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CORRELATION ANALYSIS OF REGIONAL WIND POWERS IN JAPAN

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SUMMARY: This paper shows the relationships among the electricity generations by wind powers in nine regions of Japan. The electricity generations by wind power are simulated using the hourly weather data of Extended AMEDAS 2000. Ninety nine wind power sites with annual capacity factor larger than 18% are selected from 842 data sites. The correlational analysis of hourly and daily wind powers in nine regions throughout a year show that the correlation coefficient is 0.51-0.58 between Hokkaido and Tohoku, but those among the other adjacent regions are as low as 0.145-0.38. The results show that the electricity generations by adjacent regional wind power except Hokkaido and Tohoku can be mutually complementary.

Keywords: renewable energy, wind power, regional resources, correlation analysis

INTRODUCTION

The domestic renewable energy sources are important from the view point of safety, security, energy independence and no carbon emission. But there are problems that the electricity generations by wind power and solar photovoltaics are intermittent and fluctuating because of weather changes. The solution to these problems are proposed as follows,

1) Hydro and geothermal power for complementary
2) Pumped hydro and battery for energy storage
3) Combination of wind and solar in remote areas
4) Weather forecast
5) Demand responses

This paper is a basic analysis for combining use of wind powers in different regions. It is expected that the combinations of wind powers from different regions will make total electricity output stable, if they are connected through electricity grid. In order to analyze the effects, we developed a computer program to simulate hourly wind electricity generations throughout a year for the correlation analysis among wind powers in different regions.

WEATHER DATA

We used Extended AMEDAS weather data of the year 2000, which have hourly wind speed data at 842 sites nationwide in Japan. [1]

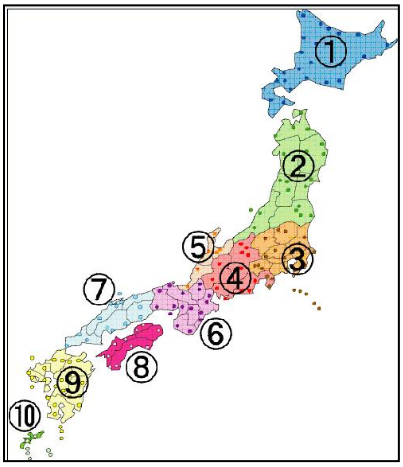

Figure 1. Ten regions of wind power sites in Japan

Figure 1 shows ten regions of Japan according to the areas of electricity supply companies. The regions are (1)Hokkaido, (2)Tohoku, (3)Kanto, (4)Chubu, (5)Hokuriku, (6)Kansai, (7)Chugoku, (8)Shikoku and (9)Kyushu from north to south in Figure 1. We do not include (10)Okinawa in this study because it is not expected to be easily connected with the other regions through electricity grids.

WIND POWER POTENTIAL

The potential wind power resources were studied by Ministry of Environment in 2010. [2] It shows very large potentials in on-shore and off-shore as shown in Fig.2. The total wind potential is 1856GW, of which 283GW on-shore and 1573GW off-shore. The off-shore potential is six times larger than that of on-shore. The largest on-shore potential is 140GW in Hokkaido and the largest off-shore potential is 454GW in Kyushu.

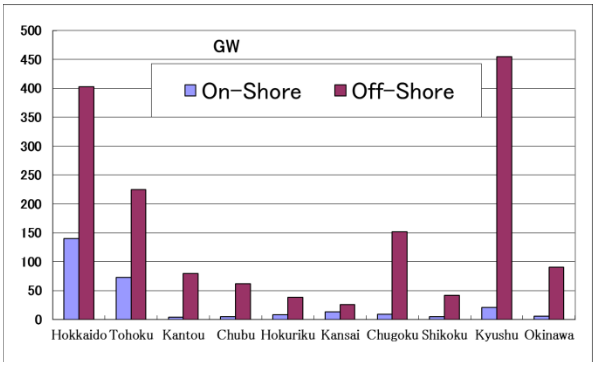

Fig.2 Potential wind power resources (GW)

Until the end of 2013, the cumulative capacity of 2,660MW wind machines have been already constructed in Japan. It is estimated the future possible scale of wind power on-shore and off-shore as 50GW or more in 2050 by Japan wind power association.

