Design of Optimal Combination for New and Renewable Hybrid Generation System

Kun Hyun Park, Chul Uoong Kang, Gi Min Lee, and Joung Hwan Lim

Department of Mechatronics, School of Engineering, Jeju national University,
102 Jejudaehakno, Jejusi, South Korea
{3313park,cukang,jhlim}@jejunu.ac.kr,
01051359154@hanmail.net

Abstract. Hybrid generation system is basically merging systems of two or more different types of generation systems. Hybrid Generation System is more effective than utilization of single renewable energy resource. The combination of different types of generation systems are vary important because the total cost for generation is dependent on the combination. This study presents a method to design the optimal combination for new and renewable hybrid system. The method aims at finding the configuration, among sets of system components, that meets the desired system requirements, with the lowest value of the energy cost.

Keywords: Optimal combination of Hybrid Generation System, new and renewable energy.

1 Introduction

Recently, the hybrid generation system has became significant because of the complementary characteristics among the new and renewable energy resources. To use the energy resources of hybrid system more efficiently, the combination of different types of generation systems that constitute the hybrid system is very important because the energy cost depends on the kinds of new and renewable energy resources. However, the combination of the hybrid system is performed on the basis of experience and intuition, which is not attained the optimum efficiency.

Since new and renewable energy resources have stochastic behaviour, the major aspects in the design of the hybrid system are the reliable power supply of the consumer under varying atmospheric conditions and the cost of energy. In order to use the new and renewable energy resources more efficiently and economically, the design of optimal combination of hybrid system with battery plays an important role in this respect.

Various optimization techniques of hybrid system have been reported in the literature. Kellogg [1] and Chedid [2] reported the linear programming technique. On the other hand, Karaki [3] and Bagul [4] developed the probabilistic approach, and iterative technique was developed by Kellogg [1]. Musgrove [5] presented dynamic programming, and Yokoyama et al. [6] developed multi-objective method. Yang et al.

T.-h. Kim et al. (Eds.): FGCN 2011, Part II, CCIS 266, pp. 189–198, 2011.

[7] and Beyer et al. [8] have obtained the set of different configurations which meet the load using the autonomy level of the system.

Protogeropoulos et al. [9] presented general methodology by considering design factor such as autonomy for sizing and optimization. Recently, Diaf at al.[10] suggest very accurate mathematical approach for characterizing PV module, wind generator and battery. However, these techniques are only for the optimal sizing of the hybrid system given the combination of energy resources.

This paper presents a methodology for the design of optimal combination of hybrid generation system with storage batteries. The methodology adopted LPSP concept which was presented by Diaf [10]. By modifying the LPSP, we present a methodology to perform the optimal combination of a new and renewable hybrid generation system. The methodology aims at finding the combination, among sets of system components, that meets the desired system requirements, with the lowest value of the energy cost. The availability of the method is demonstrated with the results produced through sets of simulations.

2 Mathematical Modeling of Hybrid System Components

There are many kinds of new and renewable energy resources. In this paper, we consider the typical new and renewable energy resources such as wind, PV, tidal energy resources. Any other new and renewable energy resources can also be considered to be the component that constitutes the hybrid system as far as it can be modeled mathematically.

2.1 Modeling of Wind Generator System

There are many types of wind generators that have different power output performance curves, so that the model used to describe the performance of wind generators is expected to be different. Some authors assume that the turbine power curve has a linear, quadratic or cubic form. Other authors approximate the power curve with a piecewise linear function with a few nodes.

In this study, we use the original mathematical model of output power for wind generation system. This may be somewhat different from the actual power curves. The model, however, can be applied any types of wind generation system.
The mathematical model of wind turbine output can be defined as:

$$P_w = \frac{1}{2}(\rho A v) \cdot v^2 = \frac{1}{2}\rho A v^3 \tag{1}$$

where, ρ is air density, *A* is diameter of rotor, *v* is wind speed.

For a specific wind generator, a mathematical model can be developed according to its power output performance curve that is given by the manufacture. The power output is modeled through interpolation of the values of the data provided by the manufacturers. Since the power curve can be assumed to be smooth, they can be approximated using a line interpolation. The fitting equation of the output characteristic of wind generator can be expressed as:

$$P_W(v) = \begin{cases} 0, & v \le v_s \\ a_1 v + b_1, & v_s < v < v_1 \\ a_2 v + b_2, & v_1 < v < v_2 \\ \cdots\cdots\cdots & \\ a_n v + b_n, & v_{n-1} < v < v_r \\ P_r, & v_r < v < v_c \end{cases} \tag{2}$$

Where, $P_W(v)$ is the output power of wind generator at wind speed v, P_r is the rated power, v is the wind speed, v_s, v_r and v_c are the cut-in, rated and cutout wind speeds, respectively. n is the number of cubic spline interpolation functions corresponding to n +1 values couples (speed, power) of data provided by the manufacturers and *a,b* are the coefficients of the line interpolation functions which depend on the wind turbine generator type.

