Data Analysis of Spanish Electrical Grid System

Hiroshi Chin and Rikiya Abe
Department of Technology Management for Innovation, Graduate School of Engineering, The University of Tokyo, Japan
Email: hiroshi.chin@gmail.com, abe-r@tmi.t.u-tokyo.ac.jp

***Abstract*—Spanish electrical system is one of most successful cases for electric power generation from renewable energy sources such as the wind and solar. In order to reveal the key points for the introduction of renewable energy in the electrical grid, we performed the statistical analysis of the composition of Spanish the power sources. Based on the Spanish power generation and demand, as well as the type of power source by area, we analyzed the error in demand forecast made by REE. Furthermore, we performed a Cross-correlation analysis for the time series of energy source data. As a result, we could understand buffering systems like International Power Interchange are inevitable for a high percentage of unstable renewables and unpredictable demand. One way to reduce the burden for the power grid is to construct segmented grids, and in this way improve the demand response balance within the gird.**

***Index Terms*—smart grid, renewable energy, Spanish electrical grid system, cross-correlation analysis**

I. Introduction

Recently, electric power generation from renewable energy resources such as wind and solar has increased in many countries. Europe has set a target of 27% of final energy consumption to be produced by renewable resources by 2030 [1]. United States and Japan are also having active debates to set ambitious goals to enhance the introduction of renewable energy [2]. It is very challenging because the generated energy and power demand vary unpredictably. This makes it increasingly difficult to manage the power flows throughout the grid, and to meet the demand and supply balance. Despite this difficulty, Spain has one of the most advanced electricity systems that allow more than 40% of renewable energy as a power generation source [3]. The main renewable energy compositions are Solar 5.1%, Hydro 15.4%, and Wind 20.4%.

One of the key points for this success is the advanced demand forecast and renewable power generation forecast system. Another key point is that European countries could develop a network between them, which allows balancing supply demand by interchanging electricity between districts and countries [4]. Especially, Spain has several interconnections between France, Northern Africa and Portugal that allow Spain to manage the unpredictable demand and sudden change of renewable energy output. Furthermore, the grid management system control connects with the CECRE (Control Center for Renewable Energies) [3] has an essential role for covering the imbalance of power supply -demand and reduce the cost of International Power Interchange by backup-supports from Combined Cycle, Hydro and Coal power generation.

Even though there has been much attention paid on the Spanish electricity system, there are few researched using the real power generation data that reveals how the Spanish electrical system behaves against unstable renewable energy and what the critical points for designing the future electricity grid are. We consider it is of value to understand and the system of the Spanish power grid for the future grid designs such as Digital Grid [4]. In this paper, with the data provided by Red Eléctrica España (REE) [5], we have performed a histogram analysis and Cross-correlation analysis for the forecast error and power sources.

II. Data and Method

A. Detail of Acquired Data

The data was acquired from REE that includes realtime electricity demands of the Spanish peninsula. Specifically, the data is updated every 10 minutes for both the actual demand, the forecasted demand and the scheduled demand. The web image is shown in the Fig. 1 and Fig. 2. Scheduled demand means the scheduled production of the generating units which have been allocated the responsibility of supplying the electricity required to meet the forecasted demand [5]. Also, data contains different power sources necessary to meet the demand, including the energy to be exported and imported.

Data Source: Red Eléctrica España (REE) [5]
Contents: Electricity composition by area, Real-time demand, and generation
Term: From 27th Oct. 2013 to 27th Oct. 2014 (One Record: Every 10 min, 66065 records)
Areas: Main Land, and other 12 areas
Detailed Data Contents:

Power demand and forecast:
1) The actual demand
2) The forecasted demand

Power generation and Electricity composition:
1) Combined Cycle Power Generation
2) Hydro Power Generation
3) Coal Power Generation
4) Nuclear Power Generation

Manuscript received July 15, 2015; revised January 4, 2016.

doi: 10.18178/ijoee.4.1.62-66

5) Wind Power Generation
6) Solar Power Generation
7) International Power Exchange
8) Other Power Exchange

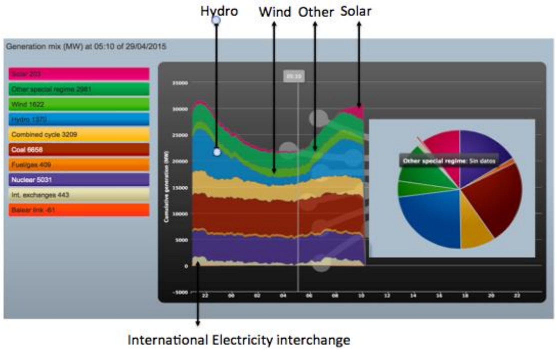


Figure 1. Power generation and Electricity composition [5]

