[논문] 태양에너지
Solar Energy
Vol. 11, No. 1, 1991

자연에너지 복합 이용시스템에 대한 다목적 평가

배 상 현 · 이 재 연*
조선대학교 자연과학대학
조선대학교 대학원*

Multi-Objective Evaluation for Hybrid Use of Natural Energy in Power System

Sang Hyun Bae · Jae Youn Lee*

College of natural Sciences, Chosun University
Graduate school, Chosun University*

요 약

에너지 소비 구조의 개선을 목적으로 한 자연에너지 이용시스템의 도입이 전력 계통의 계획·운용에 미치는 영향을 다목적 최적화 방법을 이용하여 평가하는 방법이 논하여 지고 있다. 본 연구에서는 시험 제작한 태양 열과 풍력 에너지를 주체로하는 자연에너지 복합 이용시스템이 특정 지역에 복수 도입되어 지는 경우 전력 통계 운용에 의한 경제성, 안정성, 환경에 대한 영향 평가 방법을 검토하였다. 연구 방법은 대상 지역의 일사 분포와 풍속 분포에 의해서 취득 가능한 에너지를 산정하여 전력 계통 부하의 형상에 미치는 영향을 구하였고, 다음에는 대상 기간에 의한 최적 발전 배분을 결정하여 경제성, 안정성, 환경 지표 등의 평가를 하였다.

지금까지는 자연에너지 이용시스템의 도입에 대하여 경제적 측면만 논의되었지만, 본 연구에서 제한된 방법에 의해 안정성과 환경 보전의 영향을 고려한 평가 방법도 가능하다는 것을 나타내었다.

ABSTRACT

Research and development works on practical application of natural energy utilization systems involving solar, wind and sea wave energies are under promoting for the purpose of improving the energy consumption structure. These natural energies, made available with the use of relatively simple apparatus, are clean economically efficient and highly effective in the conservation of environment. However, these natural energies also have low energy density, randomness and regional variations. To compensate for these

characteristics, hybrid utilization of solar and wind energies is currently under study.

The introduction of a plural number of the natural energy hybrid utilization systems into a specific area will affect the economic efficiency, reliability and environmental conservation. Evaluation method of such effects has been examined in this study.

The present method consisted of the steps described below. First, available energy was calculated from insolation distribution and wind velocity distribution in the specified area, and then the effect on the configuration of the power system load was obtatined. This was followed by the determination of the optimal power dispatch over the specified period and by evaluations in light of economic efficiency, reliability and environmental indices.

Introduction of the Effect of Natural Energy Hybrid Utilization System

Research and development works on the practical applications of natural energies, such as the solar, wind and sea wave energies, are being undertaken for the purpose of improving the energy consumption structure. These natural energies are available with the use of comparatively simple apparatus, and in addition to being clean, and it is assumed that they are low energy cost and effective in the conservation of the environment. Natural energies, however are characterized by low energy density, randomness and regional variations.[1-4] In order to take advantage of such characteristics, utilization thereof as energy sources matching regional variations under small and medium scale decentralized systems, instead of under large scale centralized system is taken as follow. Also, the random input energies of solar and wind energies will be stable by applying the hybrid utilization. These natural energy hybrid utilization systems, being of small–capacity and medium–capacity, subject to little restrictions by the regional conditions, feasible to dispersed positioning with in the power system and having the storage functions, contribute to the leveling off of load curves, giving rise to expectations for various benefits in the system operation.

In the present study, the economic efficiency, reliability and the environmental effect evaluation method for the power system operation for the case of introduction into a specific area a plural number of the natural energy hybrid utilization systems based on the used of solar heat and wind energy has been examined.

The system used for the study consisted of a trially type made under the grant in aid of the scientific research project of the Ministry of Education, Science and Culture and installed at the Faculty of Engineering, University of Hiroshima. The present method consists of the steps described below. Available energy was calculated from insolation distribution and wind velocity distribution in the specified area, and then the effect thereof on the configuration of the power system load was obtained.

This was followed by determination of the optimal power dispatch over the specified period and by evaluations in light of economic efficiency, reliability and environmental indices. Ultimately, overall evaluation with the inclusion of the cost of the hybrid utilization system has been attempted.

Evaluation of the Effect of Planning and Operation of Natural Energy Utilization on Power System

The natural energy utilization systems are likely to be utilized for the immediate future as auxiliary power sources for business-use and home-use air conditioners or as heat sources and are expected to contribute to reduction of daytime peak load and leveling off of load curves. Futhermore since the equipment themselves are of small-capacity and medium-capacity and are subject to little restrictions by the conditions of location, they are anticipated to be introduced into the power systems in various areas. When plural numbers of such natural energy utilization systems of certain capacities are to be introduced into the power system, of a specific area, the effects of such introduction is important from the riewpoint of power system planning and operation in the area will become necessary.

Existing methods of analyzing the effects on the planning and operation of power generating equipment include those cited below.[5)]

1) The method of calculating the economic effect from the fixed and variable costs needed and the output obtained during the specified period.

2) The method based on the successive simulation of operation.

3) The method of calculating the effect on the basis of load duration curve modification.

Research efforts have thus been directed principally of economic evaluations. The natural energy utilization systems, however, are clearly inferior to conventional power sources in economic efficiency, because it is required for gathering up low-density energy, and this fact is impeding introduction thereof into the power systems.

Utilization of low-pollutant natural energy, however, contributes markedly to the conservation of environment and offers the benefit of upgrading the power system reliability and security through reduction of peak load. When, therefore, the natural energy utilization system becomes a power system component factor and is incorporated into the power system planning and operation, it becomes necessary to assure quantitative grasp not only of its economic utility but also of its effect on the reliability, security and environment and also to clarify the trade-off relationship among them.

In the evaluation of reliability and economic efficiency, energy generating probabilities like insolation and win velocity distributions, load variations and probability of generator outages should be bring into focused. The Method (3), which lends to easier handling of these matters, is, therefore, considered to be optimally suited to the purpose on hand. In this paper, the techniques for making comprehensive evaluation of the effects on the power system planning and operation will be discussed in light of multi-dimension indices, such as the economic efficiency, reliability, security and environmental conservation, based on the modification of the load duration curve resulting from the introduction of the natural energy utilization system.

Multicriteria Feature in Evaluation of Natural Energy Hybrid Utilization Systems

The general flow for evaluating the hybrid utilization system of solar heat and wind energy is shown Figure 1.

The evaluation procedure of impact on power system planning and operation can be devided into 12 steps as follows.

Step 1 Determination of amount for available energy and usable energy for the specified area.

Step 2 Selection of the insolation distribution and the wind velocity distribution which are obtained based on meteorological data for a period shown in Figure 2. Weibull distribution is often used for wind velocity distribution.[4,6)]

Step 3 Characteristic of solar collector and output characteristic of wind generator are

