Probabilistic Production Cost Simulation and Reliability Evaluation of Power System Including Renewable Generators

Jintaek Lim, *Student member, IEEE*, Jinhwan Jang, Jaeseok Choi, *Senior Member, IEEE*, Kyeonghee Cho, and Junmin Cha *Member, IEEE*

***Abstract*--Renewable energy resources such as wind, wave, solar, micro hydro, tidal and biomass among others are becoming more important because of increasingly restricted environmental constraints. In order to evaluate the credits of economics and reliability of renewable generators, probabilistic reliability and production cost simulation methodology are very important. This paper presents a method suited for the purpose and presents details of a reliability evaluation study on a power system with wind turbine generators. Test results indicate the viability of the method.**

***Index Terms*-- Wind turbine generator, solar cell generator, reliability, production cost simulation, CO_2**

I. Introduction

THE utilization of renewable resources has been receiving considerable attention in recent years [1],[2]. This is due to the fact that these non-conventional energy units are environmental friendly and use sustainable energy. Wind energy and solar radiation in particular have been fast growing and is recognized as the most successful energy source of all available sources. As a result of available high capacities of wind turbine and solar cell generators, the generation costs are becoming competitive. A challenging task relates to their modeling. In order to evaluate the credits of economics and reliability of renewable energy generators, probabilistic reliability and production cost simulation methodology are important. The reliability and economics contributed impact of the renewable generators may be described as credit. The two-state model for reliability evaluation, however, is not suitable for modeling wind turbine generators(WTGs) and solar cell generators(SCGs) because wind speed and solar radiation do not maintain a specified stable level. As a result, more complicated model is necessary and a multi-state model should be used[3].

This work was supported by the Korea National Research Foundation (K-NRF) grant funded by the Korea government (MEST) (No. #2012R1A2A2A01012803) and the MKE.

Jintaek Lim, Jinhwan Jang and Jaeseok Choi are with Dept. of Electrical Engineering, ERI, Gyeongsang National University, Jinju, GN, Korea (e-mail: jtlim@gnu.ac.kr, jhjang1@gnu.ac.kr, jschoi@jnu.ac.kr).

Keonghee Cho is with KERI, Chanwon, GN, South Korea.(e-mail: kx1004xh@keri.re.kr)

Junmin Cha is with Dept. of Electrical Engineering, Daejin University, Pochun, GG, Korea (e-mail: chamin@daejin.ac.kr).

This paper proposes a method for reliability evaluation of power system including WTGs and SCGs. The use of convolution integral in order to construct the Effective Load Duration Curve (ELDC) considering the multi-state model of the WTG and SCG for probabilistic reliability evaluation and production simulation is presented in the paper. It is possible not only to evaluate of reliability of power system but also to calculate CO_2 reduced by WTGs and SCGs using the proposed method. The reliability and economic credits meaning the reliability and economics contributed impacts of the renewable generators are described in this paper.

Results from the case study indicate the usefulness of the method for reliability evaluation on power systems with WTGs and SCGs.

II. Power Output Model and Outage Capacity Table Of WTG and SCG

A. Power-Wind speed Model of WTG

The theoretical power generated by a WTG is expressed as (1).

$$P = \frac{1}{2} C_p \rho V^3 A \tag{1}$$

where,

P: power [W]

C_p: power coefficient

ρ: air density (1.225 kg/m^3)

V: wind velocity (m/sec)

A: swept area of rotor disc (m^2)

Fig. 1 presents the typical relationship between the power output of a WTG and wind speed [2]-[5].

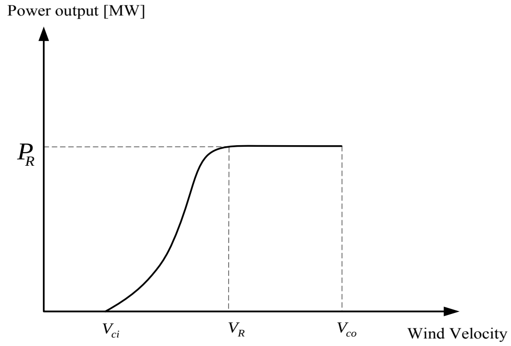

Fig. 1. Power output model of wind turbine generator

where ,
V_{ci}: the cut-in speed [m/sec].
V_R: the rated speed [m/sec].
V_{co}: the cut-out speed [m/sec].
P_R: the rated power [MW].