ALLOCATION OF WIND POWER

In this study, Unit of 2MW wind machine with horizontal axis and three blades is used to calculate the wind power in respective sites. The rotor start to work at cut-in wind speed 3m/s, and stop at cut-out wind speed 25m/s. The conversion efficiency is assumed 40%. The diameter of rotor is 80m and hub height is 56m. The weather data show wind speed at the height of 6.5 m. We arranged the data by power factor law to calculate the wind speed at the height of rotor hub of wind machines.[3],[4] The wind data sites include remote islands.

At first the hourly generation amount by single unit of 2MW wind machine for respective site are calculated. As we excluded the wind power sites having capacity factor less than 18%, finally 99 sites are selected among 842 sites of Extended AMEDAS data for the year 2000.

We assumed the allocation of wind powers in nine regions around 2050 as shown in Table 1. The necessary unit numbers of wind machine 2MW are calculated according to allocation factors of respective areas. But they are only on-shore sites because there are not enough data about off-shore sites. If they are included in the future, the capacity factor will be larger.

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The unit numbers of wind machines are multiplied with hourly generation of unit machine to calculate annual electricity supply. The result shows the total wind power is 67 GW with average capacity factor 27%. This scale of wind power is 3.6% of wind potential and can supply to 17% of electricity demand in 2008.

Table 1 Allocation of wind power

	Capacity	Generation	Capacity Factor
Region	MW	GWh	%
Hokkaido	8,874	23,593	30.35
Tohoku	9,188	20,223	25.13
Kanto	9,813	25,198	29.31
Chubu	6,298	15,087	27.35
Hokuriku	2,043	3,852	21.52
Kansai	3,568	7,543	24.14
Chugoku	11,882	25,359	24.36
Shikoku	2,762	7,543	31.18
Kyushu	11,549	28,248	27.92
Okinawa	1,409	3,852	31.21
Total	67,384	160,498	27.19

MONTHLY GENERATIONS

We summed up the hourly electricity generations and made the monthly electricity generations throughout a year for respective areas.

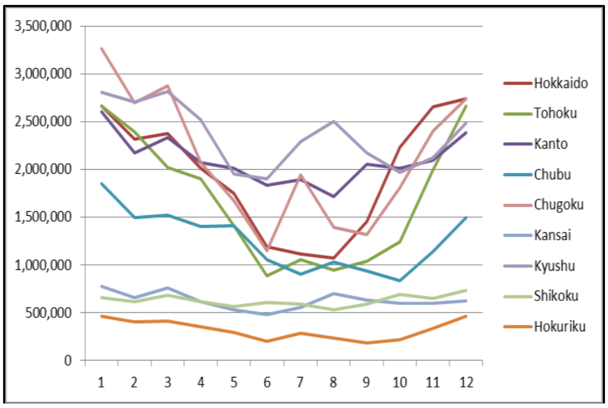

Fig.3 Monthly wind power in nine areas (MWh)

Fig.3 shows the monthly electricity generations by wind power in nine areas. The monthly generations in Hokkaido, Tohoku, Kanto, Chugoku shows larger in winter and smaller in summer. Those of Hokuriku, Shikoku and Kansai are relatively flat throughout a year.

DURATION CURVES of ELECTRICITY GENERATION

Figure 4 shows the load duration curves of wind powers throughout a year in nine regions. The curves are made from the histogram of electricity generation in respective areas. As the capacities of wind powers are different depending on the allocations, the differences of Y axis multitude is not important, but the patterns of curves show the distributions of electricity output.

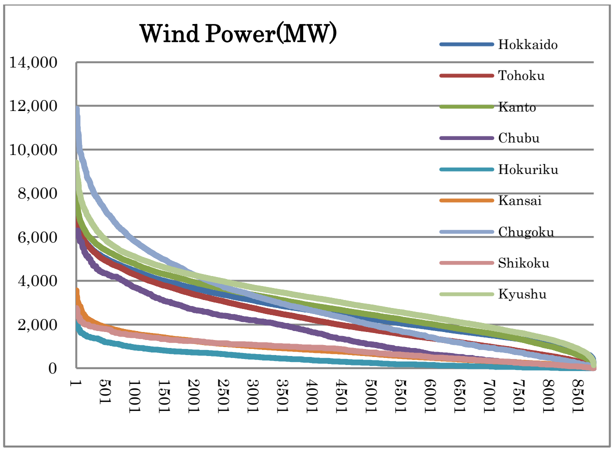

Figure 4. Load duration curves of wind powers

As the duration around the peak output of electricity generation in Hokkaido and Kyushu are very steep, it shows that the large capacity of wind machines in those areas are not working for long hours.

