Real-time Wind Power Prediction System Based on Smart-Grid in Jeju, Korea

Kwon Kim†, Young-Jun Seo*, Kyoung-Seob Moon* and Young-Mi Lee**

Abstract – Wind power prediction information is necessary for electric power system operation and electricity power market which is allowed to participate the wind power. In this study, a real-time wind power prediction system is designed for the real application for the electric power system of Smart-Grid Test Bed in Jeju island, South Korea. This study is on the first system for practicable application of wind power to the electric power system operation in South Korea. This is composed of the meteorological forecasting module, calculation module of wind power output and HMI visualization system. The final output data from this system is short-term (6hr ahead) and mid-term (48hr ahead) wind power prediction values. These values are produced by using physical and statistical model. The purpose of this study is to further improve the accuracy of this prediction system and to develop practical system for power system operation and energy market in Smart-Grid.

Keywords: Wind Power, Forecasting, Smart-Grid, Jeju

1. Introduction

Globally, renewable power is seen as central to climate change mitigation, energy diversification and economic greening initiatives. With declining capital cost curves and without fuel supply or price volatility considerations, and with strong policy support, the share of renewable energy-based generation is expected to expand significantly across the world. With increasing the capacity of renewable resources, a variety of technical methods are being developed for efficient operation of renewable energy.

Wind energy technology is one of the most rapidly expanding areas among the renewable energy resources. Integrating wind power into the power system is a new challenge to the electricity security and reliability owing to the variable and uncertain nature of wind. It is difficult for operator to make a dispatch plan because wind power output rise and fall depending on weather conditions.[1] Therefore the technology of forecasting wind power output is an essential consideration for ongoing system reliability. It play a critical role in coordinating the dispatch of power plants in both the day-ahead and hour-ahead markets to reduce the allocation of reserves and to ensure that supply always matches demand.

In Europe and the United States, forecasting system began to be developed early in 1990s, the system that reflect regional weather conditions and terrain characteristics has been applied to its power system.[2] These countries make cost savings and economic benefits through the forecasting system. The effect from the accurate prediction is able to be calculated in quantitative terms from lots of studies. A study by GE Energy estimated, if applied to 3,300MW of wind generation in New York State, would reduce utility system operating costs by about $125 million per year compared to no forecasts.[3] Eltra, TSO in western Denmark, says that it is possible to save the operating costs by about DKK 300 million ($56.5 million) per year and to expect cost cutting of DKK 5 trillion for 17 years from now.

Table 1 presents wind power forecasting models currently in use in North America by regional ISO, Table 2 shows RMSE (Root Mean Square Error) of the primary forecasting models.[4]

Table 1. The caption must be followed by the table

	Capacity (MW)	Date of operation	Forecast Model
PJM	164,895	2009.04.	Previento
ERCOT	80,076	2008.07.	eWind
Midwest ISO	138,556	2008.06.	Previento
NYISO	38,190	2008.06.	eWind
CAISO	48,954	2004.06.	eWind
Hydro Quebec	43,664	2006.11.	WPPT

In Korea, the study of wind power forecasting technology is in the beginning stage. There are basic researches related to wind power resources, 'Forecasting method of wind power generation by classification of wind

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Received: December 26, 2011; Accepted: March 7, 2012

speed patterns'[5] and 'Method of Predicting Electric power and thermal energy from new and renewable energy sources'[6] etc., but these researches are another concept which is just applied statistical methods on historical data. It is necessary to develop a new forecasting system based on real-time meteorological data for more accurate prediction, in Korea.

The purpose of this study is to launch a Korea's own forecasting system and to operate actually on Test-bed in Jeju. Accurate prediction of wind power output is crucial to reduce the allocation of reserves in advance, particularly on a time-scale of several hours to days ahead of dispatch. Experiences with forecasting show that the overall shape of day-ahead electricity production can be predicted most of the time. We look forward to successful operation of this system, cost saving effect and expanded integration of wind power through this study.

