86 KIEE International Transactions on EMECS, Vol. 4-B No. 2, pp. 86~91, 2004

A Novel Simple Method to Abstract the Entire Parameters of the Solar Cell

Minwon Park* and In-Keun Yu**

Abstract - PV power generation, which directly converts solar radiation into electricity, contains numerous significant advantages. It is inexhaustible and pollution-free, silent, contains no rotating parts, and has size-independent electricity conversion efficiency. The positive environmental effect of photovoltaics is that it replaces the more polluting methods of electricity generation or that it provides electricity where none was available before. This paper highlights a novel simple method to abstract the entire parameters of the solar cell. In development, design and operation of PV power generation systems, a technique for constructing V-I curves under different levels of solar irradiance and cell temperature conditions using basic characteristic values of the PV module is required. Everyone who has performed manual acquisition and analysis of solar cell I versus V data would agree that the job is tedious and time-consuming. A better alternative is to use an automated curve tracer to print out the I versus V curves and compute the four major parameters; V_{oc}, I_{sc}, FF, and η. Generally, the V-I curve tracer indicates only the commonly used solar cell parameters. However, with the conventional V-I curve tracer it is almost impossible to abstract the more detailed parameters of the solar cell; A, R_s, and R_{sh}, which satisfies the user, who aims at the analysis of the development of the PV power generation system, that being advanced simulation. In this paper, the proposed method provides us with satisfactory results to enable us to abstract the detailed parameters of the solar cell; A, R_s, and R_{sh}.

Keywords: Photovoltaics, PV power generation system, Solar cell, V-I tracer

1. Introduction

As the cost of PV generation systems continues to decrease, utility interactive systems are becoming more economically viable. Furthermore, increases in consumer awareness correspond to a willingness to pay a premium price for clean electrical energy generated using renewable energy resources. Renewable energy technologies, consequently, are playing an increasingly important role in supplying the world's electricity demands. PV generation systems in particular are undergoing a rapid expansion-showing an industrial growth of approximately 40% per year worldwide. As PV cell and systems technology improve, new markets become increasingly accessible. This has resulted in a heightened demand for the simulation scheme and operational technologies of utility interactive PV devices and systems. The simulation schemes that can be applied to the utility interactive PV generation systems readily and cheaply under various conditions considering the type of solar cell, the capacity of systems and the converter system are strongly expected and emphasized among researchers.

In this paper, the novel simple method to abstract the entire parameters of the solar cell is introduced. In the development, design and operation of PV power generation systems, a technique for constructing V-I curves under different levels of solar irradiance and cell temperature conditions using basic characteristic values of the PV module is required. Everyone who has performed manual acquisition and analysis of solar cell I versus V data would agree that the job is tedious and time-consuming. A better alternative is to use an automated curve tracer to print out the I versus V curves and compute the four major parameters; V_{oc}, I_{sc}, FF, and η . Generally, the V-I curve tracer indicates only the commonly used solar cell parameters. However, with the conventional V-I curve tracer it is almost impossible to abstract the more detailed parameters of the solar cell; A, R_s, and R_{sh}, which satisfies the user, who aims at the analysis of the development of the PV power generation system, that being advanced simulation. In this paper, the proposed method gives us the satisfactory results to abstract the detailed parameters of solar cell; A, R_s, and R_{sh}.

2. The Solar Cell Equation and the V-I Trancer

This Equation 1 [1-2] expresses the characteristics of the

---

* Center for Applied Superconductivity Center, Korea Electrotechnology Research Institute, Korea. (paku@keri.re.kr)
** Dept. of Electrical Engineering, Changwon National University, Korea. (yuik@sarim.changwon.ac.kr)

Received February 5, 2004 ; Accepted May 3, 2004

solar cell including parasitic resistances. Equation 2 shows the saturation current of Eq. 1. From an engineering standpoint, it is extremely attractive that the entire parameters of Eq. 1 and Eq. 2 be obtained. So far the method to abstract the limited parameters is to use the commercialized V-I curve tracer.