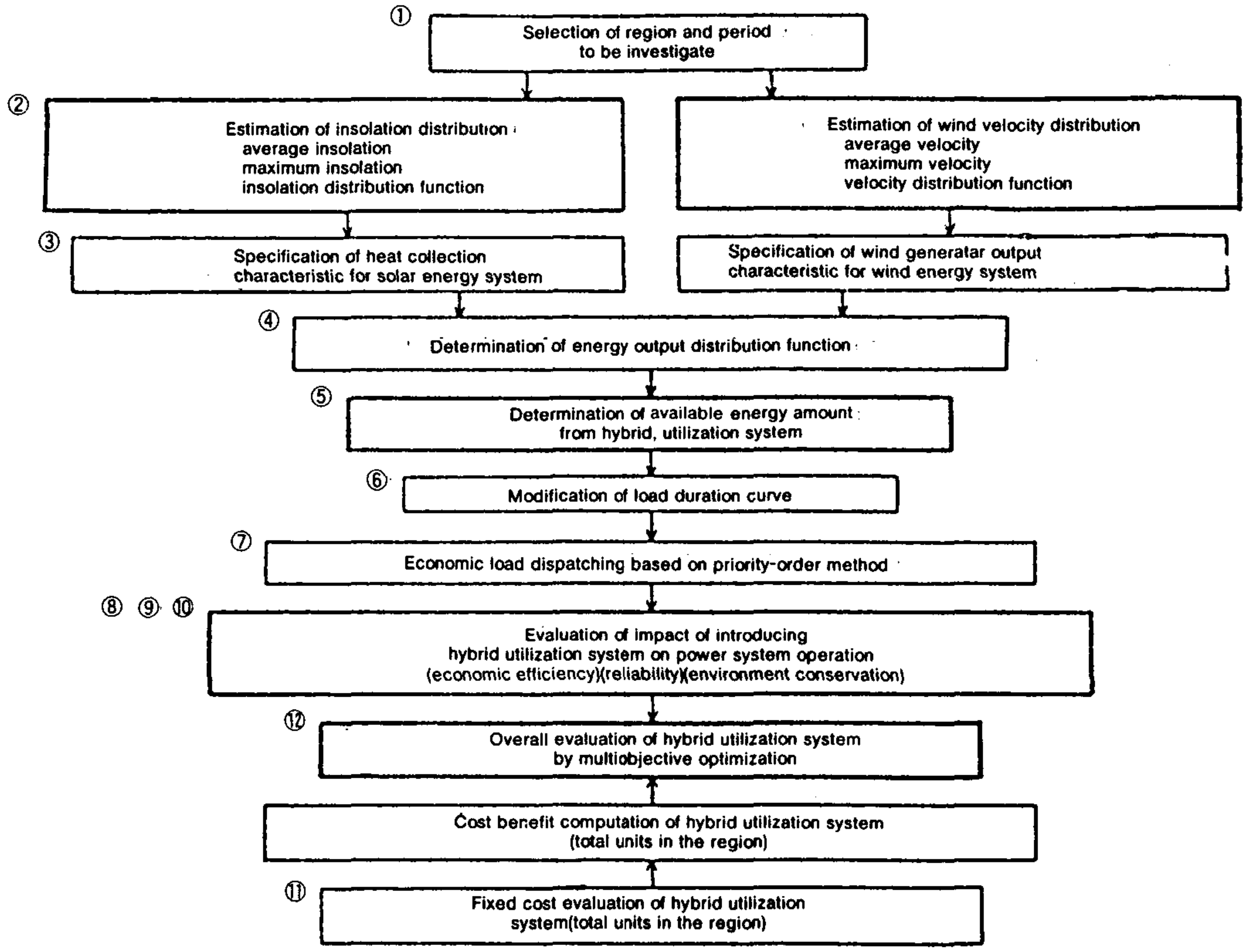

Fig. 1 General flow of procedure for evaluating hybrid utilization system.

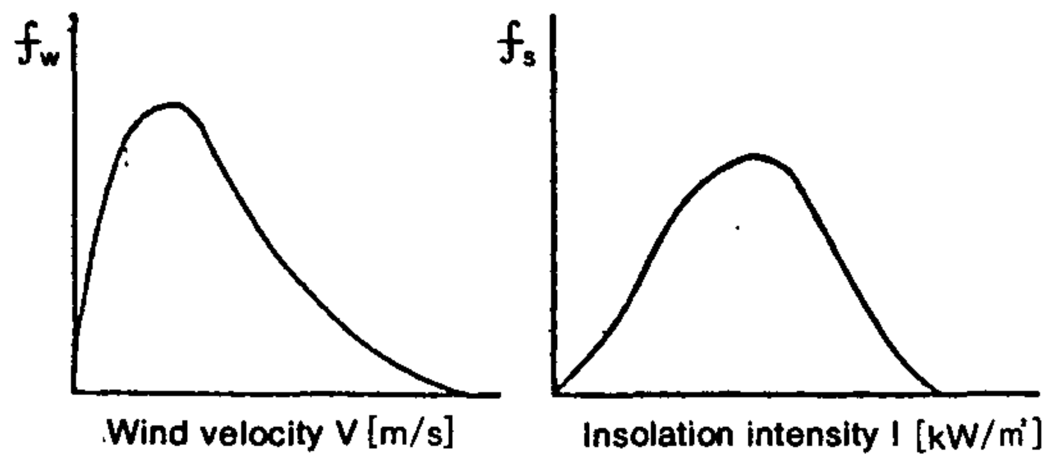

Fig. 2 Distribution of insolation and wind velocity

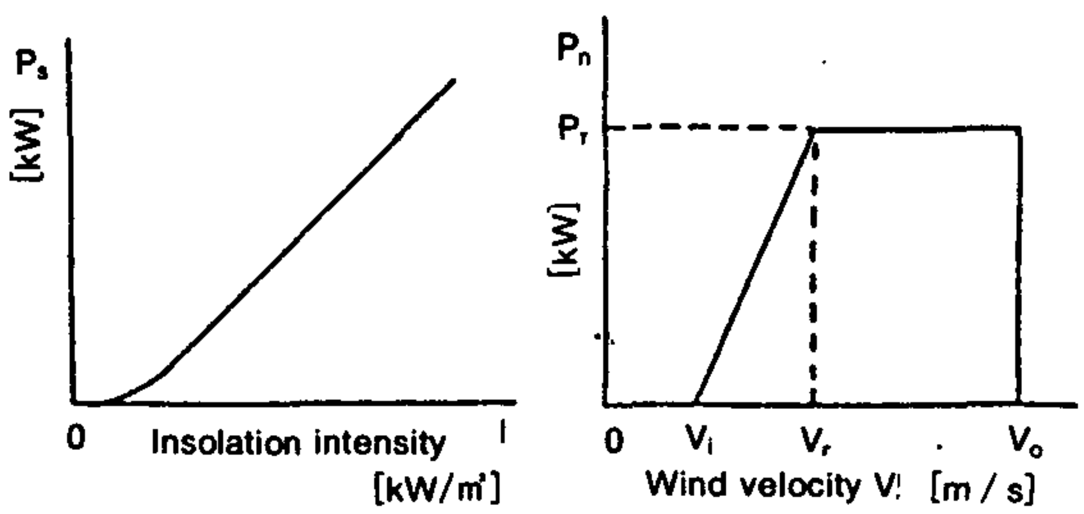

Fig. 3 Characteristic of heat collector and output characteristic of wind generator

assumed to be as shown in Figure 3. The collector characteristic is approximated by a linear function and the wind generator output characteristic can be represented by a trapezoid al function.

Step 4 Output characteristics of the solar heat collector and the wind generator are expressed by following distribution functions.(Figure 4)

$$g_s(P_s)=\frac{1}{a}f_s(\frac{P}{a}) \qquad (1)$$

$$g_w(p_w)=[\int_0^{V_i} f_w(V)dV+\int_{V_o}^{\infty} f_w(V)dV]\,\delta(o)+\frac{1}{F}f_w\,|\,\phi(P)\,|+[\int_{V_r}^{V_o} f_w(V)dV]\,\delta(P_r) \qquad (2)$$

