

Development of Matlab/Simulink Module for Voltage Flicker Simulation in Distribution Power Systems

Soo-Hwan Cho*, Jae-Ahn Jung*, Gilsoo Jang*, Sae-Hyuk Kwon[†] and Moon-Ho Kang**

Abstract – Power quality simulation plays an important role in many practical cases, for example, when deciding the capacity of the related mitigation devices, assessing the influence of installing a nonlinear load in the distribution part, dissolving the quality issues between utilities and customers, and so on. For these purposes, many dedicated tools have been used in order to assess the level of quality distortions by various kinds of PQ indices. However, there are few modules that can accurately simulate the flicker phenomenon, that is, P_{st} and the nonlinear and chaotic behavior of the electrical arc furnace, which is one of the representative nonlinear loads. This paper deals with the useful and simple modules for the voltage flicker simulation in the distribution and transmission level under the environment of Matlab/Simulink. With these modules, the various conditions of distribution systems and the capacities of arc furnaces with the chaotic characteristic can be easily taken into account.

Keywords: Chaotic EAF module, Chua's circuit, Flickermeter, IFL meter, Matlab/Simulink

1. Introduction

With the continual development of computer techniques, it becomes easier and easier to assess, diagnose, and predict the status of power systems, one of the representative nonlinear systems in the real world. Power engineers find it useful to formulate a plan to enhance or change the power system and prepare some countermeasures against catastrophic electrical disasters. There are many available computer tools and even dedicated programs that can be used for these purposes.

In the distribution levels of the power network, these tools are also used to assess the quality of power. It is, however, more difficult to accurately simulate and make predictions in a complicated distribution system, compared with the transmission power system that can be interpreted with the simplified models in the R.M.S level, that is, the steady-state response.

For quality assessment, many kinds of PQ indices are used, of which THD (Total Harmonic Distortion) is the most universal since it has the most analytic index. THD is based on the result of Fourier transform of the voltage signal and is easily executed by an algorithm of fast Fourier transform, shortly FFT, as programmed in the discrete manner. Other PQ indices except P_{st} used to evaluate

the flicker level, are also analyzed by discrete signal processing and are easily simulated with the transient programs.

As mentioned above, the process to calculate P_{st} is not simple. It is the most remarkable difference that the statistical procedure is inevitable when calculating P_{st} . According to IEC standard 61000-4-15, which is accepted as the international standard on measuring flicker, the flickermeter is divided into 2 parts [1]:

- Task 1: Simulation of lamp-eye-brain response which is realized with the signal processing techniques such as filtering, squaring, and resampling.
- Task 2: Statistical data evaluation of flicker level selected by CPF (cumulative probability function) as the standard defines.

Most of the power system analysis programs (for example, PSCAD) can execute the time simulation of the first task without difficulty. But they have an obstacle in Task 2. Since they are optimized to simulate the transient phenomenon or power flow of the power system graphically and easily, they cannot allow a user to apply the statistical algorithms, in this case, CPF, with the data yielded from a previous task and a following procedure to compute P_{st} with the percentile values of CPF, and to modify the hidden control blocks as he/she wants.

Matlab/Simulink could be a solution to this problem. They are interconnected with each other closely and efficiently. As well, each has its own strength that can cover the other's weakness.

[†] Corresponding Author: Dept. of Electrical Engineering, Korea University, Korea. (shkwon@korea.ac.kr)

* Dept. of Electrical Engineering, Korea University, Korea. ({joswany, bsang317, gjang}@korea.ac.kr)

** Power Quality and Safety Group, Power Distribution Lab., Korea Electrical Power Research Institute, Korea. (mhkang@kepco.kr)