CORRELATION ANALYSIS of HOURLY GENERATION

We tried correlation analysis on the hourly electricity generation by wind machines in nine regions at the corresponding time for a year. The results of correlation coefficients between wind powers of two regions are shown in matrix form as in Table 2. [5]

The correlation coefficients are distributed from 0.035 to 0.510. If the number is large, it means there is strong relationship between two wind powers. If the number is small, there is complementary relationship between two wind powers.

The results show that correlation coefficients between adjacent regions are from 0.145 to 0.510. The largest correlation coefficients between adjacent regions are 0.510 for Hokkaido and Tohoku. The reason is inferred that the two regions have similar longitude and the weathers depend on a low pressure area which moves from the west to the east usually.

Table 2. Hourly Correlations among nine regions

	Hokkaido	Tohoku	Kanto	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu
Hokkaido	x								
Tohoku	0.510	x							
Kanto	0.135	0.258	x						
Chubu	0.288	0.328	0.251	x					
Hokuriku	0.267	0.342	0.171	0.311	x				
Kansai	0.122	0.123	0.227	0.340	0.220	x			
Chugoku	0.338	0.370	0.139	0.348	0.359	0.313	x		
Shikoku	0.060	0.035	0.097	0.043	0.054	0.157	0.145	x	
Kyushu	0.162	0.226	0.219	0.251	0.217	0.312	0.314	0.224	x

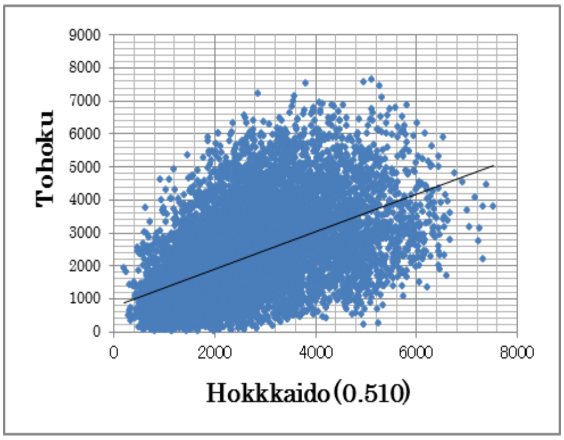

Figure5. Hourly correlations between Hokkaido and Tohoku

Figure 5 and 6 show the hourly correlations between wind power outputs of two regions. Each point in the figures shows the corresponding wind powers at the same time during 8760 hours. Figure 5 shows the relationship between Hokkaido and Tohoku with coefficient 0.510. Figure 6 shows the relationship between Kansai and Chugoku with coefficient 0.313.

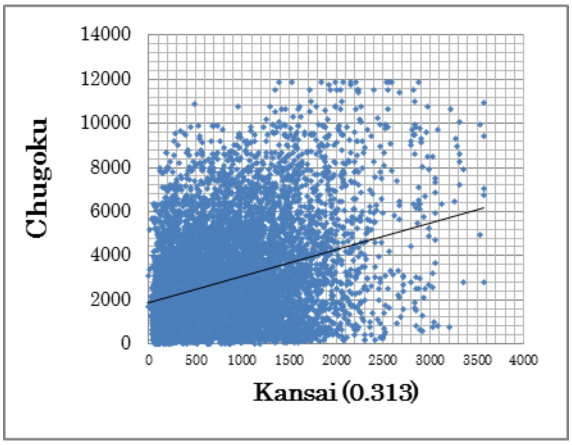

Figure 6. Hourly correlations between Kansai and Chugoku

If the correlation coefficients between two adjacent regions are not so large, the wind powers of two regions are expected to be complementary. Such combinations are those except combination of Hokkaido and Tohoku.

CORRELATION ANALYSIS of DAILY GENERATION

We tried correlation analysis of the daily electricity generation to confirm the difference from the hourly correlation. If we have some electricity storage to cope with fluctuations, the daily correlation may be useful. The coefficients of daily correlations between wind powers of two regions are shown in matrix form as in Table 3.