Table 2. RMSE(%) of the primary forecast models

	Previento	eWind	WPPT
6 hours ahead	6~8%	5~7 %	18%
24 hours ahead	8~10%	10~15%	21%

2. Configuration of the System

2.1 System overview

This wind power prediction system is composed of meteorological forecasting module, calculation module of wind power output and HMI (Human Machine Interface) visualization system. The meteorological forecasting module and wind power output calculation module are built in the main server, and all of processes are performed on the main server. The forecasting information that produced from the main server is confirmed in various forms anywhere users want.

The meteorological forecasting module that is the most important thing in this system is performed with combination of physical model and statistical model. This system receives real-time meteorological data in the wind farm and uses that as input data for the meteorological forecasting. By using real-time weather data that are gained from the wind turbine, we can improve forecasting accuracy of that wind turbine.[7]

It needs the electrical characteristics to make a calculation of wind turbine output. Those characteristics are power curve of wind turbine, its position, wake deficit and so on, are done an advance setting for more accurate forecast.

The final output from this system is short-term and mid-term wind power output. Using physical model and statistical model, Short-term forecasting output is composed of 5-minutes interval prediction data and updated every 10 minutes. Mid-term forecasting output is comprised of 1-hour interval prediction data and updated every 1 hour. Mid-term output only use physical model.

Prediction cycle is designed in the light of impact on electricity security by wind power, concerns for reliable interconnection and reflection of the significant flexibility of power system.

Fig. 1 shows the total configuration of this system.

2.2 Real-time monitoring system

It is necessary to develop real-time monitoring system of the wind power's output. This monitoring data is used for

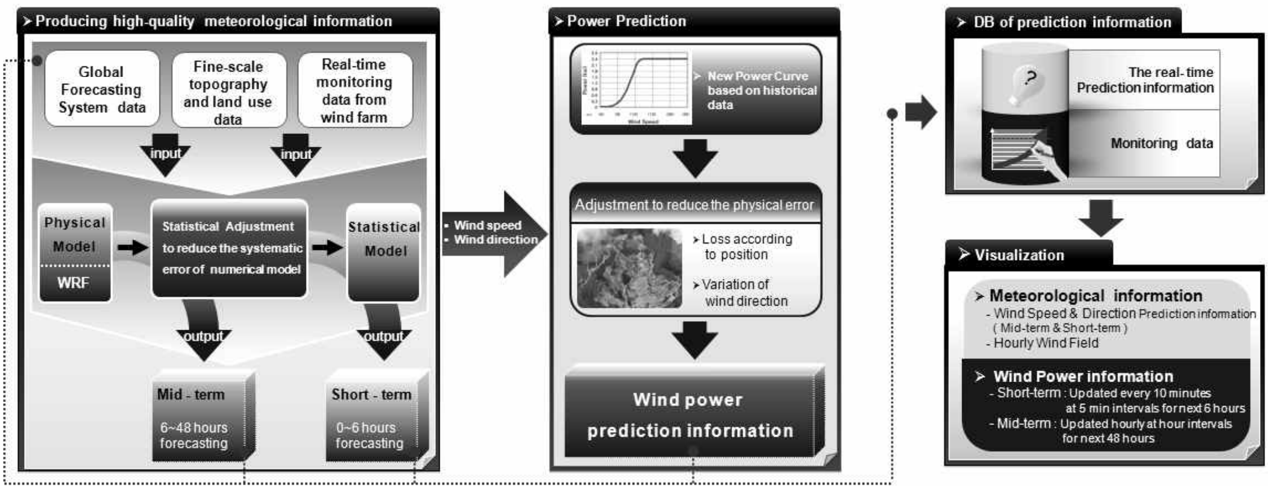

Fig. 1. Total configuration of the wind power prediction system in this study.

more accurate forecasting and as basic information for the improvement of statistical model.

The monitoring data can be divided into two parts, meteorological data and wind power output data in the wind farm. Meteorological data that is wind direction, wind velocity, temperature and humidity obtained by measuring device in the wind farm is received every 10 minutes. Wind power output data is also acquired every 10 minutes from the measuring device of plants.

With this monitoring data, a lot of characteristics of wind turbine (positional information, power curve, uncertainty of measurement, wake deficit, rated power, cut-in/rated/cut-out wind speed, tower data, nameplate etc.) is added to this system. These monitoring and turbine data is used for increasing accuracy of prediction, and to be input data of data assimilation stage and statistical model. In addition, wind power output data is stored as database and used for improvement of system.