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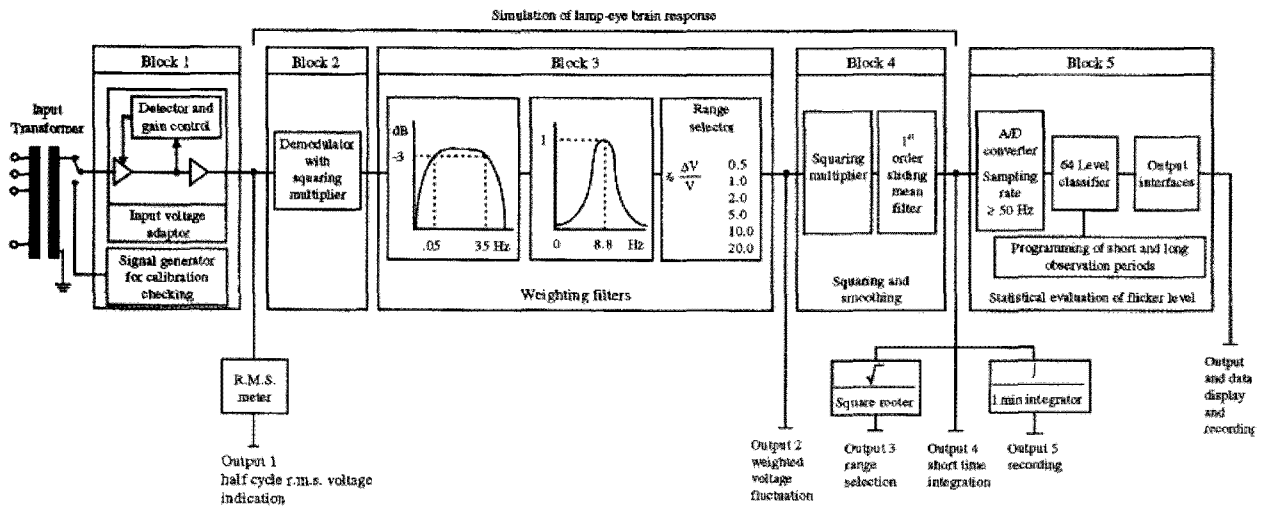


Fig. 1. Block diagram of IEC flickermeter

The graphic user interface of Simulink makes the design and simulation of the flicker measurement algorithms easier, and Matlab helps the user to manipulate the simulated data and to program the statistical computation.

SimPowerSystems of Simulink has a very powerful and convenient interface, providing the users with many embedded models. It also enables simulation of even the most complicated distribution systems with the automatically-variable step size in the time domain. As soon as the simulation finishes, it can transfer the output data to the Matlab workspace, with which the final value of P_{st} can be calculated in the Matlab.

The main goal of this paper is presenting how to simulate the flicker of a distribution system caused by the nonlinear loads such as electric arc furnace (EAF) to be as similar with the actual phenomenon as possible. For this purpose, the IFLmeter module, which is implemented to compute the value of IFL (output 5) from the input voltage signal in the Simulink environment and to consider the various distribution conditions, is proposed. The chaotic EAF model is also modularized for convenience sake, which is characterized with the real dynamic and chaotic behaviors by Chua's circuit [2, 3] and whose operational parameters are adjustable according to the user's demands. Lastly, as a case study, these modules are used to compute the transfer coefficients that are required to determine the flicker emission limits.

2. Calculating P_{st} with the IFLmeter Module

Details on how to calculate the IEC flicker indices and the implementation of the IEC flickermeter in a digital manner can be consulted through many previous papers, so

this paper does not address it [4–7]. The block diagram of the IEC flickermeter is shown in Figure 1.

At first, an algorithm to compute P_{st} should be implemented in the Simulink/Matlab environment. As mentioned above, two different tasks of the IEC flickermeter, that is, Task 1 and 2 are allocated to these two platforms, Simulink and Matlab, respectively.

Concretely speaking, the IFLmeter module given in Figure 2 is devised to take charge of Task 1, which is implemented in Simulink in order to compute only the IFL (Instantaneous Flicker Level, Output 5 in IEC flickermeter) value as a subsystem, the under mask of which is shown in Figure 3 on the next page. Each block of Figure 3, where some embedded modules involved in Signal Processing Blockset and SimPowerSystem are used, represents a data process from block 2 to block 4 of Figure 1. For versatility, this module has two options on the panel: System frequencies of 50Hz or 60Hz, and distribution voltage levels of 120V, 220V, or 230V.

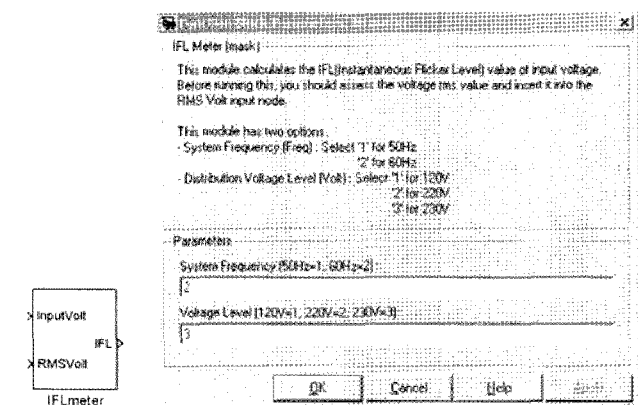


Fig. 2. Appearance (left) and functional block (right) of the Newly developed IFLmeter module