B. Outage Capacity pdf of WTG

The operation state model of the WTG is necessary for reliability evaluation of power system including the WTG. The epistemic uncertainty of the WTG's operation model results mainly from uncertainties associated with the supply of the wind speed rather than the forced outage uncertainty (aleatory) of the generator unlike the case with the convention generators [5]. Wind speed model is presented usually as Weibull *pdf*.

The outage capacity probability density function(*pdf*) of the WTG can be obtained by combining the WTG's power output model and the wind speed *pdf* model as shown in Fig. 2. This yields a multi-state model because the wind speed is distributed widely. The probabilities of identical power are cumulated. Therefore, the state number is different from the wind speed band number. In this paper, the reliability indices for systems including WTGs are evaluated using the multi-state model for the WTGs and the two-state model for the conventional generators.

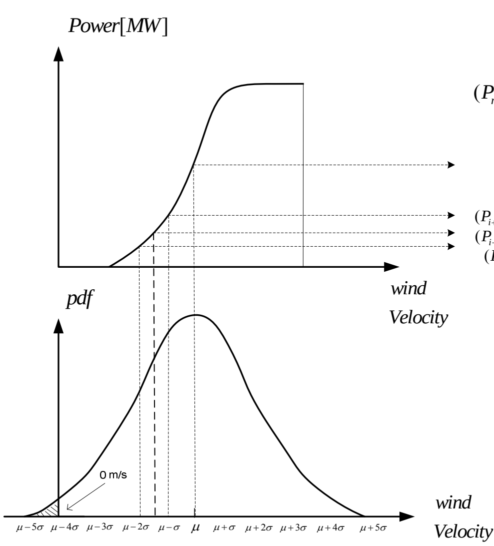

Fig. 2. Outage capacity *pdf* from the wind speed model combined the WTG power output model

C. Power-SR Model of SCG

Equation (1) is the general mathematical expression for the power curve of SCG [16]-[18]. The generated power $P_{bi}(G_{bi})$ corresponding to a given solar radiation G_{bi} for band i (i=1,…, N_b) can be obtained using (2) with N_b being the total number of bands.

$$\begin{aligned} P_{bi}(G_{bi}) &= P_{sn}(G_{bi}^2/(G_{std}R_c)),\ \ 0 \le G_{bi} < R_c \\ &= P_{sn}(G_{bi}/G_{std}),\ \ R_c < G_{bi} \le G_{std} \\ &= P_{sn},\ G_{bi} > G_{std} \end{aligned} \tag{2}$$

where,
P_{bi}: Solar radiation-to-energy conversion function for solar radiation band i of the SCG [MW]
G_{bi}: Forecasted solar radiation at band i [W/m^2]
G_{std} : Solar radiation in the standard environment set usually as 1,000 [W/m^2]
R_c: A certain radiation point set usually as 150 [W/m^2]
P_{sn}: Equivalent rated capacity of the SCG [MW]

Fig. 3 presents the typical relationship between the power output of a SCG and solar radiation(SR) [16-18].

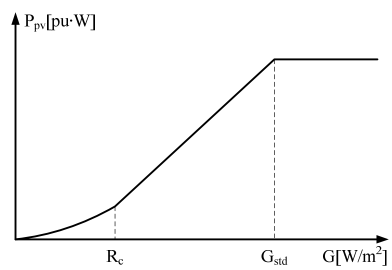

Fig. 3 Power model of the SCG

D. Outage Capacity pdf of SCG

The operation state model of the SCG is necessary for reliability evaluation of power system including the SCG as like as WTG.

The outage capacity *pdf* of the SCG can be obtained by combining the SCG's power output model and the solar radiation *pdf* model as shown in Fig. 4. This yields a multi-state model because the solar radiations are distributed widely. The probabilities of identical power are cumulated. The situation is occurred over G_{std} as shown in Fig. 4. Therefore, the state number is different from the solar radiation band number.

In this paper, the reliability indices for systems including SCG are evaluated using the multi-state model for the SCGs and the two-state model for the conventional generators.