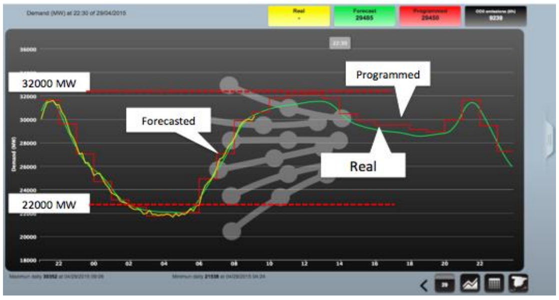


Figure 2. Power demand and forecast [5]

B. *Methods*

1) Forecast error analysis

The actual demand shows the instantaneous value of electricity demand. The demand forecast is drawn up by REE based on historical electricity consumption data [5] (we assume it is 10 minutes ahead forecast). We calculated the Mean Absolute Percentage Error (MAPE) which provides a measure of the accuracy of a method for constructing fitted time series values in statistics [6]. It is defined by the formula (1), where A is the actual value, n is the number of data and F is the forecast value.

$$\frac{1}{n}\sum_{k=1}^{n}\frac{|F_k - A_k|}{A_k} \tag{1}$$

2) Histogram analysis

We analyzed the histogram of the total term of the International Power Interchange and other power generation sources. International Power Interchange is the amount of energy export and import happening every 10 minutes. A positive value means energy is imported from regions outside Spain and negative values mean energy is exported to regions outside Spain.

3) Auto and cross-correlation analysis

Cross-correlation analysis [7] was performed for the acquired data. The cross-correlation is a measure of similarity between two time series as a function of the lag of one relative to the other. It is commonly used for searching the leading index of certain time series. We also performed an Autocorrelation analysis [4] to study the randomness and the fluctuations.

a) Definition 1: Autocorrelation [4]

Given time-series, $Y_1, Y_2, ..., Y_N$ at time $T_1, T_2, ..., T_N$, the lag k Autocorrelation function (acf) is defined as formula (2).

$$acf_k = \frac{\sum_{i=1}^{n-k}(Y_i - Y)(Y_{i+k} - Y)}{\sum_{i=1}^{n}(Y_i - Y)^2} \tag{2}$$

b) Definition 2: Cross-Correlation [4]

Given time-series, $Y_1, Y_2, ..., Y_N$ and $X_1, X_2, ..., X_N$, the lag k Cross-correlation function (ccf) is defined by the formula (3).

$$ccf_k = \frac{\sum_{i=1}^{n-k}(Y_i - Y)(X_{i+k} - X)}{\sum_{i=1}^{n}(Y_i - Y)^2} \tag{3}$$

III. Result

A. *Statistical Analysis*

1) Forecast error analysis

The Distribution of Forecasted Error is shown the Fig. 3. The MAPE of the demand forecast is 0.8%. The histogram of MAPE is an almost symmetric Gaussian distribution, where the maximum value and minimum value greatly exceed 3 sigma. It means that an allowance is needed for the high percentage of error even if it rarely occurs.

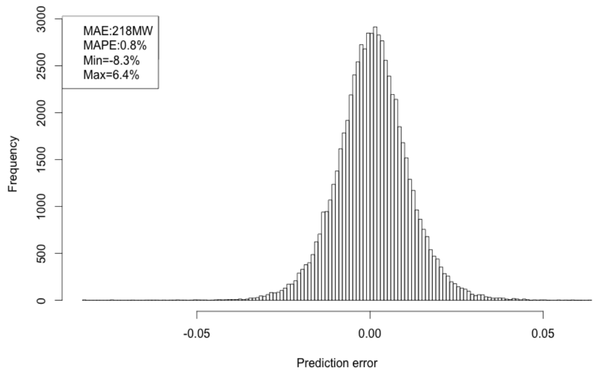


Figure 3. Distribution of forecasted error

2) Histogram analysis

a) Combined cycle and hydropower generation

We see from Fig. 4 that Combined Cycle and Hydropower generation histogram are widely distributed. Especially, the median of Combined Cycle is around 2000[MW], whereas the maximum is about 12000[MW]. It stands for that the Combined Cycle serves as a dispatchable power resource for renewable energy and demand fluctuation, there is much margin of power generation. Hydro does not serve as the same way of Combined Cycle, but the histogram is widely distributed as well.

b) Coal power generation

Contrarily to the Combined Cycle, Coal (see Fig. 4) is rather evenly distributed so that we can understand that coal serves as middle power source, which changes the amount of power generation in relatively longer time span comparing with Combined Cycle and Hydro.