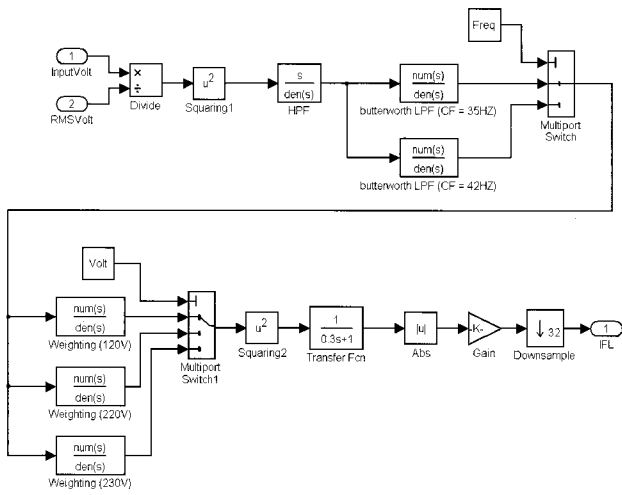


Fig. 3. Inner signal flow of proposed IFLmeter

There is an inherent function of *Callbacks* in Simulink model properties, which plays an important role in this simulation. The *Callbacks* function calls the m-file of Matlab at any moment demanded by the user. In this case, an m-file programmed to carry out the statistical analysis of CPF and the calculation of P_{st} as defined in the IEC standard should be called as soon as the simulation of the IFLmeter is completed.

It is also required that the IFLmeter be adoptable to various distribution conditions. Recently, IEEE declared that North America would accept the IEC standard on flicker index as its own standard [8]. Furthermore, the modification for the Korean system complying with IEC was introduced by the previous paper [9]. These functions are implemented in the developed Simulink modules as shown in Figure 3.

To verify whether the IFLmeter’s performance is good or not, IEC recommends that the flickermeter should comply with the test spec. According to the specification, one unit of perceptibility at output 5 with $\pm 5\%$ error should be yielded by the same input voltage fluctuations. Figure 4 is the test system of the IFLmeter and Figure 5 reveals that the output waveforms of the calculated IFL for the reference inputs of 8.8Hz, 0.250% sinusoidal voltage fluctuation and 20Hz, 0.546% rectangular voltage fluctuation are similarly converging into about 1.00, verifying that they are within the error permitted.

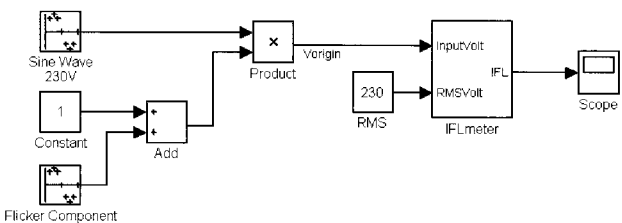


Fig. 4. Test specification of IFLmeter for analog response

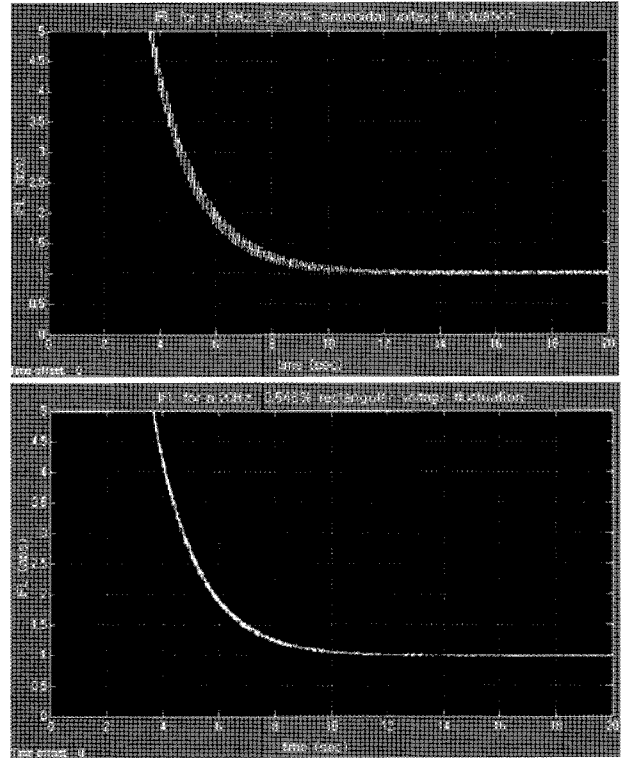


Fig. 5. Resultant waveforms excited by reference inputs of sinusoidal (left) and rectangular (right) voltage fluctuation, yielding one unit of perceptibility

3. EAF Module with Chua’s Circuit

Another challenge for the accurate simulation of circumstance polluted by voltage flicker is to establish the non-linear load model which reasonably operates. The most probable flicker source in real power networks is an electric arc furnace (EAF). So it has a key to the good simulation phenomenon.