$$I = I_{sc} - I_{os}\left\{\exp\left[\frac{q\cdot(V + I\cdot R_s)}{n\cdot k\cdot T}\right] - 1\right\} - \frac{V + I\cdot R_s}{R_{sh}} \tag{1}$$

$$I_{os} = AT^{\gamma}\exp\left(\frac{-E_g}{n\cdot k\cdot T}\right) \tag{2}$$

Generally, the commercialized conventional V-I curve tracer indicates only the limited solar cell parameters as depicted in Table 1. And, as shown in Fig. 1, A, B, C and D are displayed by the commercialized V-I curve tracer with weather conditions. Anyone who has performed manual acquisition and analysis of solar cell I versus V data would agree that the job is tedious and time-consuming. A superior alternative is to use an automated curve tracer to print out the *I* versus *V* curves and compute the four major parameters; V_{oc}, I_{sc}, FF, and η . However, with only the conventional V-I curve tracer it is impossible to abstract the more detailed parameters of solar cell; A, R_s, and R_{sh}. Therefore, it hardly satisfies the user, who aims at the analysis of the developed PV power generation system [3-6] and requests more detailed parameters.

Table 1 Limited solar cell parameters from the commercialized conventional V-I curve tracer

Parameter	Symbol	Definition	Units
Open-circuit voltage	V_{oc}	Cell voltage at 0 current	V
Short-circuit current	I_{sc}	Cell current with 0 Volts	A
Voltage at max. power point	V_{mp}	Voltage when VI is at a maximum	V
Current at max. power point	I_{mp}	Current when VI is at a maximum	A
Fill factor	FF	$FF=V_{mp}*I_{mp}/V_{oc}*I_{sc}$	
Light power in	P_{IN}	Light power at surface of cell	kW/m^2
Light power to power conversion efficiency	η	$\eta=(V_{mp}*I_{mp}/P_{IN})*100\%$	%
Maximum power	P_{max}	Maximum power produced by cell at a particular P_{IN}	W

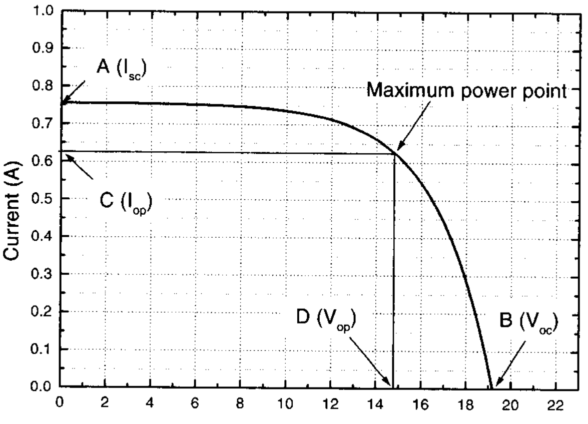


Fig. 1 Basic parameters of solar module on V-I characteristics curve

3. Novel Simple Method to Abstract the Parameters of a Solar Cell

Table 2 depicts the comparison of the conventional V-I tracer and the one proposed. The decisive purpose of the proposed V-I tracer is to abstract every kind of parameter of the solar cell equation as described in Eq. 1 and Fig. 2, and to actualize the two-way communication between user and solar cell. In the conventional V-I tracer, users can be notified as to the approximate values of key parameters, but with those it is impossible to describe the detailed V-I characteristics equation. However, the proposed V-I tracer helps users to build an equation that is more essential and much more hand-friendly.

Table 2 Comparison of the conventional V-I tracer with the Proposed V-I tracer

Comparison	Conventional V-I tracer	Proposed V-I tracer
Abstracted parameters	V_{oc}, I_{sc}, V_{mp}, I_{mp}, FF, Irradiance, Cell temperature	V_{oc}, I_{sc}, V_{mp}, I_{mp}, FF, Irradiance, Cell temperature, At 1.0kW/m2 and 25℃ (V_{oc}, I_{sc}, V_{mp}, I_{mp}), A, R_s, R_{sh}
GUI	One-sided communication	Two-way communication
Hardware & program	Fixed and one body type	Flexible and separated type

3.1 Hardware Composition

The proposed simple method to abstract V-I characteristics parameters is composed of sensors for weather condition, OP amp, electric load, CT for current, PT for voltage, A/D converter, and a personal computer (PC). Fig. 2 shows the schematic diagram of hardware composition.