where, $g_s(P)$:Output distribution function of heat collector

$g_w(P)$:Output distribution function of wind generator

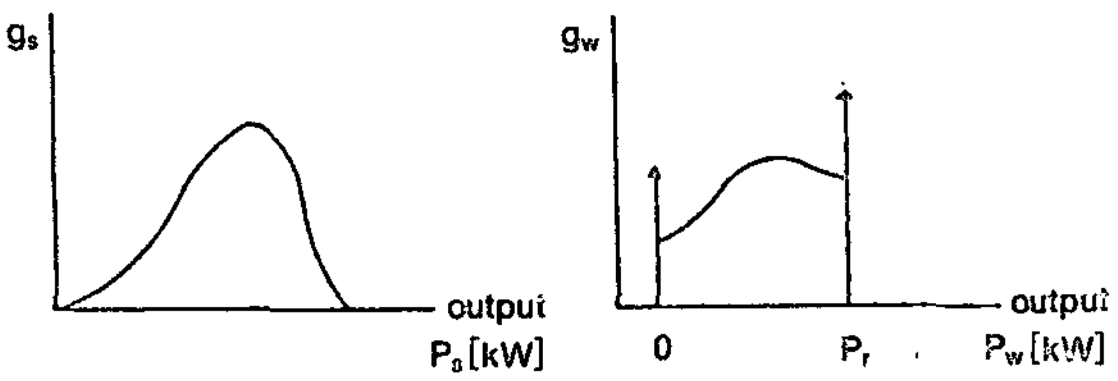

Fig. 4 Output distribution of heat collector and wind generator

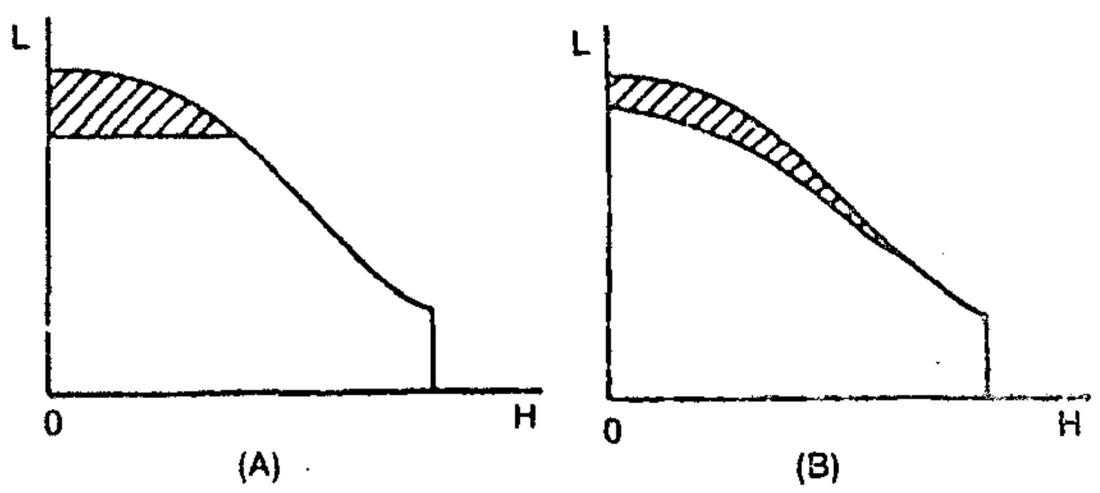

Fig. 5 Modification of load duration curve

$f_s(I)$:Distribution function of insolation
$f_w(V)$:Distribution function of wind velocity
V:Wind velocity
I:Insolation intensity

and

$$P_s = aI,\ P_w = d(V),\ F = \int_0^{\infty} f_w(V)dV$$

Step 5 Computation of available energy P_{st}, P_{wt} in the period of discussion based on the distribution functions and the output characteristics for the natural energies. By making total period H, available energy is denoted as follows.

$$P_{st} = [\int_0^{\infty} a\ f_s(I)dIH \quad (3)$$

$$P_{wt} = \int_{V_i}^{V_r} bVf_w(V)dVH + \int_{V_r}^{V_o} f_w(V)dVP_rH \quad (4)$$

where, $b = \frac{dP}{dV} (V_i \leqq V \leqq V_r)$

Step 6 Load shape in the region is given by a load duration curve. A part of the load can be supplied by the energy obtained from the hybrid utilization system. As shown in Figure 5, it brings modification of the load duration curve. Several kinds of modification can be applied depending on heat storage capacity of the system and availability of the natural energies.[7]

Step 7 Rest of the load supplied by hybrid utilization system is dispatched by thermal units which are equipped in the region. Output scheduling of the generators is determined on the basis of the conventional economic dispatching method. The priority order method is applied for determining the unit commitment first, and the optimal power flow approach is used for dispatching among generators as illustrated in Figure 6.

Step 8 **Economic evaluation:**For evaluating economy level of the system, total generation cost is assumed standard value. The total generation cost C_t of the load given by the duration curve is expressed by the next equation.

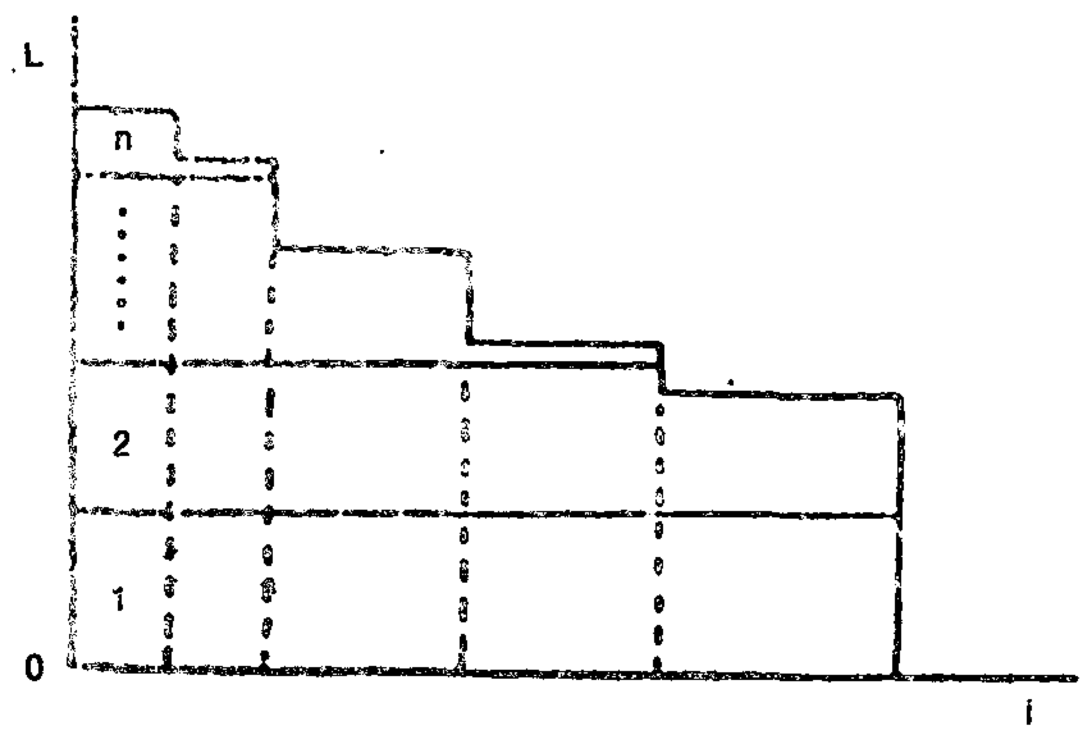

Fig. 6 Dispatching of thermal generating plants

$$C_t = \sum_i f_{cj}(L_i)H_i \quad (5)$$

where, j:number of operating generators
f_{cj}:generation cost function for unit j
L_i: amount of load in i-th period
H_i:hour of i-th period

By comparison of the total generation cost of power generation system with and without the hybrid utilization system, effect of introducing the system can be evaluated quantitatively.

Step 9 Reliability evaluation: Careful and deliverate evaluation for influence of introducing the natural energy utilization systems on power system reliability is needed. Usually, natural energies have greater randomness and uncertainty in it's availability comparing with the conventional generation units. Therefore, introduction of the natural energy utilization systems brings some extent of deterioration in reliability in the region. The loss of load probability(LOLP) is used here as a measure to evaluate the regional system reliability. The output distribution of the hybrid utilization system is given in Step 4. Probability of the regional system reliability is given by next equation.[5]

$$r = Prob(X \leq P) = \int_{0}^{P} h(X)dX \quad (6)$$

where, $h(X)$:Output distribution function of the hybrid utilization system.

The reliability expressed by equation (6) means probability which available power output by the hybrid utilization system is less than a certain value P.

Step 10 Environmental assessment: Total amount of NO_x emission from thermal units may be an appropriate measure to evaluate the environmental impact of the hybrid utilization system. Generally amount of NO_x emission is expressed by non–linear functions of the committed generators output. As sams as the economic evaluation total amount of NO_x emission can be obtained if load duration curve in the period under consideration is offered. Total amount of NO_x emission can be written as follows.[9]

$$E_{NOX} = \sum_{i} f_{cj}(P_{gj})H_i \quad (7)$$

where, E_{NO_x} Total amount of emission in the period

$f_{cj}(P)$:NO_x emission characteristic function

Step 11 Determination of fixed cost of the hybrid utilization system. Presently it is difficult to determine the fixed cost of the actual–scale hybrid utilization system. So it is estimated from the cost of an experimental system.

Step 12 Evaluation of introduction of the hybrid utilization system with various indices is done for the power system planning and operation.

Computational Algorithm for Multi–objective Optimization Problem

In this section, we shall formulate the optimization problems in power system planning and operation studies which have multiple non–commensurable objectives. In optimizing power flows, the three most important evaluation indices are taken into account here, i.e., economy, environment impact, and security.