2.3 Physical forecast model

In this study, it is used WRF (Weather Research and Forecasting) model for real-time meteorological physical model. Physical model uses numerical equation and computes physically a meteoric phenomenon in the wind farm. This physical model is provided as basic data for meteorological forecasting.

The WRF model is a next-generation meso-scale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.[8]

The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community. Fig. 2 shows a flow chart of WRF model.[9]

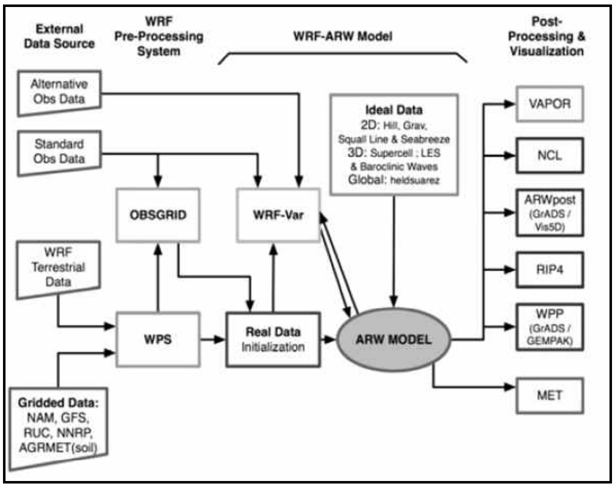

Fig. 2. Flow chart of WRF model.

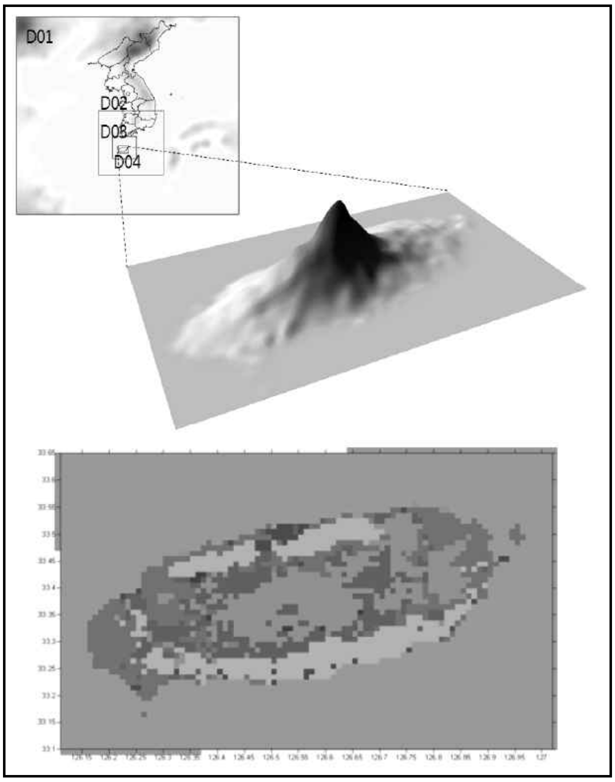

Fig. 3. Domains of the forecast and terrain data of Jeju.

2.4 Detailed terrain data

Wind, energy resource of wind power, is greatly influenced by terrain in wind farm. Accordingly, the local wind prediction model should take into account the effect of its terrain. In particular, for the weather forecasting of the specific point, it should be built a high resolution terrain data and accurately reflected terrain condition where we want predict. Terrain data here means elevation data and surface data. Elevation data is an important factor in deciding the air flow, and surface data has an influence on wind speed due to its surface friction.[10]

We make use of EGIS (Environmental Geographic Information System, http://egis.me.go.kr) that gives land cover information of 100m interval resolution provided by Ministry of Environment, Korea, and define the whole area of Jeju as a final forecasting domain. In addition to these settings, we use WRF's nesting method that is utilized when he wants to gain detailed forecast of a specific area. Nesting method is applied over a whole regional domain, not only along the lateral boundaries, and dynamics and physics are treated as perturbations only, it is referred as perturbation method. We conduct this method with East Asia as a Domain 1, and narrow our range down stage by stage as domain 2,3,4. Fig. 3 shows domains of the forecast and terrain data of Jeju island.