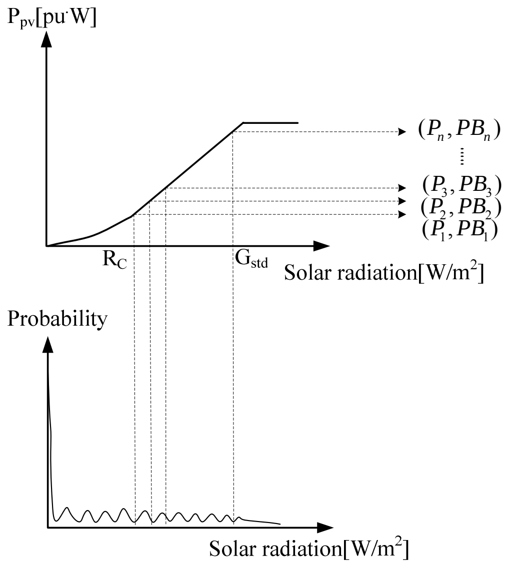

Fig. 4 Outage capacity *pdf* from the solar radiation model combined the SCG power output model

E. Rounding Method of Outage Capacity pdf of WTG and SCG

The use of the original multi-state model in reliability evaluation, makes it difficult to perform practical studies as it is computationally expensive due to step size-related reasons [6]. A simplification of the model is therefore needed for reasonable computational requirements. In this paper, a simplification of the original multi-state model is proposed using linear rounding which shares the ratio of probability linearly. The rounding method is presented graphically in Fig. 5 and mathematically described by (3) and (4).

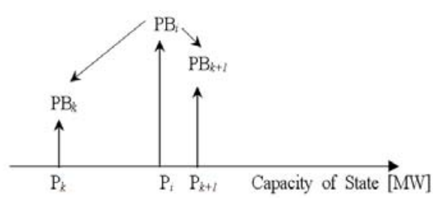

Fig. 5. Illustration of the proposed rounding method

$$PB_k = \left(\frac{P_{k+1} - P_i}{\Delta P}\right) \times PB_i \quad (3)$$

$$PB_{k+1} = \left(\frac{P_i - P_k}{\Delta P}\right) \times PB_i \quad (4)$$

where,
$\Delta P = P_{k+1} - P_k$ [MW]
k: State number of the simplified multi-state model
i: State number of the original multi-state model

III. Reliability Evaluation and Production Cost Simulation of Power Systems Including WTG and SCG

Probabilistic reliability indices have been used extensively for generation expansion planning. The indices can be calculated by using the Effective Load Duration Curve (ELDC referred to in the following as Φ), (5) as given in [6].

$$\begin{aligned}\Phi_i &= \Phi_{i-1} \otimes f_{oi} \\ &= (1 - \sum_{j=1}^{NS} q_{ij})\Phi_{i-1}(x) + \sum_{j=1}^{NS} q_{ij}\Phi_{i-1}(x - C_{ij})\end{aligned} \quad (5)$$

where,
$\otimes$: The convolution integral operator
Φ_0: Original inverted load duration curve (ILDC)
x: Random variable of Φ
NS: The total number of states
f_{oi}: The outage capacity *pdf* of generator *i*
q_{ij}: Forced outage rate (FOR) of generator *i* at state *j*
C_{ij}: Outage capacity of generator *i* at state *j*

The basic reliability evaluation indices, namely the Loss of Load Expectation (LOLE), the Expected Energy Not Supplied (EENS), the Energy Index of Reliability (EIR) and probabilistic production energy(E_i), production cost(PC_i), capacity factor(CF_i) and total CO_2 emissions, TCO_2, are described using the effective load duration curve, Φ(x) by (6)-(12).

$$\text{LOLE} = \Phi_{NG}(x)\big|_{x=IC} \quad \text{[hours/year]} \quad (6)$$

$$\text{EENS} = \int_{IC}^{IC+L_p} \Phi_{NG}(x)dx \quad \text{[MWh/year]} \quad (7)$$

$$\text{EIR} = 1 - \frac{\text{EENS}}{\text{ED}} \quad \text{[pu]} \quad (8)$$

$$\Delta \text{E}_i = \text{EENS}_{i-1} - \text{EENS}_i \quad (9)$$

$$\Delta \text{PC}_i = F_i(\Delta \text{E}_i, \text{LOLE}_{i-1}) \quad (10)$$

$$\text{CF}_i = (\Delta \text{E}_i / \text{CAP}_i / \text{T}) \times 100 \quad (11)$$

$$TCO_2 = \sum_{n=1}^{NT}\sum_{i=1}^{NG} \xi_i \Delta E_{in} \quad \text{[Ton/year]} \quad (12)$$

where,
L_p : Peak load [MW]
IC_i : Installed capacity of generator *i* [MW]
ED : Total demand energy [MWh]
NG : The total generator number
Φ_{NG} : The final effective load duration curve
ξ_i : CO_2 emission coefficient of the *i*-th unit [Ton/MWh]

IV. Flow Charts

The step-by-step process for reliability evaluation of power systems including WTGs and SCG are shown in Fig. 6 and Fig.7 respectively.