c) Nuclear power generation

Seeing from Fig. 4, it is notable that nuclear is the base power resource. It has 3 power generation mode between 5000[MW] and 7000[MW].

d) Solar and wind power generation

Although Solar and Wind are both renewable energies, the characteristics look rather different. The ability of power generation of Solar is weaker than Wind. Wind has higher power generation ability, but it is the most widely distributed among the each power generation sources (0~15000[MW]).

e) International power interchange

The value of International Power Interchange follows a near Gaussian distribution. The average International Power Interchange is 547.7MW. It means that there is more export than import normally. Also, the maximum and minimum are far beyond 3 sigmas of the distribution so that backups trigger allow the additional import and export of electricity if necessary.

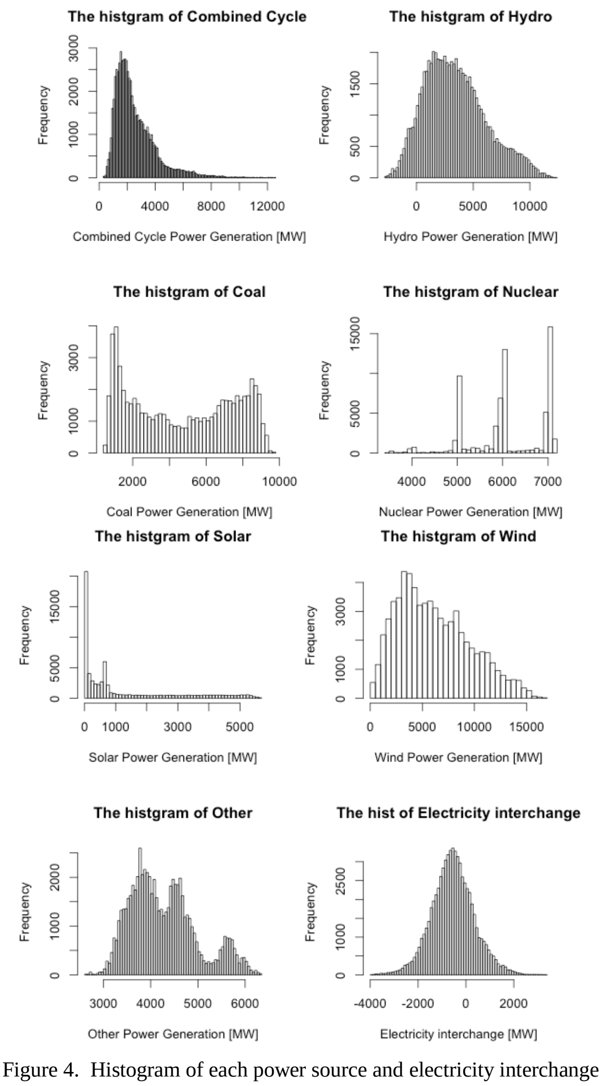


Figure 4. Histogram of each power source and electricity interchange

B. Cross-Correlation Analysis

Fig. 5 shows the result of Cross-correlation between International Power Interchange and each power source as well as the Autocorrelation of each power source. The result of Cross-correlation is indicated at the left side of the Fig. 5, and the result of the Autocorrelation is indicated at the right side of Fig. 5.

Regarding Cross-correlation, the horizontal axis is for the lag between the times series x variable and y variable, and the vertical axis is for the degree of the Cross-correlation. The positive side of the vertical axis shows the two variables have a positive correlation, and negative side of the vertical axis shows the two variables have a negative correlation. In other words, if one variable increases, the other variable will decrease. Furthermore, the dotted line stands for the 95% confidence interval for the Cross-correlation.

Given that the maximum point of the Cross-correlation is located at the origin of the horizontal axis, it means that the two variables have positive correlation without a time lag.

Let us suppose that the maximum point of the Cross-correlation is located on the positive side of horizontal axis, it shows that y are predictors of x, and the lag is between maximum point of the Cross-correlation and Lag 0. Likewise, the maximum point of the Cross-correlation is located on the negative side of horizontal axis, it shows that x is predictor of y, and the lag is between the maximum value of the Cross-correlation and lag 0. On the other hand, the Autocorrelation indicates that there are fluctuations and randomness of the time series in a certain period of time. The abrupt change of the Autocorrelation shows that there is a fluctuation in the time series. Thus, given that there is a change of Autocorrelation, the Cross-correlation shows a periodical change in certain period of time (Fig. 5). On the other hand, given that there is little change of autocorrelation, the Cross Correlation remains constant. One lag stands for 10 minutes.