Generally, EAF’s behaviors are divided into two categories. One is the dynamic behavior determined by the differential equation and the other is the chaotic characteristic.

The dynamic equation of EAF has already been derived as follows [3].

$$k_1 r^n + k_2 r \frac{dr}{dt} = \frac{k_3}{r^{m+2}} i^2 \quad (1)$$

$$v = \frac{i}{g} = \frac{k_3 i}{r^{m+2}} \quad (2)$$

where $m=0$, and $n=2$, meaning the refining stage of EAF. The final differential equation for the variable r is given by

$$\frac{dy}{dx} = \frac{k_3}{k_2} \frac{1}{r^{m+3}} i^2 - \frac{k_1}{k_2} r^{n-1} \quad (3)$$

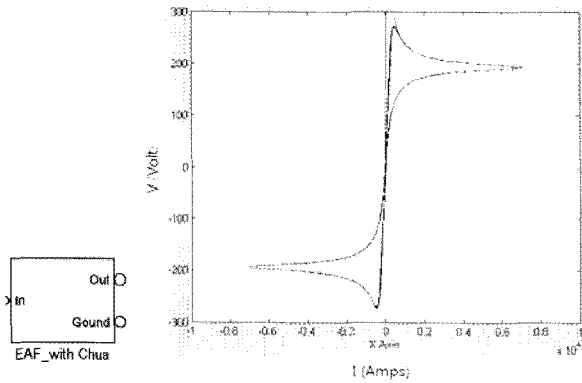


Fig. 6. EAF module with Chua's diode (left) and V-I curve of 250V/70 kA arc furnace (right)

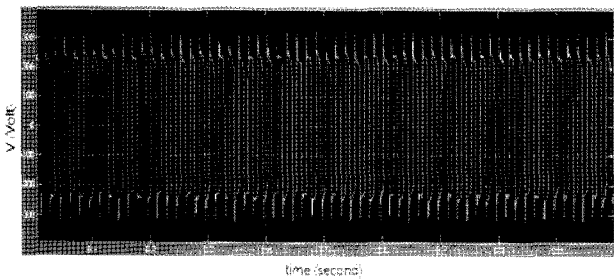


Fig. 7. Voltage waveform contaminated by EAF

The above dynamic equation is implemented in the EAF module shown in Figure 6 and in which the dynamic V-I characteristic of a 250V, 70kA furnace is also shown.

In order to generate the actual chaotic voltage signal, the Chua's circuit is supplemented to this module according to the previous achievement [3].

Using the EAF module combined with these two parts, the resultant voltage waveforms is shown as Figure 7.

4. Simulation

4.1 Performance Testing Inputs

In Table 5 of [1], the test specifications for the flicker-meter classifier are listed. For each input of rectangular voltage change, the P_{st} value should be 1.00 ± 0.05 . In order to verify that the Simulink flicker simulation is reasonable, it is necessary to check whether it satisfies this criterion or not.

Because the general Simulink model is executed for a few seconds, the changes less than ten-times per minute, about 0.1Hz, are insufficient for the simulation.

So, only four inputs of Table 5 of [1] are used for each voltage level.

The test configuration and corresponding settings are given in Figure 8.

Table 1 shows the resultant P_{st} values for the typical test voltage inputs with the simulation time of 60 seconds.