A. Flow Chart for WTG

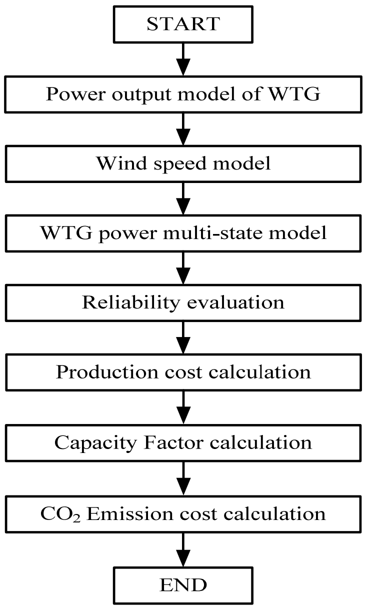

Fig. 6. A flow chart describing the proposed method

B. Flow Chart for SCG

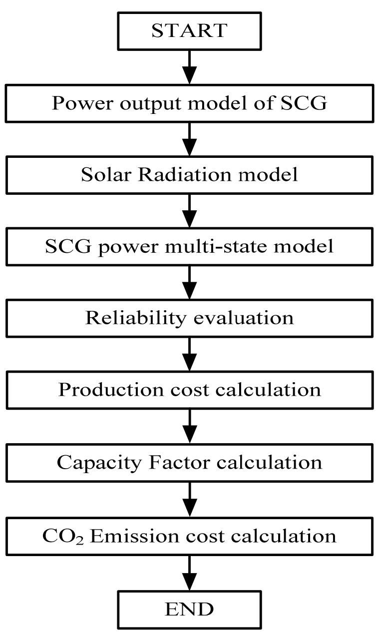

Fig. 7 The flow chart of the proposed method

V. Case Studies

A. Case Study I- WTG

The Jeju Island power system in Korea as shown in Fig. 8 is used to demonstrate the usefulness of the proposed method. In Jeju Island, three wind farms(WF) are constructed at three different locations where are Halim (JCN), Sungsan (SSN) and Hangwon (HWN).

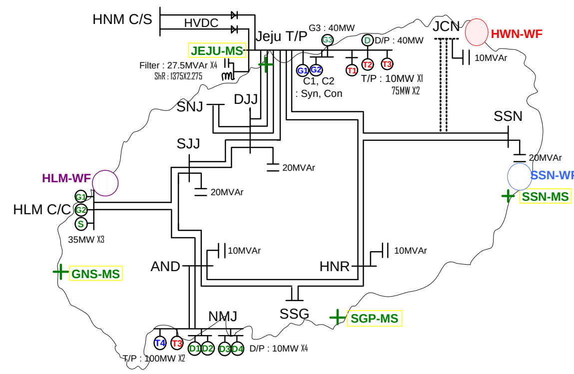

Fig. 8 Jeju power system in Korea

TABLE I
The Generators Data of Jeju Island Power System

	Name	Type	Capacity [MW]	Num.	α [Gcal/ MW^2h]	β [Gcal/ MWh]	γ [Gcal /hr]	Fuel cost [$/Gcal]	CO_2 emission [Ton/MWh]	FOR
1	HWN	WTG	50	1	-	-	-	-	-	-
2	SSN	WTG	30	1	-	-	-	-	-	-
3	HLM	WTG	20	1	-	-	-	-	-	-
4*	HVDC	DC	75/ 150*	2	0.004	1.512	45.207	43.300	0.65	0.010/ 0.028*
5	NMJ3	T/P	100	2	0.004	1.512	45.207	43.300	0.65	0.012
6	JJU1	T/P	10	1	0.062	2.100	5.971	43.599	0.96	0.015
7	JJU2	T/P	75	2	0.003	1.832	30.231	43.599	0.70	0.012
8	HLM1	G/T	35	2	0.004	2.401	20.320	77.909	0.95	0.013
9	HLM1	S/T	35	1	0.004	2.401	20.320	77.909	0.95	0.013
10	JJU3	D/P	40	1	0.025	0.364	28.484	43.599	0.59	0.018
11	NMJ1	D/P	10	4	0.006	1.999	1.360	43.300	0.62	0.018
	Total		945	18	-	-	-	-	-	

