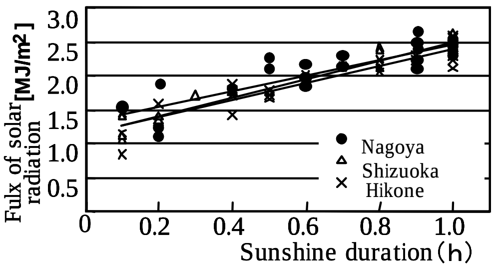

Fig.5 Correlation between of sunshine duration and fulux of solar radiationduring 9:00 – 10:00 in August.

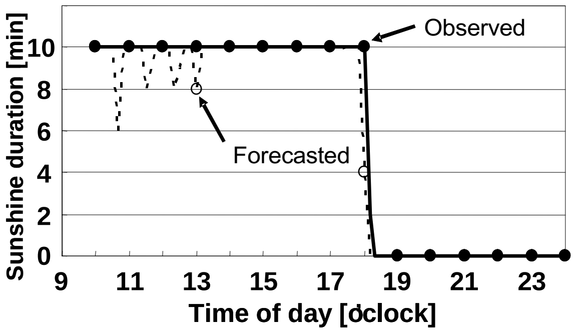

Fig.7 Time series forecast of sunshine duration (August 27. 2005)

was considered that meteorological data (SDP; offered by Meteorological Agency) according to the observation data on the ground is used[14]. But the observation point of solar energy is very little as shown in Fig. 4.

Then, the relationship between sunshine duration and solar energy at Shizuoka, Nagoya and Hikone is examined in order to be able to widely grasp the time series of solar energy by the sunshine duration. An example of the result is shown in Fig. 5. It is confirmed that there is the correlation between sunshine duration and solar energy. Therefore, the solar energy may be estimated from the sunshine duration.

3.2 Forecasting of sunshine duration

The neural network shown in Fig. 6 was used for the time series of the solar energy. The input data to the neural network are 4 values of the sunshine duration observed at t on 4 observation points near Nagoya. The output layer has a single node. The output from the neural network is the forecasted values of sunshine duration at one hour ahead.

The training of the neural network was repeated using sunshine duration data of the similar weather day extracted by the pattern matching method[12]. The forecasting is begun at 9 o'clock by using trained neural network.

The sunshine duration on August 27, 2005 was forecasted by using the forecasting system after the training of the neural network. The results are shown in Fig. 7. From this figure, it is confirmed that the forecasted value is close to the observed one. The forecasted value of the flux of solar radiation was calculated using Fig.5. The result is shown in Fig. 6. It is also confirmed that the forecasted solar energy is close to the observed one.

Table 4. Error of Time series forecast of durations of sunshine.

Day for forecast	Forecast error [min]
08.15.2005	4.3
08.18.2005	0.9
08.20.2005	3.6
08.21.2005	0.3
08.26.2005	1.2
08.27.2005	0.4
Average	1.8

In order to quantitatively compare the forecasted result, the instantaneous value error of the forecasted values *E*rrs is estimated by using the following equation:

$$Errs = \frac{\sum_{i=1}^{n} \left| s_{fi} - s_{oi} \right|}{N} \text{ [min]} \qquad (4)$$

where *N* is number of forecasted values, s_{fi} and s_{oi} are the forecasted and observed values of the duration of sunshine , respectively.

The errors of the forecasted values of the duration of sunshine are shown in Table 4. As shown these errors, the maximum is 4.3 minutes and the average is 1.8 minutes. These values are 18% and 43% for maximum durations of sunshine that is 10 minutes. The comparatively good results are given on the day when weather was stable.

3.3 Simulation of photovoltaic power generation

The simulation of solar generation was carried out by using the forecasted result of the sunshine duration. The model of the solar panel is used as shown in Table 5.

The output electric power P_s by the solar panel is calculated by using the following equation

$$P_S = \frac{Sr \times A \times h \times 10}{3600} \text{ [kW]} \qquad (5)$$

where S_r is flux of solar radiation, *A* is surface area of solar panel, h is the generation efficiency of the solar panel., respectively. The η is assumed by 10%.

The forecasted value of output power of solar battery was calculated using forecasted results of sunshine duration. One of the results is shown in Fig. 8. It is also confirmed that the forecasted power of the solar battery is close to the observed one.