Criterion for Economic Efficiency: The fuel cost of a thermal unit can be regarded as an essential criterion for economic feasibility. The fuel cost curve is assumed to be approximated by a quadratic function of generator active power output as

$$f_1 = \sum_{i=1}^{n} \alpha P_g^2 + \beta P_g + \gamma \text{ :Generator fuel costs}$$

Criterion for Environmental Conservation: Nitrogen–Oxide(NO_x) emission is taken as the index from the viewpoint of environment conservation. The amount of NO_x emission is given as a function of generator output, that is, the sum of a quadratic and exponential functions.[8]

$f_2 = \sum_{i=1}^{n} a + bP_g^2 + cP_g^2 + d\exp(eP_g)$: No_x emission quantity

Criterion for System Security: Overloading in a transmission line can lead to system collapse in an extreme case. Hence, we adopt, as the security index, a weighted sum of line flow deviations of all transmission lines. The line flow deviation of a transmission line implies the amount which exceeds its reference transmission capacity. Thus, security index is defined as.

$f_3 = \sum_{k=1}^{L} w_i F(P_1 - P_1^s)$: Total amount of violation of standards line flows

where, $F(X) = X\ (X > 0)$, $F(X) = 0\ (X \leq 0)$

These criteria are non–commensurable and even incompatible each other. No priority exists among the criteria for the power system operations, such as *economic efficiency, reliability* and environmental conservation.

Therefore, the evaluation should be treated as the multi–objective problem. The multi–objective optimization offers several trade–off solutions which have been compromised considering the non–commensurable criteria. Then by investigating the trade–off solutions, the effect of the hybrid utilization system not only on economical efficiency but also on reliability and environmental conservation can be evaluated.

In this analysis the concept of non–inferiority or indifference must be added to the concept of *maximums* and *minimums*. To be brief, some decision set will be non–inferior or indifferent if it is impossible to improve any of the objectives without degarding at least one of the other objectives as illustrated in Figure 7. A mathematical definition of the non–inferior solution is given in the next.[9]

The general multi–objective optimization problem is defined

$$\text{minimize } \{f_1(X), f_2(X), \ldots, f_n(X)\} \quad (8)$$

$$\text{s.t. } X_i \leq X \quad (9)$$

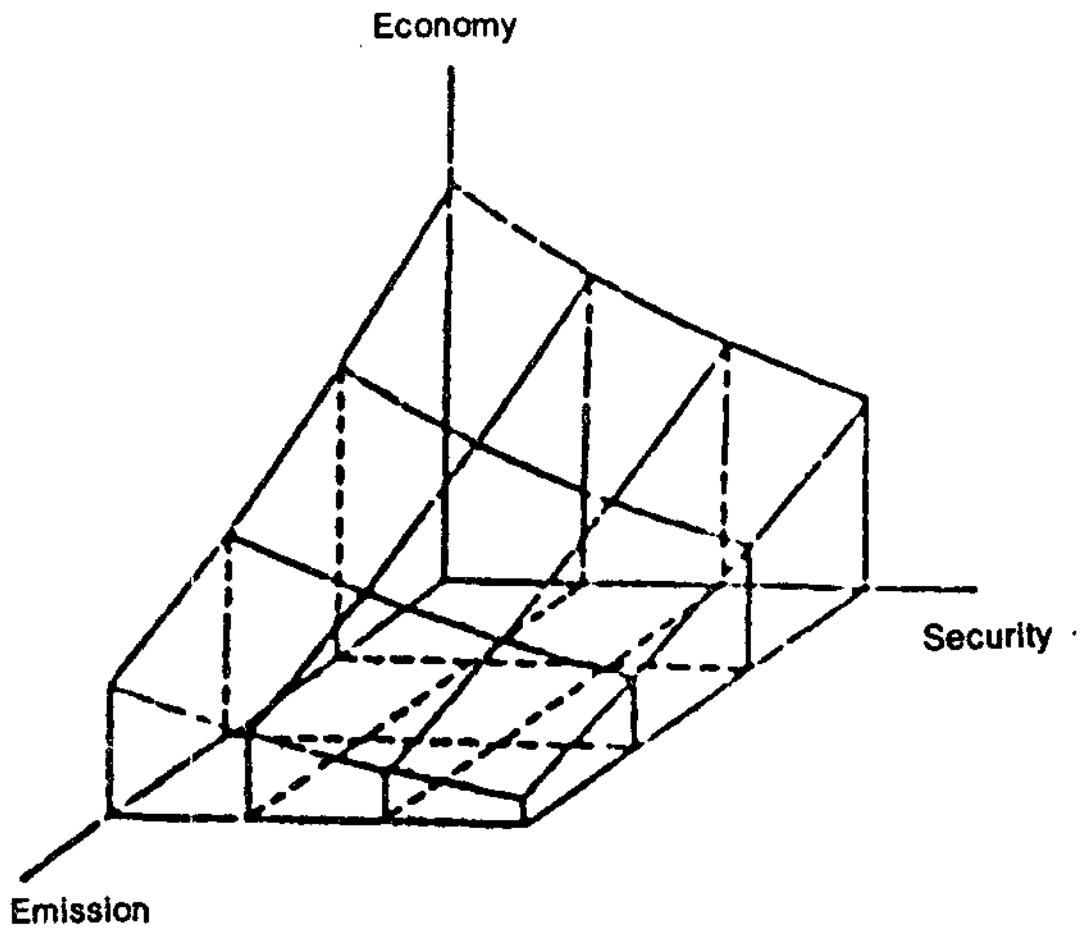

Fig. 7 Non–inferior solution surface

$\varepsilon_k(X) \leq 0$

where, X is a J–dimensional vector of decision variable and X is a feasible set of X ; $f_i(X)$, where i=1, 2, ..., n are n–objective functions, and $g_k(X)$, where k=1, 2, ..., m are m–constraint functions. It may be assumed that all functions are non–linear in X. This problem has been studied as a single–objective optimization problem using various approaches. All of the approaches involve identifying the non–inferior solution.

One approach used to identify the non–inferior solution is called the constraint approach. This technique retains one objective as primary and treats the remaining (n–1) objectives as constraints, such as

$$\text{minimize } f_n(X) \quad (10)$$

$$\text{s.t. } f_1(X) \leq \varepsilon_i,\ i=1,2,\ldots,n-1 \quad (11)$$

$$X < X$$

$$g_k(X) \leq 0,\ k=1,2,\ldots,m$$

where, ε_i are parametrically varied desired levels of the (n–1) objectives. In order to obtain the non–inferior solution set, many different values of each ε_i must be respectively examined.

Another approach, the parametic approach, replaces the multi-objective optimization problem in equation (8) with

$$\text{minimize } \sum_{i=1}^{n} \theta_i f_i(X) \quad (12)$$

subject to equation (9), where θ is a vector of weight where $\sum_{i=1}^{n} \theta_i = 1$.

This method clearly is inferior to the constraint approach in that it cannot identify the entire non-inferior solution set when it is non--convex. Both the constraint approach and the parametric approach require a technique to solve a general non-inferior programming problem.

The optimization by the constraint approach is performed through the following steps[10]:

Step 1 The generation dispatching problem with a set of multi-objectives is decomposed into n-subproblems with a performance index. N-subproblems are optimized separately by minimizing the own performance index. Let the optimal value of the performance index for the i-th subproblem be shown as, that is,

$$\text{minimize } f_i(X) = \varepsilon^0_i,\ i=1,2,\ \ldots,\ n \quad (13)$$

Step 2 We single out deliberately one of the performance index of problem (8), say $f_n(X)$. For each of the remaining indices $f_1(X)$, $f_2(X)$, ..., $f_{n-1}(X)$ is chosen a parameter (i=1,2, ... n-1), such as

$$\varepsilon_i = \varepsilon_i^{\circ} + \varepsilon_1,\ i=1,2,\ \ldots,\ n-1 \quad (14)$$

where, ε_i is some positive value. The single-objective problem is now formed as follows:

$$\text{minimize } \{f_n(X) \mid f_1(X) \leq \varepsilon_1,\ \ldots,\ f_{n-1}(X) \leq \varepsilon_{n-1}\} \quad (15)$$

Denote the solution of problem (15) as

$$\Psi(\varepsilon) = f_n[X^{\circ}(\varepsilon)] \quad (16)$$

where, $\varepsilon = [\varepsilon_1,\ \varepsilon_2,\ \cdots,\ \varepsilon_{n-1}]$. If the ε is proper, $X^{\circ}(\varepsilon)$ is a non-inferior solution.