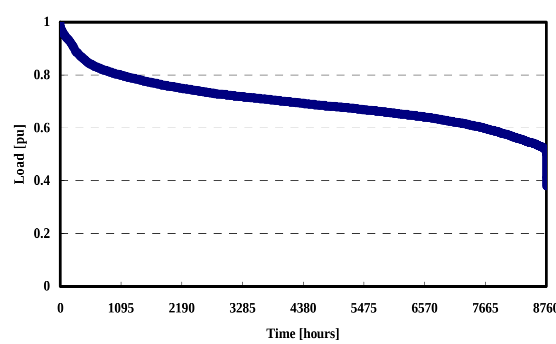

Fig. 9 Pattern of hourly peak load variation curve in the case

The data of Jeju island power system and actual CO_2 emission data in 2008 year were used as input data as shown in Table I. The system load duration curve in 2008 year of Jeju Island was used as shown in Fig. 9 and the peak load is 681MW. The data related to the three wind farms are given in Table II. Table III shows the results of case studies to compare with reliability indices, production cost and CO_2 emission of power system after adding WTG. It is assumed that CO_2 emission cost is 24$/Ton referred EU emission trading market price[7]. The total reduced cost, not only production cost but also environment cost, is 30.16M$/year by adding WTG. Table IV and V show the production energy, capacity factor, production cost and CO_2 emission of each generator in detail.

TABLE Ⅱ
THE DATA OF EACH WF

WF Name	HLM-WF	SSN-WF	HWN-WF
WTG capacity	20MW	30MW	50MW
Cut-in speed(V_{ci})	5m/sec	5m/sec	5m/sec
Rated speed(V_R)	14m/sec	15m/sec	16m/sec
Cut-out speed(V_{co})	25m/sec	25m/sec	25m/sec
Wind speed range	0~35	0~40	0~45
Mean wind speed	6.4	7.6	8.5
Standard deviation	9	10	11

TABLE Ⅲ
RESULTS OF CASE STUDIES

	without WTG	with WTG	difference
SRR [%]	24.08	38.77	14.69
EENS [MWh/year]	83.92	44.52	39.4
LOLE [hours/year]	2.25	1.26	0.99
Total production cost [M$/year]	426.91	400.75	26.16
Total CO_2 Emission [10^3Ton/year]	**2,727.88**	**2,561.31**	**166.57**
Total CO_2 Emission Cost [M$/Ton]	65.47	61.47	4

TABLE Ⅳ
PRODUCTION ENERGY AND CAPACITY FACTOR OF EACH GENERATORS

Num. of Gen.	Without WTG		With WTG	
	Production energy [GWh/year]	Capacity factor [%]	Production energy [GWh/year]	Capacity factor [%]
1	-	-	133.97	30.59
2	-	-	73.52	27.98
3	-	-	38.87	22.19
4	2,541.20	96.70	2,540.80	96.68
5	1,424.80	81.33	1,245.40	71.08
6	29.41	33.57	20.32	23.20
7	161.77	12.31	108.05	8.22
8	7.26	1.18	4.47	0.73
9	1.17	0.38	0.70	0.23
10	0.60	0.17	0.30	0.09
11	0.16	0.05	0.09	0.03
Total	4,530.93		4,530.98	

TABLE Ⅴ
PRODUCTION COST AND CO_2 EMISSION OF EACH GENERATORS

Num. of Gen.	Without WTG		With WTG	
	Production cost [M$/year]	CO_2 Emission [10^3TON/year]	Production cost [M$/year]	CO_2 Emission [10^3TON/year]
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	265.38	1,651.79	265.28	1,651.54
5	139.39	926.15	120.71	809.48
6	4.20	28.23	2.90	19.51
7	15.95	113.24	10.65	75.64
8	1.66	6.90	1.02	4.25
9	0.27	1.11	0.16	0.66
10	0.04	0.35	0.02	0.18
11	0.02	0.10	0.01	0.05
Total	469.27	2,984.94	441.38	2,813.23

B. *Case Study II- SCG*

The second case study of SCG, the Jeju Island power system in Korea as shown in Fig. 8 is used to demonstrate the usefulness of the proposed method. In stead of three wind farms, three solar farms(SF) are assumed at three different locations where are Halim (HLM), Sungsan (SSN) and Hangwon (HWN). The data related to the three solar farms are given in Table VI. Fig. 10 shows probabilistic distribution function of solar radiation used for the three solar farms.

Table VII shows the results of case studies to compare with reliability indices, production cost and capacity factor of power system after adding SCG. Fig. 11 shows the variation of CF and peak SR of SCG weekly. Fig. 12 shows the variation of CF and mean SR of SCG weekly. Fig. 13 shows the Capacity Credit of SCG.