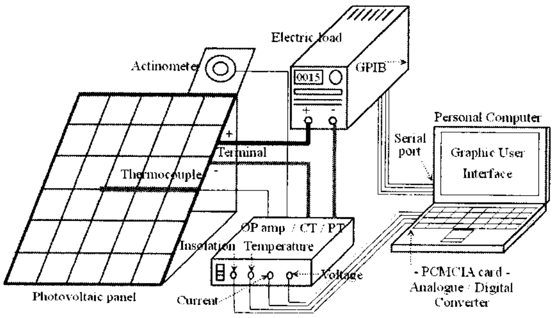


Fig. 2 Hardware composition of the proposed simple method to abstract V-I characteristics parameters

The OP amp box adjusts the output voltage level (0 mV~10 mV) of the actinometer [7] and thermocouple to the proper voltage level for A/D converter (± 5 Volts). Electric load works as the variable resistor connected to the output terminal of the PV module, and is automatically controlled by the graphic user interface program installed in the PC. The output current of the PV module is transferred to a voltage level via CT and the output voltage of the PV module is divided into a proper voltage level for the A/D converter. Fig. 3 displays the operation process of the proposed simple method used to abstract the parameters of V-I characteristics, and the electric load is controlled by the VI tracer program via GPIB. The output of the PV module and weather conditions are interfaced to the V-I tracer program via the A/D converter.

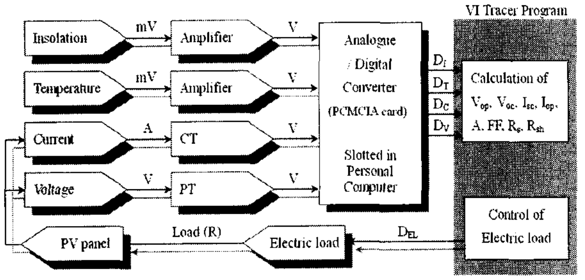


Fig. 3 The operation process between V-I tracer program and solar module with weather conditions

3.2 Software Composition

A GUI (Graphic User Interface) is installed to help users. Fig. 4 shows the conceptual diagram of the GUI installed. There are four input data; D_I, D_T, D_C, D_V, and one output data; D_{EL}. As soon as the program starts, I_{sc} is settled. Then, the program proceeds to the next step to decide V_{oc}. After determining the detailed parameters; A, R_s, R_{sh}, the program finally gives users all of the abstracted parameters; V_{oc}, I_{sc}, V_{mp}, I_{mp}, FF, irradiance, temperature at 1.0kW/m^2 and 25℃(V_{oc}, I_{sc}, V_{mp}, I_{mp}), A, R_s, and R_{sh}.

Fig. 5 illustrates the flowchart to decide I_{sc} on the first step of the program. If users click the first step of the program to decide I_{sc}, the electric load is quickly dropped down to 0 Ω . Then, the output current of the PV module becomes the short-circuit current of the irradiance level at that time. As the next step, as shown in the box (Calculation of I_{sc}) in Fig. 5, the short-circuit current of 1.0kW/m^2 of irradiance is finally obtained. Fig. 6 indicates the flowchart to decide V_{oc} on the second step of the program. If users click the second step button of the program to decide V_{oc}, the electric load is in a moment jumped up to ∞ Ω .