1) The relationship between international power interchange (interchange) and combined cycle power generation (combined cycle) (The 1st row in the Fig. 5)

Interchange leads Combined Cycle for 30~40 minutes. The Autocorrelation of the Combined Cycle power generation shows fluctuations.

2) The relationship between interchange and hydropower generation (hydro) (The 2nd row in the Fig. 5)

Interchange leads Hydro by 70 minutes. From the Autocorrelation, we found that Hydropower generation decreases slightly more than Combined.

3) The relationship between interchange and coal power generation (coal) (The 3rd row in the Fig. 5)

Interchange leads Coal by 100 minutes. From the autocorrelation, we found that Coal does not act actively to backup the Interchange.

4) The relationship between interchange and nuclear power generation (nuclear) (The 4th row in the Fig. 5)

Nuclear is unrelated to Interchange according to the autocorrelation.

5) The relationship between interchange and solar power generation (solar) (The 5th row in the Fig. 5)

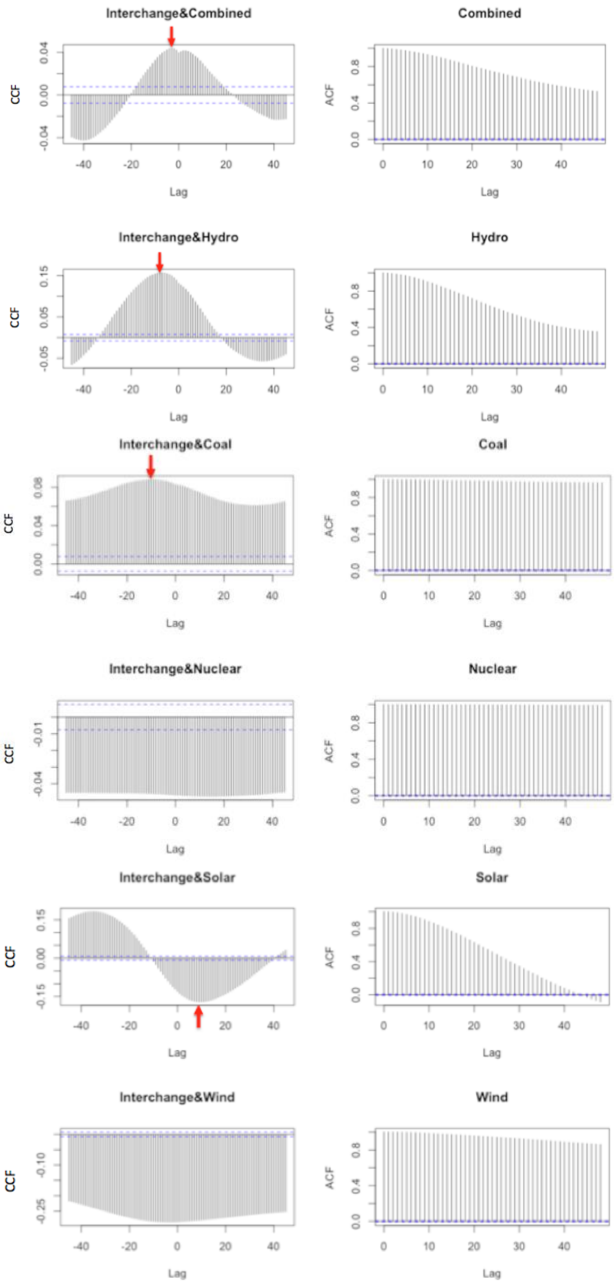
Since the maximum Cross-correlation closest to zero is in the negative, the relationship between Interchange and Solar is in a relationship of negative correlation. In addition, because the maximum Cross-correlation closest to zero is coming from the negative side, it can be inferred that Solar leads Interchange by 70 minutes.

6) The relationship between interchange and wind power generation (wind) (The 6th row in the Fig. 5)

Wind is almost constant. We consider that Interchange is not corresponded to Wind.

7) The relationship between interchange and forecasted error (The 7th row in the Fig. 5)

The forecast is calculated by the subtracting the planned demand from forecasted demand. From the Cross-correlation, Forecasted Error leads the Interchange for about 10 minutes. From the Auto-correlation, we found that the Forecast error is randomly distributed in the time series and changes the Auto-correlation is a short period of time. Therefore, there is a high possibility that the forecast error is adjusted by the International Power change.