TABLE VI
THE DATA OF EACH SF
(*: Please see Eq.(2) and Fig.3)

SF Name	HLM-SF	SSN-SF	HWN-SF
SCG capacity	20MW	30MW	50MW
Gstd*	1,000W/m2	1,000W/m2	1,000W/m2
Rc*	150W/m2	150W/m2	150W/m2

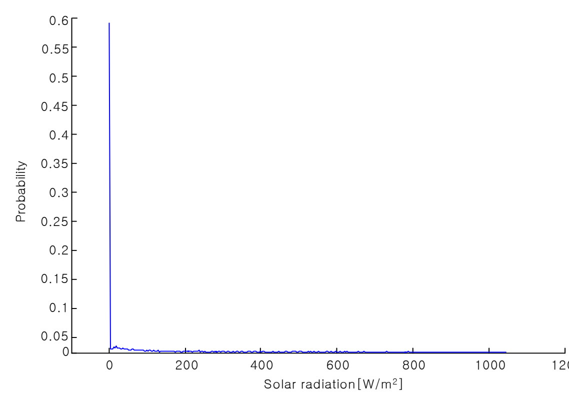

Fig. 10 Probabilistic distribution function of solar radiation at Jeju (1998~ 2007)

TABLE VII
PRODUCTION ENERGY AND CAPACITY FACTOR OF EACH GENERATORS

Num. of Gen.	Without WTG		With WTG	
	Production energy [GWh/year]	Capacity factor [%]	Production energy [GWh/year]	Capacity factor [%]
1	-	-	63.731	14.55
2	-	-	38.238	14.55
3	-	-	25.492	14.55
4	2541.2	96.7	2541.2	96.7
5	1424.8	81.33	1335.5	76.23
6	29.411	33.57	24.267	27.7
7	161.77	12.31	131.02	9.97
8	7.2602	1.18	5.6183	0.92

9	1.1725	0.38	0.89939	0.29
10	0.59742	0.17	0.41471	0.12
11	0.16235	0.05	0.11576	0.03
Total				

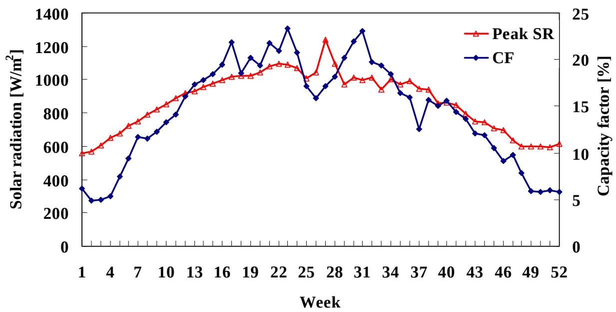

Fig. 11 The variation of CF and peak SR of SCG weekly

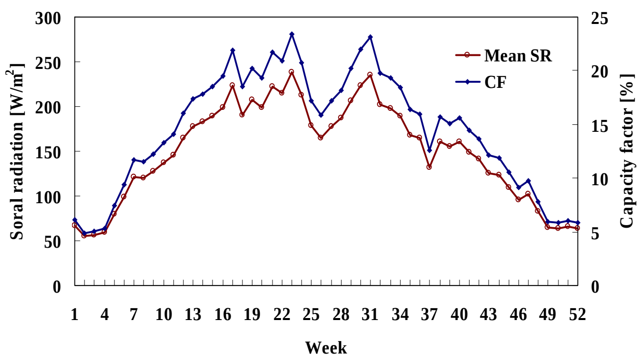

Fig. 12 **The variation of CF and mean SR of SCG weekly**

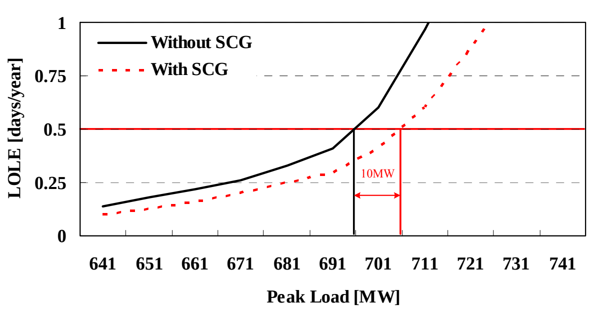

Fig. 13 **CAPACITY CREDIT OF SCG**

The capacity credit of the SCG is evaluated as following.

$$Capacity\ Credit = \frac{\Delta L}{C_A} \times 100 = \frac{695 - 705}{100} \times 100 = 10 \ [\%]$$

VI. CONCLUSIONS

This paper reports on a reliability evaluation study on a power system containing WTG and SCG. This paper is focused on the development of a methodology and simulation tools for evaluating the contribution of WTGs and SCGs to the reliability and economic efficiency of power systems under the Markov assumption, that the transition rate between any two states is independent of prior history. The contributions of this paper may be summarized as follows.