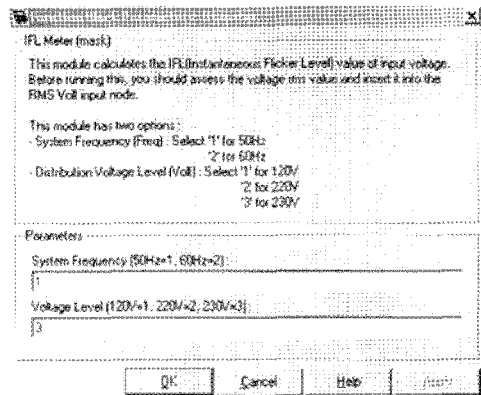
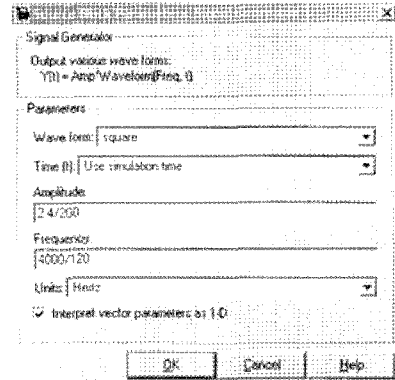
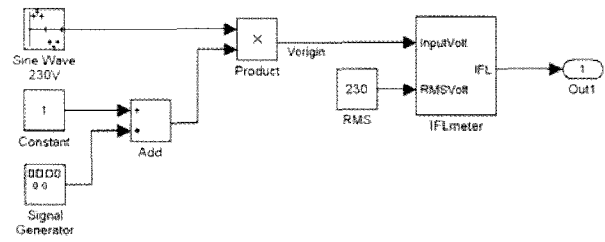


Fig. 8. Simulink implementation of performance test (top) and the components' settings (middle and bottom)

Table 1. Resultant P_{st} values for the reasonable inputs

		120V Lamp 60Hz system		230V Lamp 50Hz System	
Rectangular changes per minute	Hz	Voltage change (%)	P_{st}	Voltage change (%)	P_{st}
39	0.325	1.044	0.953	0.906	0.952
110	0.917	0.841	1.033	0.725	1.024
1620	13.5	0.547	1.038	0.402	0.999
4000	33.33	-	-	2.40	1.042
4800	40	4.834	1.038	-	-

4.2 Simulation of Flicker Transfer Coefficient

Another main standard on flicker, IEC 61000-3-7, deals with how to assess the flicker emission limits generated by the fluctuating load installations. Specially, when calculating

transfer coefficient, also known as influence coefficient, the Simulink modules addressed in this paper would be very useful.

IEC defines the transfer coefficient as the relative level of disturbance transferred between two parts of a power system for various operating conditions [10].

According to the assessment guideline in [10], the flicker transfer coefficient between two points A and B is computed as the ratio of P_{st} values which are measured simultaneously in both places, in case that a flicker source is located at location A.

$$T_{PstAB} = \frac{P_{st}(B)}{P_{st}(A)} \tag{4}$$

Figure 9 presents the simplified test system diagram and system implementation for Simulink simulation. As a result of simulation, $P_{st}(A)$, $P_{st}(B)$ and $P_{st}(C)$ are 2.052, 1.966, and 1.935, respectively. Finally, the transfer coefficients between A and B and A and C, are $T_{PstAB} = 0.958$ and $T_{PstAC} = 0.943$. This proves that the influence of flicker decreases

as it propagates from upstream to downstream and Load C is stronger than Load B to suffer the flicker disturbance.

This experimental process is actually very cumbersome and difficult because the real flicker generator at the considered location should be placed and the P_{st} values should be measured in some places simultaneously. So, this is the most contributive merit of the developed modules.

5. Conclusion

In this paper, the EAF module with the chaotic Chua’s circuit and IFLmeter module, which is used to ultimately calculate the P_{st} value cooperating with Matlab, are introduced and their effectiveness and usefulness are presented.

Particularly, both can be used to adopt the IEC Std. 61000-3-7 when the emission limits should be set under the various system conditions.

This project is the cornerstone of the standardization of international specification, IEC Standard, related to emission limits.