Table 5. Specification of solar panel

Solar panel type	Polysilicon type solar battery
System capacity	50kW
Surface area	550m^2

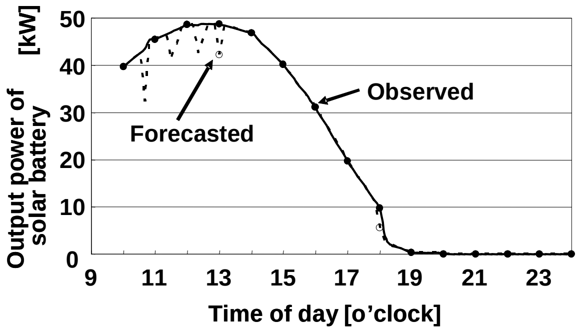

Fig.8 Time series forecast of output power of solar battery (August 27. 2005)

Table 6. Error of forecasted output power of solar battery

Day for forecast	Forecast error [kW]
08.15.2005	10.1
08.18.2005	7.6
08.20.2005	10.3
08.21.2005	0.9
08.26.2005	2.3
08.27.2005	0.7
Average	5.3

As well as equation (3), the instantaneous value error of the forecasted ones *E*rrps is estimated by using the following equation:

$$Errps = \frac{\sum_{i=1}^{n} \left| P_{fi} - P_{oi} \right|}{N} \text{ [kW]} \qquad (3)$$

where *N* is number of forecasted values, P_{fi} and P_{oi} are the forecasted and observed values of output power of solar battery, respectively.

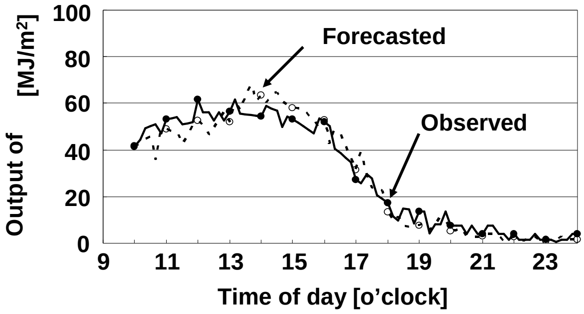

Fig.9 Simultaneous forecast of wind and solar power (August 27. 2005)

Table 7. Simultaneous forecast error of wind and solar power

Day for forecast	Forecast error					
	Wind-mill generator		photovoltaic generation		Wind-mill generator and photovoltaic generation	
	[kW]	*[%]	[kW]	*[%]	[kW]	*[%]
08.15.2005	6.5	12.9	10.1	20.1	12.6	12.6
08.18.2005	1.9	3.8	7.6	15.3	6.3	6.3
08.20.2005	2.8	5.6	10.3	20.7	8.7	8.7
08.21.2005	3.0	6.0	0.9	1.8	3.3	3.3
08.26.2005	6.3	12.6	2.3	4.5	7.0	7.0
08.27.2005	3.6	7.2	0.7	1.4	4.0	4.0
Average	4.0	8.0	5.3	10.6	7.0	7.0

The errors of the forecasted values of output power of solar battery are shown in Table 6. As shown these errors, the maximum is 10.3kW and the average is 5.3 kW. These values are 20.6% and 10.6% for solar capacity that is 50kW.

3.4 Simultaneous forecast of wind and solar power

The simultaneous forecast of the wind power and solar power was carried out using by the time series forecast of wind power and solar power. For system capacity, we used 100kW of wind-power generator 50kW and solar cell 50kW, in total. The one of the results of simultaneous forecast of wind and solar power is shown in Fig.9.

In the Table 7, the simultaneous forecast error is shown. The forecasted results of wind power and solar energy by wind-mill generator and photovoltaic generation, respectively is shown again in the table. As shown these errors, the maximum is 12.6kW and the average is 7.0kW. These values are 12.6% and 7.0% for system capacity that is 100kW. These values are smaller than each forecasted result of wind and solar power.

4. Conclusion

For effective utilization of the natural energy and the prevention from global warming, forecasting system of the time series of the wind velocity and solar energy was constructed by the neural network. In this report, we used a neural network to forecast the time series of the wind velocity and sunshine duration.

Using the forecasted value of the wind power duration, we carried out the simulation of the windmill generation. In the other, using the forecasted value of the sunshine duration, we carried out also the simulation of the photovoltaic power generation.

It is confirmed that the proposal method gives good forecasted results of the wind velocity and solar energy. In the future, the improvement on prediction accuracy is attempted using field data of wind power generator. In addition, the wind power generator with system interconnection is examined on effects and problems in practical use of an output of the change prediction result, etc..

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