- It shows how to the outage capacity *pdf* can be constructed using the multi-state models of WTG by combining the wind speed *pdf* model and the WTG power output model and also SCG by combining the Solar radiation *pdf* model and the SCG power output model. The multi-state models express the wind speed variance and solar radiation more accurately than the two-state model.
- It proposes a simplified multi-state model using rounding method for more efficient computation.
- It utilizes the ELDC (Effective Load Duration Curve) method using convolution integral for reliability evaluation to handle the multi-state model.
- The proposed approach can be assist in determining a quantitative contribution of WTG and SCG to power systems reliability and economic efficiency. It provides a useful tool for WTG and SCG planning and operation analysis.

The one of important reasons that renewable energy has been receiving considerable attention is to reduce environmental pollution as alternative energy. Especially, it contributes to reduce emission of CO_2 and it is useful to calculate the reduction of CO_2 by adding WTG and SCG. The various results can be obtained using proposed approach in this paper such as capacity factor, production cost and CO_2 emission of each generator in detail. It is expected that proposed method can evaluate the various effects on power system by adding WTG and SCG. And it can be helpful to install WTG and SCG to power system successfully. It will be extended to a model coordinated with energy storage system(ESS) in future.

VII. ACKNOWLEDGMENT

This work was supported by the Korea National Foundation (NRF) grant funded by the Korea government (MEST) (No. #2012R1A2A2A01012803). The support of the MKE (Ministry of Knowledge and Economics) is also acknowledged.

VIII. REFERENCES

[1] "Wind Power Today", Federal Wind Program Highlights, U.S. Department of Energy, Energy Efficiency and Renewable Energy, April, 2005.

[2] Nick Jenkins, Ron Allan, Peter Crossley, David Kirschen and Goran Strbac: EMBEDDED GENERATION, IEE, 2000.

[3] Rajesh Karki, Po Hu, Roy Billinton, "A Simplified Wind Power Generation Model for Reliability Evaluation," IEEE Transactions on Energy Conversion, Vol. 21, No. 2, June 2006.

[4] C. Singh, Lago-Gonzalez, "Reliability Modeling of Generation Systems Including Unconventional Energy Sources," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104, No.5, May 1985.

[5] Billinton, R., Gan, L, "Wind Power Modeling and Application in Generating Adequacy Assessment," Proceedings, the 14th Power Systems Computation Conference, Sevilla, Spain, June 24-28, 2000

[6] Boy Billinton, Wenyuan Li, "Reliability Assessment of Electric Power Systems Using Monte Carlo Methods," 1994, pp. 24-30.

[7] http://www.pointcarbon.com/

[8] P. Giorsetto and K. F. Utsurogi, "Development of a newprocedure for reliability modeling of wind turbine generators," IEEE Trans. Power App. and Systems, vol. PAS-102, no. 1, 1983.

[9] X. Wang, H. T. Dai, and R. J. Thomas, "Reliability modeling of large wind farms and associated electric utility interface systems," IEEE Trans. Power App. and Systems, vol. PAS-103, no. 3, 1984.

[10] R. Billinton and A. A. Chowdhury, "Incorporation of wind energy conversion systems in conventional generating capacity adequacy assessment," IEE Proceedings-C, vol. 139, no. 1, pp. 47–55, 1992.

[11] R. Billinton, H. Chen, and R. Ghajar, "A sequential simulation technique for adequacy evaluation of generating systems including wind energy," in IEEE/PES 1996 Winter Meeting, Baltimore, MD, January 21–25, 1996, no. 96 WM 044-8 EC.

[12] Fujio Tatsuta, Toshiyuki Tsuji, Nobuharu Emi and Shoji Nishikata, "Studies on Wind Turbine Generator System using a Shaft Generator system", Journal of Electrical Engineering & Technology, Vol. 1, No. 2, pp. 177-184, 2006

[13] E. S. Gavanidou, A. G. Bakirtzis, and P. S. Dokopoulos, "A probabilistic method for the evaluation of the performance and the reliability of winddiesel energy systems,", IEEE paper no. 92 SM 526-6 EC, 1992.