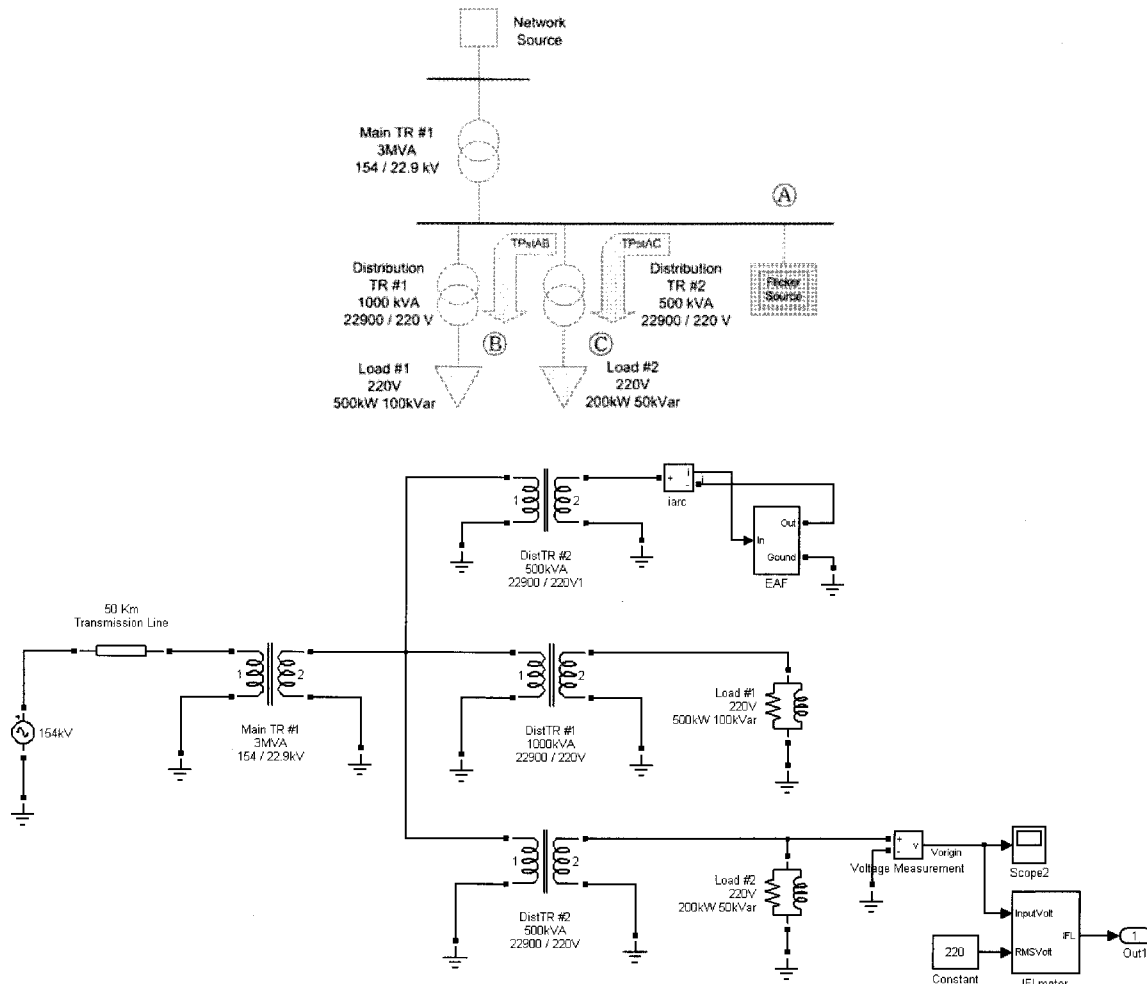


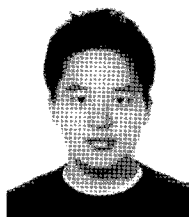
Fig. 9. Simplified diagram of test system (top) and the corresponding Simulink diagram (bottom)

Acknowledgements

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Soo-Hwan Cho

He received his B.S degree from the Dep. of Electrical Engineering, Korea University in 2002. He is currently pursuing his Ph.D. in the Dept. of Electrical Engineering, Korea University. His research interests are power quality

analysis and power signal processing.



Jae-Ahn Jung

He received B.S degree from the Dep. of Electrical Engineering, Korea University in 2007. Now he is pursuing M.S degree in the Dep. of Electrical Engineering, Korea University. His research interest is power quality

analysis.



Gilsoo Jang

He received his M.S and Ph.D. degrees from the Dept. of Electrical Engineering, Korea University in 1994 and Iowa State University in 1997, respectively. Currently, he is a Professor in the Dept. of Electrical Engineering at Korea University. His

research interests are power quality and power system control.



Sae-Hyuk Kwon

He received his M.S. and Ph.D. degrees from the Dept. of Engineering Education, Seoul National University in 1976 and ECE, Iowa State University in 1984, respectively. Currently, he is a Professor in the Dept. of Electrical Engineering at

Korea University. His research interests are power quality and power system stability.



Moon-Ho Kang

He received his M.S. degree from Ulsan University, Korea. Currently, he is working at the Korea Electric Power Research Institute of the Korea Electric Power Corporation. His research interests are the power quality analysis

in distribution systems and its simulation.