2.5 Initial and boundary data

Physical model produces weather forecasting data by using initial weather field from global forecasting model. GFS, NAM, GEFS, HRW, ECMWF etc. are commonly used as initial weather field system, most of these systems are made in the United States and Europe, produce global forecasting data by 1-degree interval.

In this study, it uses GFS (Global Forecast System) by the United States as initial weather field data. GFS is a global numerical weather prediction computer model run by NOAA. This mathematical model is run four times a day by 6-hours interval and produces forecasts up to 16 days in advance. We receive initial weather field data four times a day from GFS server by FTP.

2.6 Data assimilation

Data assimilation is an analysis technique in which the observed information is accumulated into the model state by taking advantage of consistency constraints with laws of time evolution and physical properties. However accurate physical model may be, forecast error is bound to rise with a lapse of time and GFS is not very accurate with decreasing spatial and temporal resolution over time. Data assimilation is the process of combining different sources of information in order to better estimate the state of a system and minimize the forecast error. We can improve accuracy of forecasting data through putting monitored weather data from wind farm in data assimilation process. Fig. 4 shows a flow chart of data assimilation in WRF.[11]

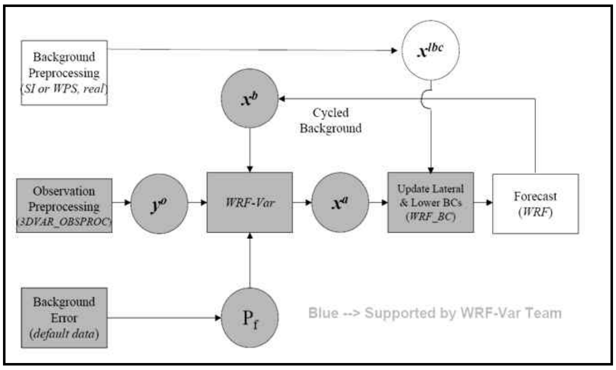

Fig. 4. Flow chart of data assimilation in WRF.

2.7 Physical model optimization

Physical model optimization is the process that applying a variety of physical options to forecasting data. This process goes along comparing measuring data and forecasting data, applying weather patterns for the data over a year period. This is essential process for detailed forecast of the specific area and for accuracy improvement.[12]

Physical model optimization consists of three stages. First, we perform the WRF model, after deciding the weather pattern representing a specific region from the analysis in that region seasonally, monthly, hourly and windy directionally, apply physical model for the period of that weather pattern.

Second is stage of comparing result of physical model and measuring data. In this study, our forecasting system makes an analysis of it with measuring weather data of various regions in Jeju : including Haengwon and Sungsan wind farm, weather stations (Jeju city, Gosan, Sungsan, Seogwipo) and automatic data detect points (Gujwa, Halim, Joongmoon, Moslepo, Seongpanak and so on).[13]

Fig. 5 shows seasonal wind fields in Jeju using measured weather data of weather stations and automatic data detect points.

In last stage, system repeatedly makes an analysis of past two process with changing its physical data options, and produces physical model optimized for the meteorological characteristics of Jeju.

2.8 Statistical model for short-term forecast

In this study, prediction system makes short-term forecast until 6 hours and mid-term forecast of 6 to 48 hours. Generally speaking, physical model takes meso-scale and localized meteorological change into consideration so that it is suitable for mid-term forecast after 6 hours. Accordingly, it needs another prediction method for the short-term forecast until 6 hours. We plan to make a statistical model for short-term forecast and to interlock it with the physical model. Our forecasting system apply the statistical model to grid prediction value from the physical model and produce a final meteorological prediction value for wind power output calculation.