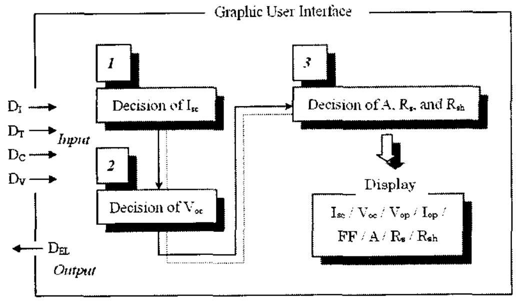


Fig. 4 Conceptual diagram of the GUI(Graphic User Interface)

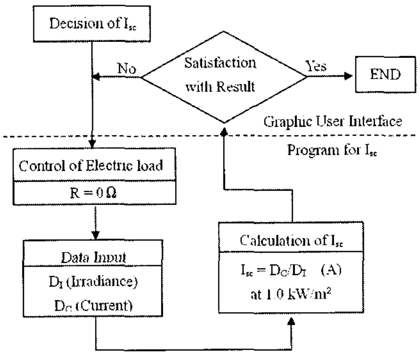


Fig. 5 The flowchart to decide I_{sc} on the 1st step of the program

The output voltage of the PV module becomes the open-circuit voltage of the irradiance and cell temperature level at that time. According to the irradiance level *Voc* is slightly changed. As shown in the box (1st Calculation of V_{oc}) in Fig. 6, the open-circuit voltage of 1.0kW/m^2 of irradiance and cell temperature at that time is obtained. As the next step, as shown in the box (2nd - Calculation of V_{oc}) in Fig. 6, the open-circuit voltage of 1.0kW/m^2 of irradiance and 25℃ of cell temperature is obtained.

The significant merit of the proposed V-I tracer is that users can simply obtain further parameters of the solar cell as described in Table 2. Fig. 7 shows the flowchart of the third step to decide the detailed parameters of the V-I characteristics equation. The explanation in Fig. 7 is as follows;