Step 3 The algorithm for obtaining the non-inferior solution used in this study works as follows. First, solve problem (15) for an initial $\varepsilon^{(o)}$, resulting in an initial optimal solution $\Psi(\varepsilon^{(0)}) = \Psi^{(0)}$. Next, modify $\varepsilon_1^{(o)} - \varepsilon_1^{(o)} - \Delta\varepsilon_1 = \varepsilon_1^{(1)}$, $\Delta\varepsilon_1 > 0$, and solve problem (15) agian, resulting in an optimal solution. This modification means that the constraints are improved toward the optimal value $\varepsilon_1^{(o)}$. Then if $\Psi^{(0)} = \Psi^{(1)}$, accept both $\varepsilon_1^{(0)}$ and $\varepsilon_1^{(1)}$, in general. $\Psi^{(0)} < \Psi^{(1)}$. If $\Psi^{(0)} = \Psi^{(1)}$, delete $\varepsilon_1^{(0)}$, since it is improper. This modification and comparison are repeated until the boundary of the proper region in the ε_1-direction is reached, and when $\Psi^{(0)} = \Psi^{(1)}$, the repetition is terminated. In the end, repeat Step 3 for other ε_i (i=2, ..., n-1).

Application Result on Regional Test System

Available energy estimation and multi-criteria evaluation

The multi-criteria approach described in the previous section was applied to a regional power system. The influence of introducing the hybrid utilization system was evaluated on the basis of criteria for economy, reliability and environment. The result of evaluation is summarized as follows.

The insolation distribution and the wind velocity distribution in the specified test area in this work are illustrated in Figure 8, then the heat characteristic of collectors and output characteristic of wind generators are specified as shown in Figure 9.

Capacity and rated output generator are shown in Table 1. Coefficients of the generator cost function and the NO_x emission function are given in Table 2. From equations (3) and (4), amount of available energy obtained from the hybrid utilization system in the period is shown Table 3.

The volume of available natural energy is

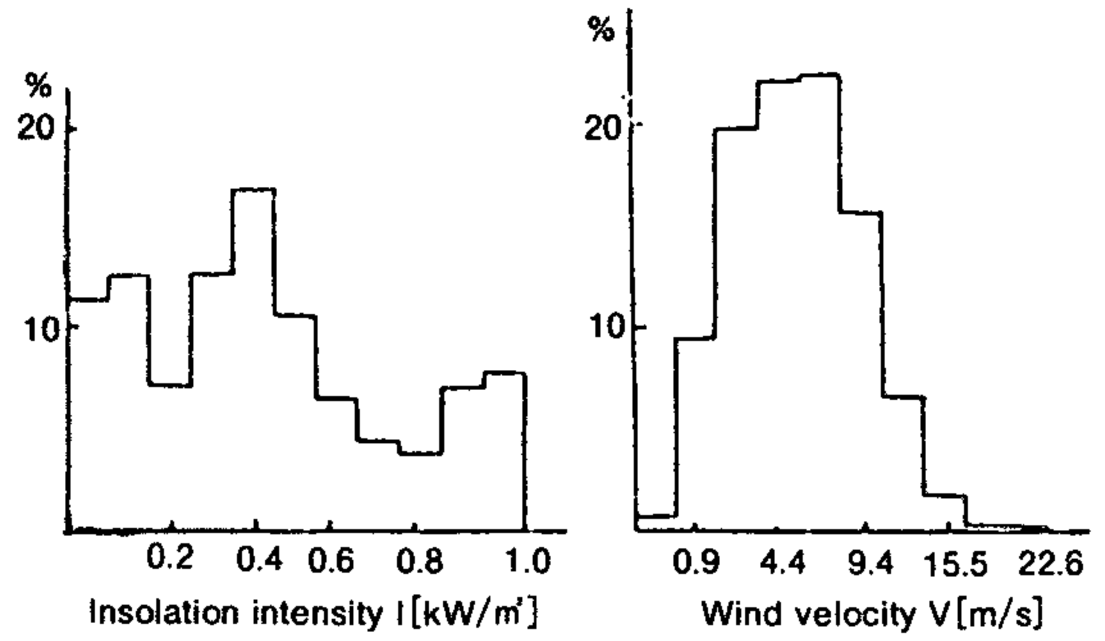

Fig. 8 Distribution of insolation and wind velocity

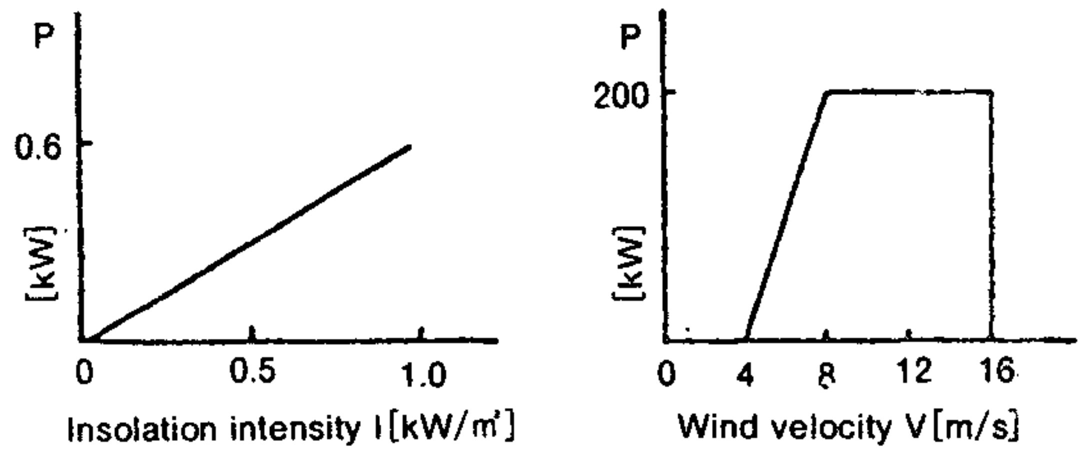

Fig. 9 Characteristic of heat collector and output

amount to 8.9 percent for the total load. In this simulation, we assume that 10 units of wind generator and totally 843m^2 solar heat collectors specified in Figure 9 are installed in the area under study.

The load duration curve given by Figure 10 is assumed to be modified as shown in Figure 11 by introducing the hybrid utilization system. As for operational scheme of the hybrid utilization system, we assume two types of the operational pattern as illustrared in Figure 11. We call pattern 1 "Peak shaving operation" and pattern 2 as "Load leveling operation" respectively. The evaluation was performed in light of three kinds of criteria, economy, reliability and environment. In order to clear influence of introducing the hybrid utilization system, the total generation cost and the NO_x emission of the conventional regional system without the hybrid utilization system are normalized and shown as 100.

Table 1 Generator capacity and rate of outage

No. of Generator	Capacity (p.u)	Rate of outage
1	1.0	0.02
2	0.6	0.01
3	0.8	0.02
4	0.6	0.02
5	1.1	0.01

The evaluation result in Table 4 shows that the regional system reliability (LOLP) has been greatly reduced from 0.078 to 0.044 by introducing the hybrid utilization system of the natural energies. Regarding influence for system economy the total generation cost has been reduced more than 10 percent by introduction of the hybrid utilization system. However no significant difference can be seen between two types of operation scheme.

On the other hand, the result shows that the introduction of the hybrid utilization system result shows that the introduction of the hybrid utilization system reduced the NO_x emission (influence for system environment) by 5–7 percent and especially operational scheme of pattern 1 contribute to more reduction of the emission, which means pattern 1 to be more effective. The major effectiveness of peak shaving operation of pattern 1 of the hybrid utilization system in reducing the NO_x emission and the fact of increasing NO_x emission exponentially with the increase of load magnitude are described in the result.

Overall Evaluation Based on Multi–objective Optimization

The structure of a test system utilization in this paper is illustrated in Figure 12. The system consists of 5–generators, 10–buses and 11–transmission lines. Base load flow of each transmission line and specified value of each bus are shown in Table 5 and 6 respectively.