[14] Cornel Ensslin, Michael Milligan, Hannele Holttinen, Mark O'Malley, and Andrew Keane, " Current Methods to Calculate Capacity Credit of Wind Power, IEA Collaboration " IEEE GM2008, Pittsburg, PA, USA.

[15] Claudine D''Annunzio, Surya Santoso, "Analysis of a Wind Farm''s Capacity Value using a Non-iterative Method", IEEE GM2008, Pittsburg, PA, USA.

[16] M. K. C. Marwali, H. Ma, S. M. Shahidehpour, and K. H. Abdul-Rahman, "Short-term generation scheduling in photovoltaic-utility grid with battery storage" *IEEE Trans. Power Syst.*, vol.13, no.3, Aug. 1998, pp.1057–1062.

[17] Ruey-Hsun Liang, and Jian-Hao Liao, "A Fuzzy-Optimization Approach for Generation Scheduling With Wind and Solar Energy Systems" *IEEE Trans. Power Syst.*, vol.22, no.4, Nov. 2007 , pp.1665-1674.

[18] Jeongje Park, Wu Liang, Jaeseok Choi, A. A. El-Keib, Mohammad Shahidehpour and Roy Billinton, "Probabilistic Reliability Evaluation of Power System Including Solar/Photovoltaic Cell Generator" IEEE PES GM2009, July 26-30, 2009, Calgary, AB, Canada.

[19] Roy Billinton and Dange Huang, "Aleatory and Epistemic Uncertainty Considerations in Power System Reliability Evaluation" *Proceedings on PMAPS2008*, Pueto Rico, May 25-29, 2008.

[20] Michaelides, J.M. and Votsis, P.P., "Energy analysis and solar energy development in Cyprus", *Computing & Control Engineering Journal*, Volume 2, Issue 5, Sept. 1991, pp.211 - 215.

[21] Cham Yew Thean, Jia Junbo and Au Wing Kong; "An Embedded Microchip System Design for Programmable Solar Panel Simulator", *Power Electronics and Drives Systems*, 2005. PEDS 2005. International Conference on, Volume 2, 28-01 Nov. 2005, pp.1606 - 1610.

[22] Mukund R. Patel: *Wind and Solar Power Systems*, CRC press, 1999, pp.125-145.

IX. Biographies

Jintaek Lim was born in Samcheonpo, Korea in 1985. He received the B.Sc degrees from Gyeongsang National University, Jinju, in 2011. His research interest includes Reliability evaluation of power systems, Web based online real-time reliability information system of power system. He is now working forward a M,Sc degree at Gyeongsang National University.

Jinhwan Jang was born in Jinju, Korea in 1988. His research interest includes Transmission Expansion Planning using Reliability Evaluation of Power Systems. He will receive the B.Sc. degree from Gyeonsang National University, Jinju, in 2013.

Jaeseok Choi (S'88–M'91–SM'05) was born in Kyeongju, Korea, in 1958. He received the B.Sc., M.Sc., and Ph.D. degrees from Korea University, Seoul, in 1981, 1984, and 1990, respectively. He was a Postdoctoral at the University of Saskatchewan, Saskatoon, SK, Canada, in 1996. He was a visiting professor at Cornell University, Ithaca, NY, USA, in 2004. Since 1991, he has been on the faculty of Gyeongsang National University, Jinju, Korea, where he is a professor. He is also adjunct professor at IIT, IL, USA since 2007. His research interests include fuzzy applications, probabilistic production cost simulation, reliability evaluation, and outage cost assessment of power systems.

Kyeonghee Cho was born in Jinhae, Korea in 1987. She received the B.Sc. and M.Sc. degrees from Gyeongsang National University, Jinju, in 2010 and 2012, respectively.. Her research interest includes reliability evaluation of power systems considering renewable energy. She jointed with KERI in 2012.

Junmin Cha (M96) was born at Inchon, Korea on 1964. He obtained B.Sc., M.Sc. and Ph.D. degrees from Korea University in 1989, 1991 and 1996 respectively. His research interest includes Fuzzy Applications, Probabilistic Production Cost Simulation, Reliability Evaluation, Outage Cost Assessment of Power Systems and Operation and Planning of Deregulated Power Market. Since 1996, he has been a faculty of Daejin University, where is now a professor.