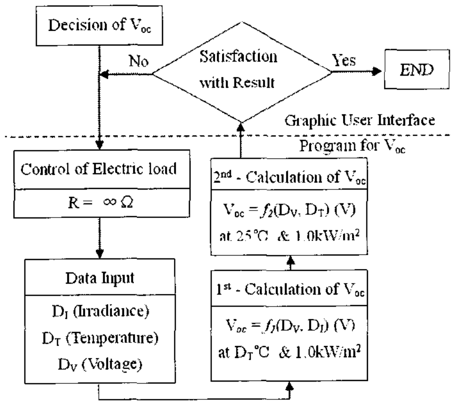


Fig. 6 The flowchart to decide V_{oc} on the 2nd step of the program

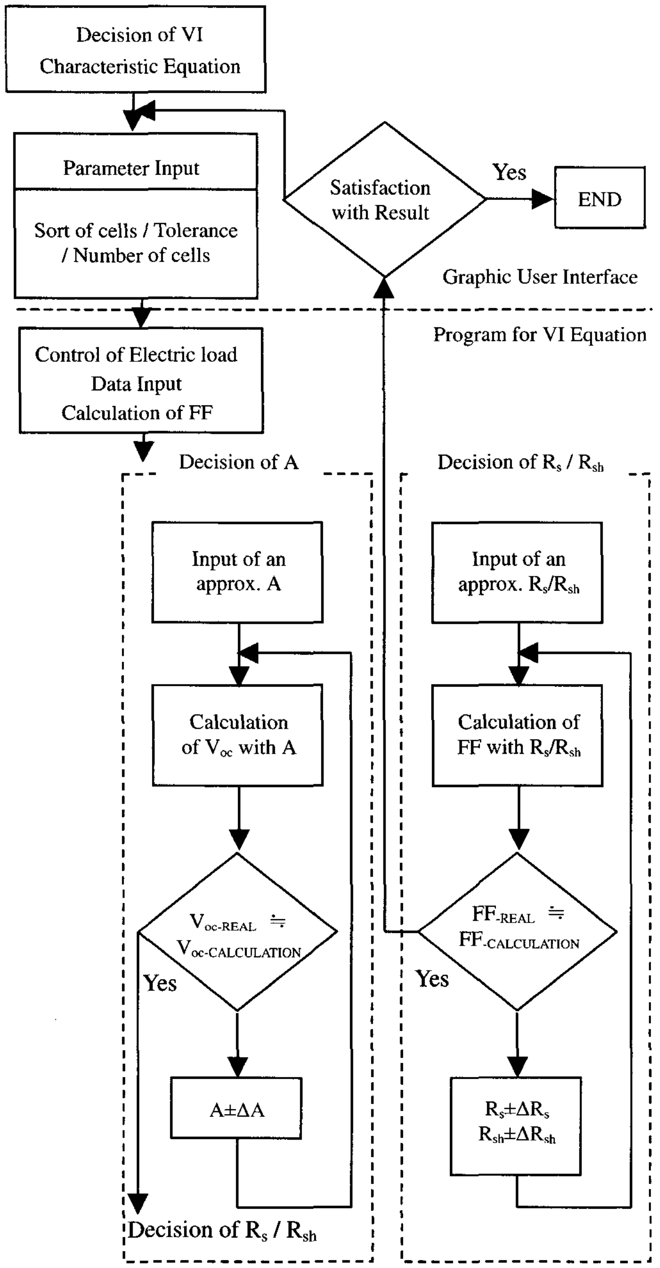


Fig. 7 Flowchart of the 3rd step to decide the detailed parameters of the V-I characteristics equation

1) Cell type; the program asks users to answer which types of solar cell; Si, Ge, GaAs, and so on, are connected.

2) Electric load; the program lets the electric load change the resistance level from ∞ Ω to 0 Ω .

3) Data input; from among ∞ Ω to 0 Ω , the output current and voltage of the PV module, irradiance and cell temperature level are interfaced into the PC via the A/D converter.

4) Fill factor; as shown in the box (Calculation FF) in Fig. 7, fill factor is calculated

5) Parameter A; $V_{oc\text{-}CALCULATION}$ is calculated with the approximate A, and compared with $V_{oc\text{-}REAL}$. Until users are satisfied with the error between $V_{oc\text{-}CALCULATION}$ and $V_{oc\text{-}REAL}$, parameters, A is slightly changed.

6) Parameters R_s and R_{sh}; $FF_{\text{-}CALCULATION}$ is first calculated with the approximate R_s and R_{sh}, and then it is compared with $FF_{\text{-}REAL}$. Until users are satisfied with how $FF_{\text{-}CALCULATION}$ and $FF_{\text{-}REAL}$ are fluently close to each other, parameters R_s and R_{sh} are slightly changed by turns.

Table 3 shows the detailed data values for the control of electric load, the data input and the equation to calculate FF.

Table 3 Detailed data values for calculation

Electric load	$R = \infty \sim 0\Omega$
Data input	D_I (Irradiance), D_T (Temperature), D_C (Current), D_V (Voltage)
Calculation of FF	$P_{EDGE} = D_C, (D_V = 0) * D_V, (D_C = 0)$ $P_{MAX} = P$, when $d(D_V * D_C)/d(D_V) = 0$ $FF = P_{MAX}/P_{EDGE} * 100\ \%$

4. The Comparison between the Proposed V-I Tracer and the Commercialized Conventional One

In order to confirm the ability of the proposed V-I tracer, the V-I characteristics curve of the tested PV array was drawn by the obtained parameters via the proposed V-I tracer. Fig. 8 depicts the comparison between the V-I curve obtained from the actual field testing and from using the parameters obtained from the proposed V-I tracer, and provides satisfactory results. As can be seen from those Fig.s, both the real field data and the simulated curve that were drawn with the parameters obtained by the proposed V-I curve tracer are corresponding well, so that the validity of the proposed method is confirmed. Many comparative studies for various conditions are performed and all results show the same configurations. [8-11]

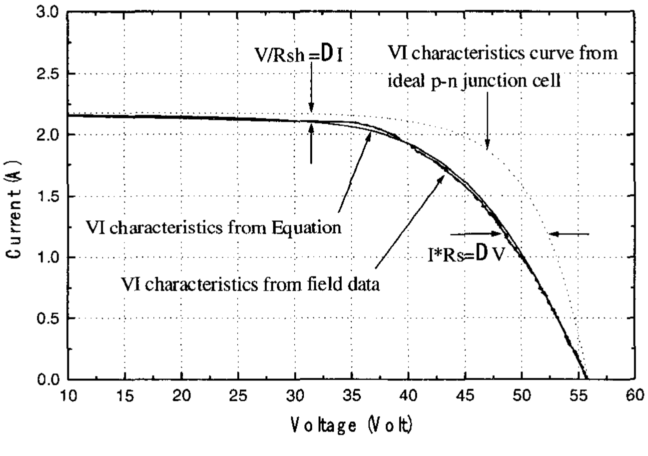


Fig. 8 Comparison between the V-I characteristics curve by the parameters obtained from the proposed V-I tracer and the V-I characteristics curve in the actual field