Table 2 Coefficients of generator cost characteristic and NO_x emission characteristic

No. of generator	Coefficients of generator cost characteristic $F_c = \alpha P_g^2 + \beta P_g + \gamma$ ($/h)			NO_x emission characteristic $F_e = a + bP_g + cP_g^2 + d\exp(eP_g)$ (ton/h)				
	α	β	γ	a	b	c	d	e
1	80	100	10	5.326	–3.550	3.380	2.0×10^{-5}	2.000
2	100	150	10	6.131	–5.555	5.151	1.0×10^{-5}	6.667
3	100	150	10	2.543	–6.047	5.638	5.0×10^{-4}	3.333
4	120	200	10	4.091	–5.554	6.940	2.0×10^{-4}	2.857
5	40	180	20	4.258	–5.094	4.586	1.0×10^{-6}	8.000
				$\times10^{-2}$	$\times10^{-2}$	$\times10^{-2}$		

Table 3 Estimation of variable energy amount by the system

Regional total demand and available energy amount	Rate of available energy by hybrid utilization system(%)	Estimates
Regional demand	100.0	17958[Mwh]
Available solar energy	4.889	878[Mwh]
Available wind energy	4.043	726[Mwh]

Table 4 Overall evaluation in the period

Operational pattern	Economic efficiency	NO_x emission	LOLP
Existing system	100.0	100.0	0.078
Pattern 1	89.0	92.9	0.044
Pattern 2	89.4	94.3	0.044

Table 5 Base load flow of lines

No.of line	P_1^s(p.u)	No.of line	P_1^s(p.u)
1	1.20	7	0.50
2	0.15	8	0.15
3	0.30	9	0.30
4	0.60	10	0.50
5	1.30	11	1.20
6	0.40		

Table 6 Specified value of buses

No.of bus	Load/Gen.	Active power	Reactive power	Bus voltage
1	L	–0.900	–0.358	
2	L	–0.420	–0.350	
3	L	–0.450	–0.199	
4	L	–1.350	–0.300	
5	L	–1.350	–0.677	
6	G			1.035
7	G			1.020
8	G			1.050
9	G			1.000
10	S			1.100