Table 3. Daily Correlations among nine regions

	Hokkaido	Tohoku	Kanto	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu
Hokkaido	x								
Tohoku	0.585	x							
Kanto	0.170	0.333	x						
Chubu	0.307	0.397	0.295	x					
Hokuriku	0.321	0.449	0.217	0.361	x				
Kansai	0.100	0.130	0.295	0.345	0.245	x			
Chugoku	0.381	0.459	0.198	0.415	0.471	0.379	x		
Shikoku	0.129	0.101	0.233	0.222	0.190	0.372	0.322	x	
Kyushu	0.122	0.260	0.295	0.253	0.247	0.408	0.350	0.380	x

The daily correlation coefficients are distributed from 0.101 to 0.585, which are larger than that of hourly correlations. Average coefficient of daily correlations is 0.2982 and that of hourly correlations is 0.2299. So the coefficient of daily correlations is 1.297 times of hourly correlation coefficients.

Figure 7 and 8 show the daily correlation between wind power outputs of two regions. Each point in the figures shows the corresponding wind powers at the same day during 365 days. Figure 7 shows the relationship between Hokkaido and Tohoku with coefficient 0.586. Figure 8 shows the relationship between Kansai and Chugoku with coefficient 0.378. Both correlation coefficients are a little larger than those of the hourly generations.

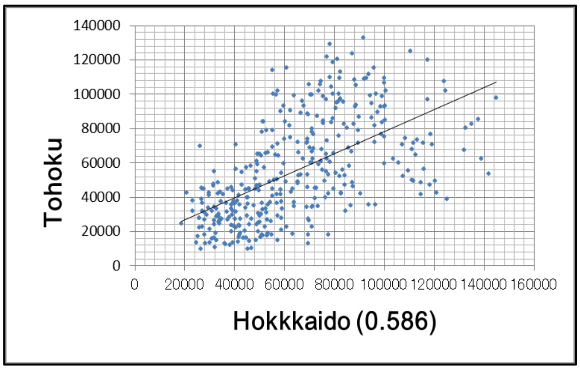

Figure 7. Daily correlations between Hokkaido and Tohoku

The results of daily generations show that correlation coefficients between adjacent regions are from 0.145 to 0.586. The largest correlation coefficients between adjacent regions are 0.586 for Hokkaido and Tohoku just as same as for the hourly correlations

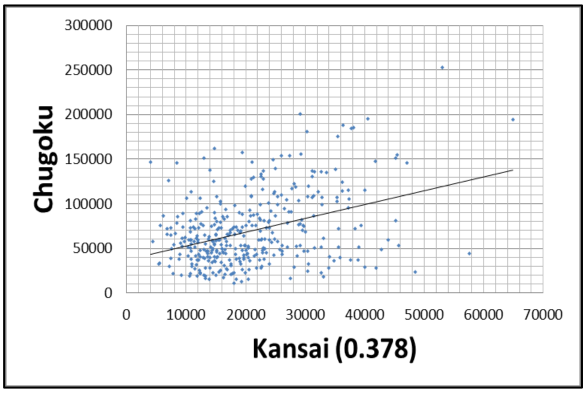

Figure 8. Daily correlations between Kansai and Chugoku

As the correlation coefficients between two adjacent regions except combination of Hokkaido and Tohoku are not so large as shown in hourly and daily correlations, the wind powers of adjacent two regions are expected to be complementary and contribute to decrease the fluctuations of wind power outputs.

CONCLUSION

We developed a computer program to simulate electricity generations from wind powers using weather data Extended AMEDAS at 842 sites in Japan. We analyzed the correlation of wind powers between nine regions by dynamic simulator using hourly and daily generations of wind powers.

Though the results of daily correlation coefficients are 1.3 times of hourly correlation coefficients, the relations are not so strong and the combination of generations in two regions is useful for decreasing fluctuations. As the results show that the wind powers in adjacent regions except combination of Hokkaido and Tohoku have not so strong correlation, the grid connections of wind powers between those regions are effective to decrease fluctuation of total power output.

We expect the results will be helpful for renewable rich energy planning including regional wind powers in the future.

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