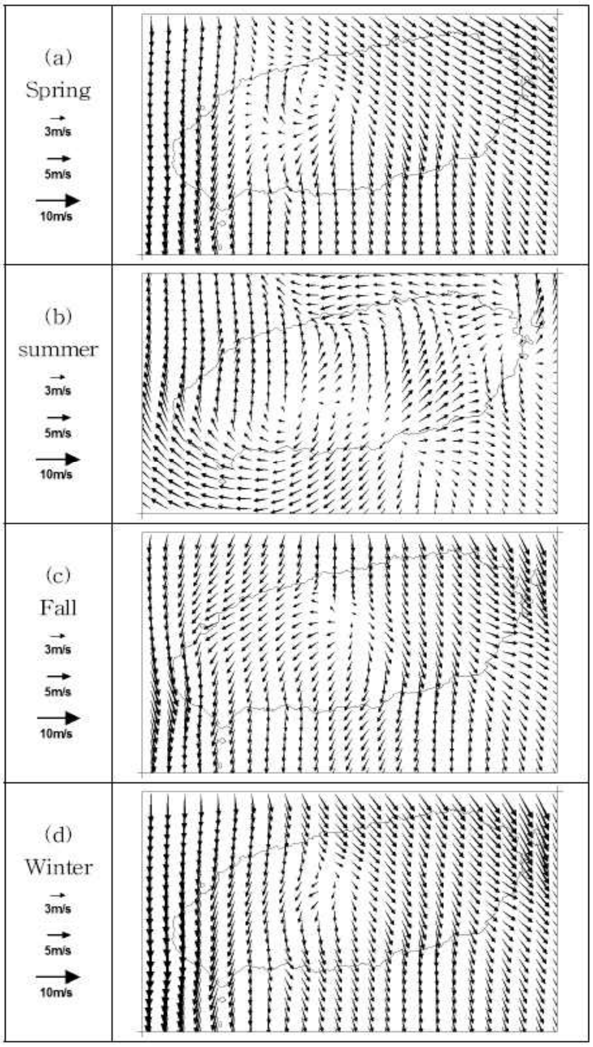

Fig. 5. Seasonal wind fields in Jeju.

There are many statistical methods currently used that are multiple regression, neural network and auto-regressive moving average. In general, there are a variety of statistical techniques because the statistical model that is excellent for all occasions does not exist and appropriate model depends on the nature of data, the purpose of analysis and the direction of study. In this study, we plan to develop and build the most appropriate statistical model for short-term forecast from data analysis more than 10 years of Jeju. We also design to make the statistical model better continuously using the accumulated data.

3. Operation and Verification

3.1 Accuracy verification

The phase tests and accuracy verification are performed to improve the accuracy of prediction in this study. These are processed along three major phases, after the third accuracy verification the optimization process is done through continuous system test operation. A primary test and accuracy verification are performed through historical data not real-time prediction data, then the verification process uses the real-time prediction data.

In this study, to verify the output prediction system, the accuracy verification of the output prediction system is performed after conducting the weather forecasting verification. The accuracy verification is basically based on the error between the prediction value and the experimental value, and taking advantage of various statistical methods.

3.2 Real-Time Process

Beginning of the process is done using the physical model from receiving the early meteorological field GFS data and the real-time monitoring data of the generation system. After the physical model is completely performed, the wind prediction data are produced based on the completion until the next 54 hours at hourly intervals, the statistical model is applied taking only within 6 hours prediction data.

Once the short and medium term wind prediction data are produced, the amount of the power output of each generator is calculated by applying compensation factor, wake deficit and the power curve of the each generator by wind farm layout. The final power output of each generator is calculated from the total power output of the each wind farm. The prediction value of the wind and power output are saved to data base of the main server with monitoring data, it is provided in the form of a variety of information to the user.

The forecasting system designed from this study is driving a real-time prediction system of the power output at regular intervals automatically. Then it is possible to design the inter-working stable operation with real-time receiving various data for the wind prediction, a physical model, a statistical model, a calculation and assessment of the power output. Out of consideration of the operation time of the weather prediction model, spending the longest time while calculating the operation hours, the hardware specifications of the system is developed to operate reliably and efficiently.

This system performs the physical model receiving the GFS data in the 6-hour intervals, 4 times a day. Due to the execution time of the physical model, this system produces the prediction data performing the physical model to the next 54 hours. Because the physical model is performed every 6 hours, to produce the prediction data until the next 48 hours, based on 6 hours after the physical model is performed, the 6 hour prediction data is needed. In 6 hours after performing the physical models, the statistical model is only performed 10 minute intervals and provides the short and medium term prediction data.