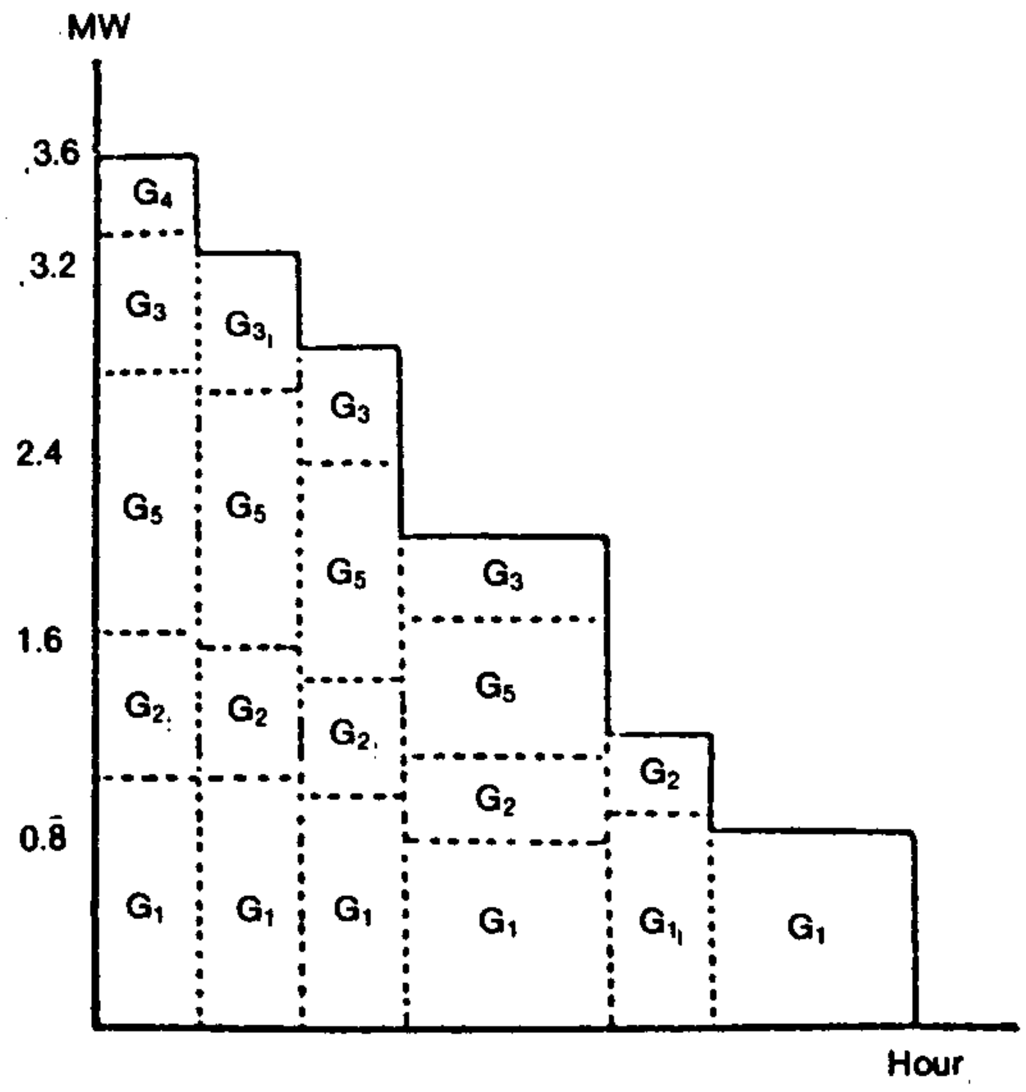

Fig. 10 Load duration curve

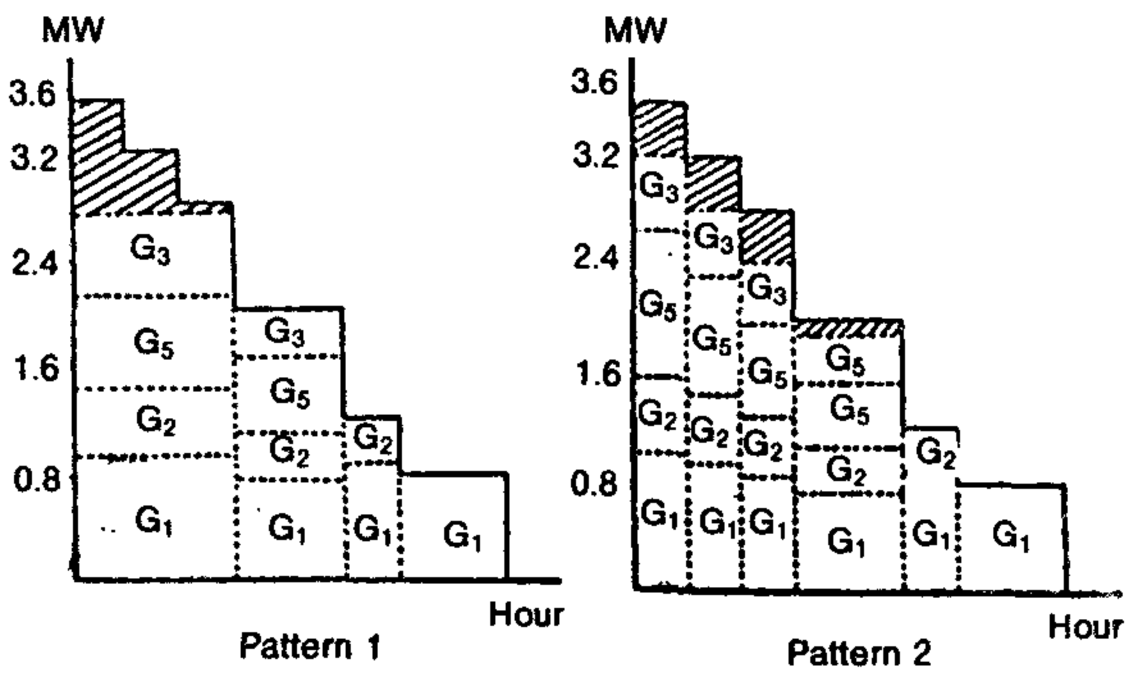

Fig. 11 Modification of load duration curve

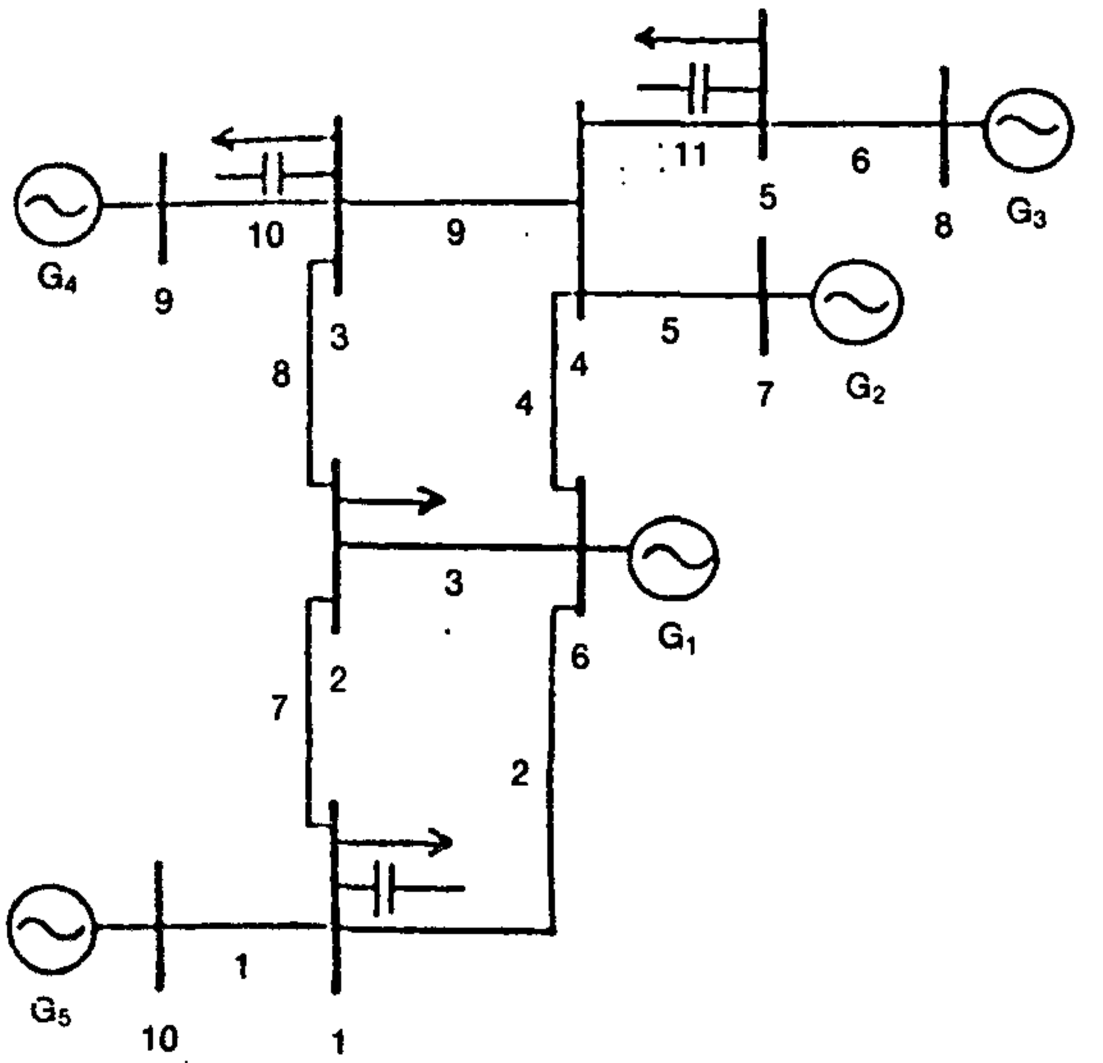

Fig. 12 Test system

The coefficients of characteristic function of generation cost and NO_x emission are indicated in Table 2.

The natural energy hybrid utilization systems are assumed to be allocated at bus 1 and 5, which brought the reduction of load at both buses by 0.14 pu.

In this configuration, the comparison of optimizations in light of three criteria of economic efficiency, reliability and environmental effect are indicated in Table 7.

The result shows definitely that a trade–off relation holds among three kinds of criteria. In order to make this trade–off relation more distinctly, non–inferior solutions are obtained by using the multi–objective optimization technique which is referred to as " ε –constraint method." The non–inferior solutions can be illustrated as in Figures 13 and 14. Figures 13 and 14 show set of inferior solutions before and after introducing the natural energy hybrid utilization system.

The inferior solution set is known to form "Non–inferior solution surface" which illustrates the trade–off relation in three–dimension space taking total generation cost, NO_x emission and reliability as coordinate axes. The figures show that minimization of one evaluation index is inevitable to bring deterioration of another two indices. From this multi–objective optimization result, it has been clarified that evaluation of introduction effects of hybrid utilization system is necessary for economic aspect in line with reliability and environment.

Inspecting difference between before and after introduction of the natural hybrid energy utilization system, the line overload problem has been eliminated by introducing the system.

So the non–inferior surface has no deformation curvature along the axis for reliability F_s, therefore the surface exists only on a curve in two dimension plane(the axes of total generation cost and NO_x emission).

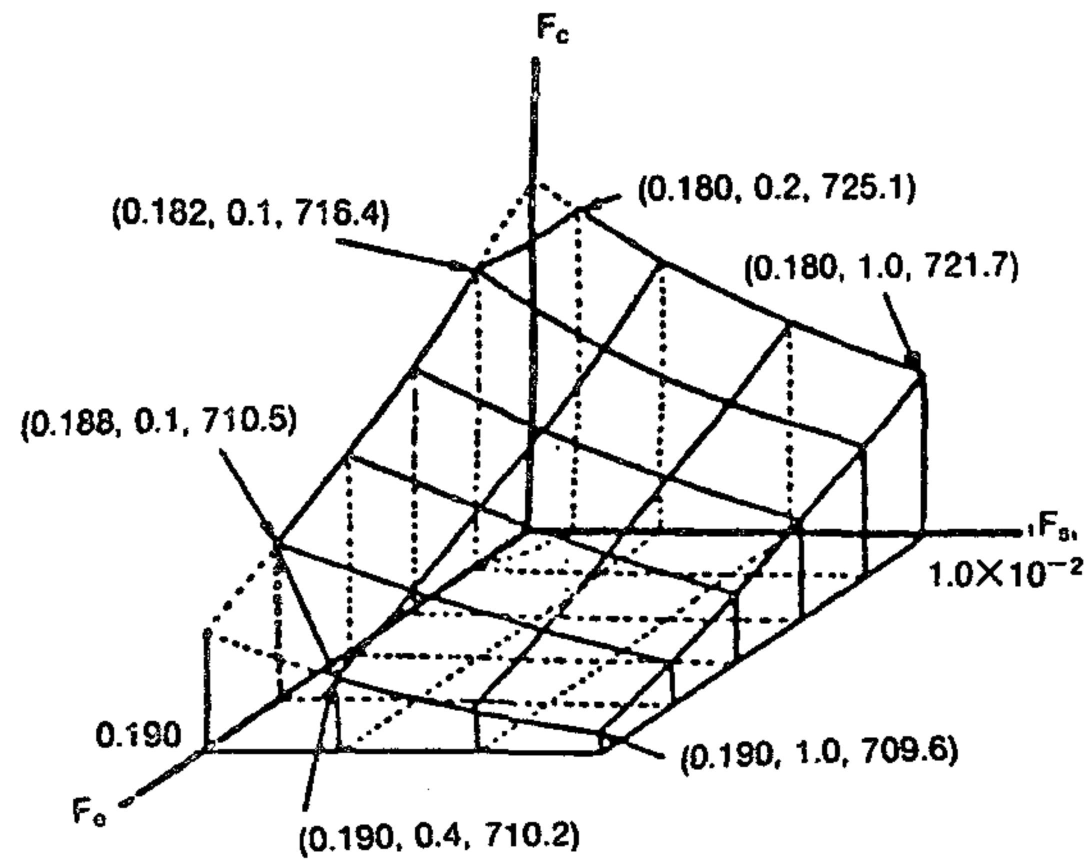

Fig. 13 Non–inferior solution surface before introducing the hybrid utilization system