Fig. 9 illustrates the analyzed PV array (produced by SANYO) established on a building whose detailed parameters are obtained by the proposed V-I tracer. Table 4 describes the obtained specification of the PV array shown in Fig. 9, and Table 5 indicates the obtained parameters of a solar cell in the PV array revealed in Fig. 9. In addition, an additional PV array (produced by TOSHIBA) was established on another building. Table 6 and Table 7 describe the obtained specification of the other PV array and the obtained parameters, respectively.

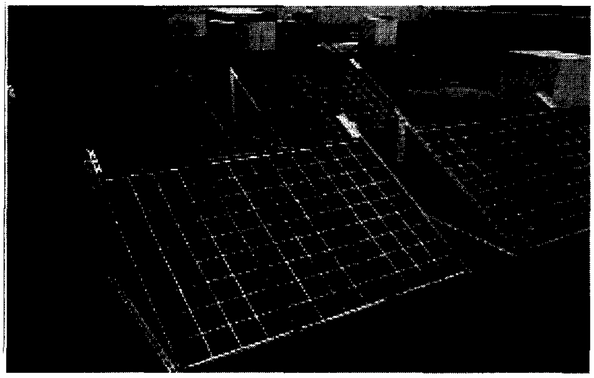


Fig. 9 The analyzed PV array established on a building

Table 4 The obtained specification of the analyzed PV shown in *Fig. 9*

A panel = 36 cells in series	$V_{oc\text{-}array}$	118Volt	$I_{sc\text{-}array}$	6A
Array = 6 panels in shunt and 2 panels in series	Fill Factor	62.9%	Rated power	445W
Total 432 cells	Multi-crystalline silicon		η	7.94%

Table 5 The obtained parameters of the analyzed PV shown in *Fig. 9*

n	1.5	γ	3
A	9e-2	E_g	1.103eV
R_s	0.028Ω	R_{sh}	1kΩ
V_{oc} at 25℃	0.58 Volt	I_{sc} at 1.0kW/m^2	3.0 A

Table 6 The obtained specifications of the other solar cell

A panel = 54 cells in series	$V_{oc\text{-}array}$	129.2Volt	$I_{sc\text{-}array}$	5.46A
Array = 4 panels in shunt	Fill Factor	70.8%	Rated Power	500W
Total 216 cells	Multi-crystalline silicon		η	13.3%

Table 7 The obtained parameters of the other solar cell

n	1.5	γ	3
A	0.143	E_g	1.103eV
R_s	0.0125Ω	R_{sh}	1kΩ
V_{oc} at 25℃	0.598 Volt	I_{sc} at 1.0kW/m^2	5.46 A

Nomenclature

I	Current flowing into load [A]
I_{sc}	Short-circuit current [A]
I_{os}	Saturation current [A]
s	Irradiation [kW/m^2]
q	Electron charge, 1.6e-19 [C]
k	Boltzman constant, 1.38e-23 [J/K]
T	PN junction temperature [º K], t [℃]
n	Junction constant
A	Temperature constant
γ	Temperature dependency exponent
Eg	Energy gap [eV]
V	Across voltage of solar cell [Volt]
V_{op}	Optimal voltage of solar cell
V_{oc}	Open-circuit voltage of solar cell
I_{op}	Optimal current of solar cell
V_{mp}	Voltage at maximum power point
I_{mp}	Current at maximum power point
FF	Fill factor
P_{IN}	Light power in [kW/m^2]
η	Light power to power conversion efficiency [%]
P_{max}	Maximum power
R_s	Series resistance of PV cell
R_{sh}	Parallel resistance of PV cell
D_I	Digital signal of irradiance
D_T	Digital signal of the surface temperature
D_C	Digital signal of the output current
D_V	Digital signal of the output voltage
D_{EL}	Digital control signal of electric load
$X_{\text{-REAL}}$	Real field value
$X_{\text{-CALCULATION}}$	Calculated value