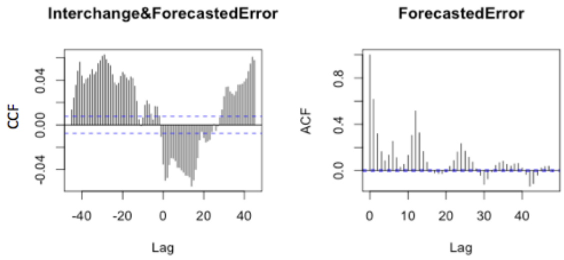


Figure 5. Cross-Correlation between international interchange and other power generation sources and autocorrelation

IV. Discussion

From the Cross-Correlation between Interchange and other power sources, we speculate that the first to correspond to Interchange is Combined Cycle corresponds, and then Hydro and Coal follow respectively. On the other hand, according to Auto-correlation, Hydro acts the most significant role for the compensation of Interchange, and then Combined and Coal. Thus, we can consider Combined Cycle and Hydro plays the key role in the process of the compensation for Interchange. Also, the result leads to our presumption that Nuclear does not follow the Interchange, whereas we could find that Interchange is mainly caused by the fluctuation of solar generation rather than wind. From the statistical analysis, contrarily to our expectation, there was no notable sign that fluctuations of Wind power are adjusted by International Power Interchange.

V. Conclusion

Even though there has been much attention paid on the Spanish electricity system, there are few researched using the real power generation data that reveals how the Spanish electrical system behaves against unstable renewable energy and what the critical points for designing the future electricity grid are. In this paper, with the data provided by Red Eléctrica España (REE), we have performed histogram analysis and Cross-correlation analysis for the forecast error and power sources. As the result, accurate demand and power forecast and the international Interchange serves a critical role to support the renewable energy in the Spanish grid system. We could find that the average of forecasted error is low, but their histograms, Solar Energy and Wind Energy Power Generation are widely distributed so that it is critical to provide additional backups to recover imbalance of power supply-demand. From the analysis, we found that the backup system mainly consists of Combine Cycle, Hydro and coal helping to balance the supply-demand. Once an unbalance of supply-demand occurs, the system will rely on the International Power Interchange to absorb it. Therefore, Power Interchange is inevitable for a high percentage of unstable renewable and unpredictable demand. However, power Interchange is not a general solution for introducing renewables due to the grid capacity, the management problem, and geographic conditions. One way to reduce the burden of the Power Interchange is to construct segmented grids, and reduce the unbalance within the grids. The concept of Digital Grid could play a key role to realize segmented grids.

ACKNOWLEDGEMENT

I would like to show my greatest appreciation to my colleague-R. Kontani whose supports and helps were more than valuable throughout the study.

REFERENCES

[1] A policy framework for climate and energy in the period from 2020 to 2030. [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0015

[2] (2015). U.S. Department of Energy. [Online]. Available: http://energy.gov/

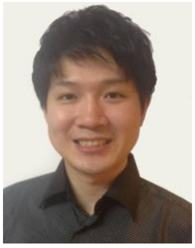
[3] (2014). Red Electrica de Espana, the Spanish electricity system, preliminary report. [Online]. Available: http://www.ree.es/sites/default/files/downloadable/preliminary_report_2014.pdf

[4] R. Abe, H. Taoka, and D. McQuilkin, "Digital grid: Communicative electrical grids of the future," *IEEE Transactions on Smart Grid*, vol. 2, no. 2, pp. 399-409, June 2011.

[5] (2015). Red Electrica de Espana (REE). [Online]. Available: https://demanda.ree.es

[6] C. Bishop, *Pattern Recognition and Machine Learning (Information Science and Statistics)*, Springer, 2011.

[7] R. H. Shumway, "Time series analysis and its applications," *Springer Texts in Statistics*, p. 17, 2010.



Hiroshi Chin was born in Xian in China on April 7th, 1985 but spend his childhood in Japan. He is a Ph.D. course student in Department of Technology Management for Innovation at the University of Tokyo, Japan now 2015. And he received Master degree from School of Frontier at The University of Tokyo, and Bachelor degree form department of Precision Engineering at School of Engineering in the Tokyo Metropolitan University.

He has worked in Mitsubishi Heavy Industry, Gas Turbine Maintenance Service Section.

His special fields of interest include data mining, machine learning, and smart grid data analysis and modeling.

Rikiya Abe was born in Fukushima prefecture in Japan on September 12, 1953. He graduated from the Electronics Engineering at the University of Tokyo, Japan. He received a doctoral degree from institutions of chemical engineering at Kyushu University, Japan.

His employment experience included the Electric Power Development Company, Tokyo; Electric Power Research Institute, USA; and the University of Tokyo.

He is a Professor since 2008 at the University of Tokyo and is teaching undergraduate students at Program for Social Innovation and graduate students at Technology Management for Innovation. His special fields of interest include renewable energy, energy storage, and smart grid.