3.3 Visualization

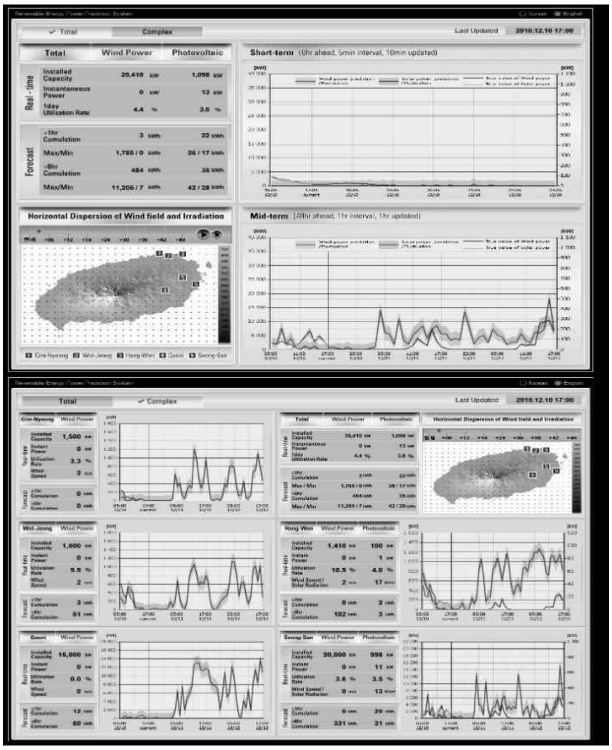

Fig. 6. Prototype of the visualization system.

The data handling system for the visualization is built by web-based, it allows the users to check in the separate PC in real-time and to set the initial setting in the user's PC. The information provided in the visualization system is about the weather status and forecasts of the power generation. The meteorological data is the prediction data received from the monitoring system on the weather status data, temperature, wind direction, wind speed, etc. of various point in Jeju. It also provides the weather information produced from the physical model within the prediction area, temperature, solar radiation, wind speed distribution and horizontal wind fields. Fig. 6 shows the prototype of the visualization display of the wind power prediction system.

4. Conclusion

In this study, we make a development a forecasting system combining both physical model and statistical model. Final outputs are short-term forecast until 6 hours and mid-term forecast of 6 to 48 hours. Short-term forecasting output is composed of 5-minutes interval prediction data and updated every 10 minutes. Mid-term forecasting output is comprised of 1-hour interval prediction data and updated every 1 hour.

The real-time wind power prediction system made by this study is based on WRF that is a 3-dimensional variational data assimilation system for real-time meteorological physical model, and uses GFS as initial weather field data. This system raises the quality and accuracy of wind forecast through the elevation and surface information of 100m interval resolution. In addition, the system performs physical model optimization process using measuring data from various regions of Jeju for detailed forecast of the specific area and for accuracy improvement.

Wind forecast data is produced by 1 hour intervals from physical model optimization, the statistical model is applied taking only within 6 hours prediction data, this system makes detailed short-term wind forecasting data. After it is produced short and mid term wind forecast data, the system applies compensation factor, wake deficit and the power curve of the each generator by wind farm layout, calculates the final wind power output and provides the final forecasting data for users through visualization system.

The real-time wind power prediction system from this study does a trial test in smart-grid test-bed of Jeju, and will be utilized as basic technology of large-scale forecast system in Korea. The next things we need to are verification of this system and improvement of accuracy. We have finished system development and will verify the system in Jeju smart-grid test-bed from June, 2011. Increased accuracy and reduced uncertainty of wind power forecast are important to encourage the use of forecasting in power system operation. We look forward to reliable operation of this system and contribution to electricity security and effective integration of wind power sources in Korea.

Acknowledgements

The authors would like to thank many people involved in

Korea Smart Grid Demonstration Project for their contribution to the preparation of this paper.

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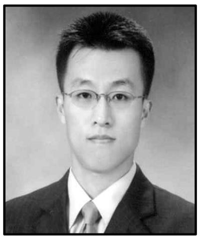

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