Acknowledgements

This work has been supported in part by EESRI (02340-17), which is funded by MOCIE (Ministry of Commerce, Industry and Energy), and in part by KEMCO (Korea Energy Management Cooperation).

References

[1] Martin A. Green, "Solar Cells Operating Principles, Technology, and System Applications", 1982 by Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632

[2] Richard C. Neville, "Solar Energy Conversion: The Solar Cell", 1980 by Elsevier Scientific Publishing Company

[3] Monji G. Jaboori, Mohamed M. Saied, Adel A. R. Hanafy, "A Contribution to the Simulation and

Design Optimization of Photovoltaic Systems", IEEE Transactions on Energy Conversion, Vol. 6, No. 3, pp.401-406, September 1991

[4] Bogdan S. Borowy, Ziyad M. Salameh, "Methodology for Optimally Sizing the Combination of a Battery Bank and PV Array in a Wind/PV Hybrid System", IEEE Transactions on Energy Conversion, Vol. 11, No. 2, pp.367-373, June 1996

[5] M. Muselli, G. Notton, P. Poggi, A. Louche, "PV-hybrid power systems sizing incorporrating battery storage: an analysis via simulation calculations", Renewable Energy 20 (2000) 1-7

[6] Kame Khouzam, Keith Hoffman, "Real-Time Simulation of Photovoltaic Modules", Solar Energy Vol. 56, No. 6, pp.521-526, 1996

[7] [MS-601, 601F Manual] EKO Co.

[8] Minwon Park, In-Keun Yu, A Novel Real-Time Simulation Technique of Photovoltaic Geeration System Using RTDS, IEEE Transactions of Energy Conversion, Vol. 19, No. 1, pp.164-169, March 2004

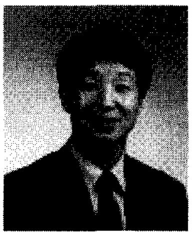
[9] Minwon Park, Kenji Matsuura, Hiroshi Yamashita, Masakazu Michihira, A Novel Simulation Method for PV Power Generation System using Real Field Weather Condition and its Application, T.IEE Japan-B, Vol. 121-B, No.11, 2001 pp.1499-1506

[10] Minwon Park, Bong-Tae Kim, In-Kuen Yu, "A Novel simulation Scheme for Grid Connected Photovoltaic Generation Systems" KIEE International Transactions on EMECS, Vol. 11B-4, 169-174 (2001)

[11] Minwon Park, Nak-Gueon Seong, In-Kuen Yu, "A Novel Photovoltaic Power Generation System including the Function of Shunt Active Filter" KIEE International Transactions on EMECS, Vol. 3B-2, 103-110 (2003)

Minwon Park

He received a Bachelor's Degree in Electrical Engineering from Changwon National University in 1997 and a Master's Degree and Ph.D in Electrical Engineering from Osaka University in 2000 and 2002, respectively. He is presently working at the Center for Applied Superconductivity Technology. His research mainly deals with the dispersed generation system and the control theory of it. And, he is also interested in the development of the simulation model of power conversion equipment and renewable energy source using EMTP type simulators.



In-Keun Yu

He received his B.S. degree in Electrical Engineering from Dongguk University in 1981 and his M.S. and Ph.D. degrees in Electrical Engineering from Hanyang University in 1983 and 1986, respectively. Currently, he is a Full Professor at Changwon National University. From 1996 to 1998, he was a Visiting Scholar at Brunel University, Middlesex, UK. His interests include wavelet transform applications, electric energy storage and control systems, peak load management & energy saving systems, PSCAD/EMTDC and RTDS simulation studies, and renewable energy sources.