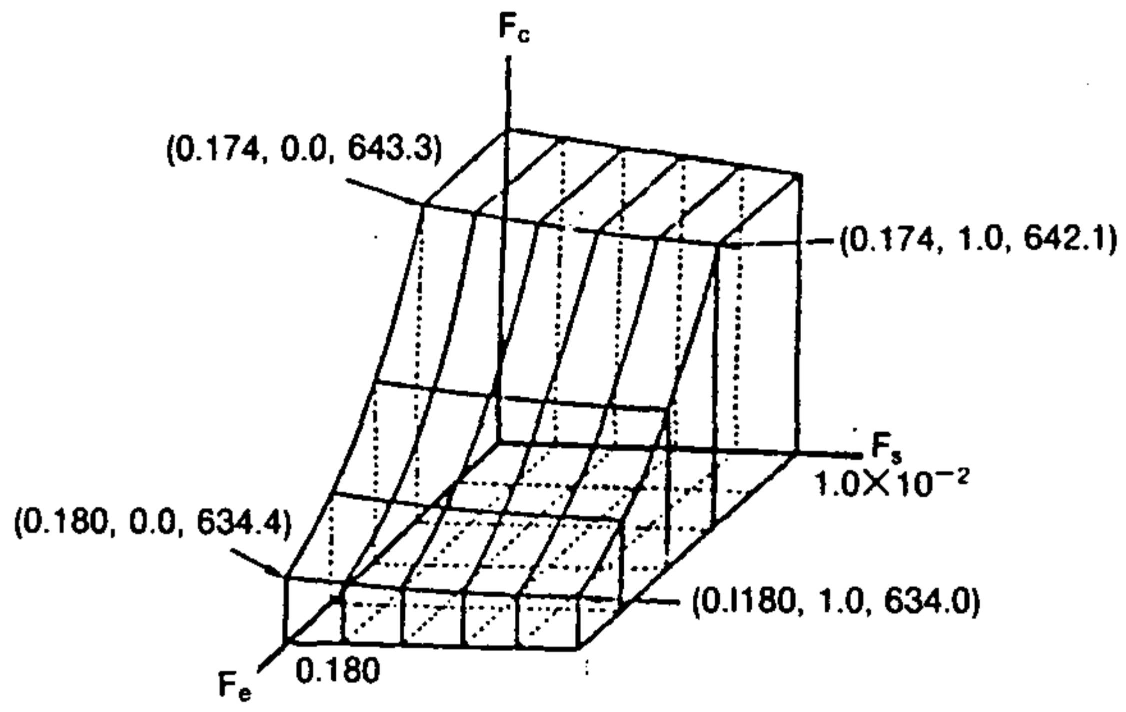

Fig. 14 Non-inferior solution surface after introducing the hybrid utilization system

Conclusion

In the present study, the techniques for making comprehensive evaluation of the effects of the introduction of natural energy hybrid utilization systems into existing power system of a specific area on the economic efficiency, reliability and the environment have been examined. Application of the techniques to a model system has revealed the results presented below.

1. When these systems with certain capacities are incorporated into a power system, various effects they exert on the power system planning and operation must be grasped quantitatively. In the analysis and evaluation, adequate considera-

Table 7 Optimal solutions for each subproblem
(a) Before introducing the hybrid utilization system

		Minimization of generation cost	Minimization of emission	Minimization of overloads
Total generation cost ($/h)		705.41	734.56	787.72
Total emission (ton/h)		0.190	0.177	0.224
Sum of overloads (p.u)		0.2466	0.5226	0.0
	1	1.017	0.654	0.388
	2	0.522	0.719	1.205
Generator output	3	0.555	0.651	0.400
	4	0.272	0.569	0.396
	5	0.802	0.600	0.830

(b) After introducting the hybrid utilization system

		Minimization of generation cost	Minimization of emission	Minimization of overloads
Total generation cost ($/h)		631.19	659.07	684.28
Total emission (ton/h)		0.184	0.171	0.192
Sum of overloads (p.u)		0.1569	0.3012	0.0
	1	0.953	0.559	0.630
	2	0.503	0.664	0.955
Generator output	3	0.506	0.597	0.150
	4	0.232	0.510	0.500
	5	0.711	0.572	0.679

tion must be given to the multi–objective features and trade–off relationship.

2. The method based on the load curve modification is best suited for evaluating the natural energy hybrid utilization system on the economic efficiency and reliability of the power system, because of the need to take the energy generating probability, generator outage probability and the load variations into consideration. It is also necessary to take into account the connection between the energy storage capacity of the natural energy utilization system and the specified duration.

3. In case the natural energy hybrid utilization system is operated so as to serve as substitute for the peak power supply, utility will be high not only with respect to economic effect but also to environmental conservation and supply reliability upgrading.

4. Various indices, such as the economic efficiency, security and environment, have been set up and treated as multi–objective problems. Because the introduction of natural energy hybrid utilization system into existing power system dispenses with the line overload restrictions, only economic efficiency and environment remain to be treated as biobjective problems. As a consequence, introduction of natural energy hybrid utilization system into the power system clearly allows more flexible planning and operation.

5. The effectiveness in such practical operations should preferably be analyzed and evaluated on the basis of actual meterological data for the relevant area and the regional load characteristics.

6. The total power generating cost, which is an economic criterion, can be taken as a definite evaluating criterion for power system planning and operation, but criteria related to reliability and security are not taken as established quantiltative criteria, since the outage probabilities of the generator and so forth need to be taken into account.

References

1. N.Takama and T.Umeda, "Decomposition and Multi–Level Optimization for Single of Multi–Objective Problems", System and Control, Vol.25, No.10, pp.642–651, Japan, 1981
2. B.A.Berezovskii and L.M.Kempner, "A Class of Multi–criteria Optimization Models with Criteria Ranged by Importance", Proceedings of the IFAC Symposium, France, 24–26 June 1980, pp. 267–272, Pergamon Press, New York, 1981
3. M.J.H. Sterling, "Power System Control", Peter Peregrinus Ltd., England, 1978
4. M.E.Ei–Hawary and G.S.Christensen, "Optimal Economic Operation of Electric Power Systems", Academic Press, New York, 1979
5. Sekine, et. al, "Load Management and its Effect on Generation Planning", Trans. IEE of Japan, 56–B9, 1982
6. Sudou and Sekine, "Evaluation of Small–Scale Decentralized Generation Resources Considering Load Characteristics, PE–83–23, 1983
7. Toyoda, "Role of Electric Power Strage System and Economical Evaluation", Trans. IEE of Japan, 59–B33, 1984
8. Morozumi, et.al, "Optimal Operation of Decentralized Strage Units on Power System", Trans. IEE of Japan, 58–B58, 1983
9. Koumoto, et.al, "Fundamental Study on Hybrid Utilization System of Solar and Wind Energy", Special Project Research on Natural Energy, The Ministry of E.S.C., No. 58040056, Mar. 1983
10. R. Yokoyama, et. al, "Design and Operating Experience of a Heating and Cooling

System by Hybrid Use of Solar and Wind Energy", Reports of Special Project on Energy, MESC SPEY 8, Mar. 1984

11. Mogi, et. al, "Economy–Security Evaluation of Hybrid Utilization System of Solar and Wind Energies", National Convention of IEE of Japan, No.1025, 1985

12. G.J.Vachtsevanos and K.C.Kalaitzakis, "Penetration of Wind Electric Conversion Systems into the Utility Grid", IEEE Trans. Power Appl. Syst., Vol.PAS–104, No.7, pp.1677–1683, July 1985

The developed system manufactured with domestic materials were installed in residential buildings in seven cities(Seoul, Pusan, Taegu, Kwangju, Taejeon, Kangneung, Cheju) for demonstration and field test and results show possibility for commercialization.

Multi-Objective Evaluation for Hybrid Use of Natural Energy in Power System

Sang Hyun Bae · Jae Youn Lee*
College of natural Sciences, Chosun University
Graduate school, Chosun University*

ABSTRACT

Research and development works on practical application of natural energy utilization systems involving solar, wind and sea wave energies are under promoting for the purpose of improving the energy consumption structure. These natural energies, made available with the use of relatively simple apparatus, are clean economically efficient and highly effective in the conservation of environment. However, these natural energies also have low energy density, randomness and regional variations. To compensate for these characteristics, hybrid utilization of solar and wind energies is currently under study.

The introduction of a plural number of the natural energy hybrid utilization systems into a specific area will affect the economic efficiency, reliability and environmental conservation. Evaluation method of such effects has been examined in this study.

The present method consisted of the steps described below. First, available energy was calculated from insolation distribution and wind velocity distribution in the specified area, and then the effect on the configuration of the power system load was obtatined. This was followed by the determination of the optimal power dispatch over the specified period and by evaluations in light of economic efficiency, reliability and environmental indices.

A Study of Semiconductor (P)SiC/(N)Si Heterojunction Solar Cells

Choon-Saing Jhoun · Won-Kyu Park · Ho-Whan Woo
Inha Univ.
Central Vocational Training Institute *
Inha Technical Junior Collage * *

ABSTRACT

In this study, the (P)SiC/(N)Si solar cell is fabricated by the vacuum evaporation method with the substrate temperature at about 200±5[℃] and its characteristics are investigated. The optimal thickness of 1.2[μm] of SiC film is derived from the relation between film thickness and conversion