2.2 Modeling of PV System

If the P_{PV} solar radiation on the tilted surface, the ambient temperature and the manufacturers data for the PV modules are available, the power output of the PV generator, P_{PV}, can be calculated according to the following equations.

$$P_{PV} = \eta_0 N A_m G_t \tag{3}$$

where, η_0 is the instantaneous PV generator efficiency, N is number of modules, A_m is the area of a single module used in a system andG_t is the global irradiance incident on the titled plane. The instantaneous PV generator efficiency η_0 is represented by the following equation.

$$\eta_0 = \eta_r \eta_{0t} [1 - \beta_t (T_c - T_r)] \tag{4}$$

where, η_r is the PV generator reference efficiency, η_{0t} is the efficiency of power tracking equipment which is equal to 1 if a perfect maximum power point tracker is used, T_C is the temperature of PV cell (°C), T_r is the PV cell reference temperature and β_t is the temperature coefficient of efficiency, ranging from 0.004 to 0.006 °C per for silicon cells. However, to simplify the model, we use the general PV generator efficiency that is used many practical approach.

2.3 Modeling of Tide Generator System

There are many types of tidal generation system. Among them the most popular one is a horizontal axis blade type of tidal generation system which is basically no different from the horizontal axis wind turbine system.

In this study, the horizontal axis blade type of tidal generation system is assumed. It, therefore, has the same mathematical model as that of wind generation system stated in Eq.(1). That is,

$$P_t = \frac{1}{2} \rho_{sea} A v_{cur}^3 \tag{5}$$

where, ρ_{sec} is sea water density, A is diameter of rotor, v_{cur} is the speed of current. Since ρ_{sec} is about 1052.2 kg/m^3 the tidal energy is much greater than wind energy when the current speed is equal to wind speed.

2.4 Modeling of Battery System

Since the state of battery is related to the previous state of charge and to the energy production and consumption situation of the system during the time from *t-1* to *t*, it should be modeled differently according to the generation and load conditions.
When the total power from the hybrid generation system is greater than the load required, the battery is in charging state and modeled as follows;

$$C(t) = C(t-1)(1-\sigma) + (E_G(t) - \frac{E_L(t)}{\eta_{inv}})\eta_{bat} \quad (6)$$

Where, $C_{(t)}$ is battery bank capacity, $E_G(t)$ is total power of the hybrid system, $E_L(t)$ is the power needed by the load at time t, σ is self discharge rate of the battery, η_{bat} is the battery efficiency, and η_{inv} is the inverter efficiency. During discharging process, the battery discharging efficiency was set equal to 1, and during charging, the efficiency is 0.65 to 0.85 depending on the charging current.

On the other hand, when total power is less than the load demand, the battery is in discharging state and modeled as follow;

$$C(t) = C(t-1)(1-\sigma) - \frac{E_L(t)}{\eta_{inv}} + E_G(t) \quad (7)$$

3 Design Model of Optimal Combination

3.1 The RLP Model

To determine the optimal combination of the new and renewable energy sources and to achieve the optimal configurations of the hybrid system in term of technical analysis, the R_{LP} model is developed, which is modified from the method of LPSP. The total power, P_{tot}, generated by the hybrid generation system at time t is calculated as follow:

$$P_{tot}(t) = \sum_{i=1}^{n} P_i(t) \quad (8)$$

where, P_i is the output power of the i-th individual generation system that constitutes the hybrid system. n is the total number of the generation systems in the hybrid system. Then, the inverter input power, P_{inv} (t), is calculated using the corresponding load power requirements.

$$P_{inv}(t) = \frac{P_{load}(t)}{\eta_{inv}} \quad (9)$$

where, P_{load} (t)is the power required by the load at time t, is the inverter efficiency.

The following two different situations may appear during the operation of the hybrid generation system.

① The total power generated by the hybrid system is greater than the power needed by the load P_{inv}. In this case, the energy surplus is stored in the batteries and the new battery capacity is calculated using Eq.(5) until the full capacity is obtained, the remainder of the available power is not used.

② The total power generated by the hybrid system is less than the power needed by the load, P_{inv}, the batteries supply the energy deficit, and a new battery capacity is calculated using Eq.(7).

In case when the total power generated by the hybrid generators is equal to the power needed by the load P_{inv}, the batteries remains unchanged, and this case can be considered as special case of ①.

If the power generated by the hybrid system is less than the load demand, The batteries should supply the energy deficit. However, if the battery capacity reaches to the minimum capacity state, C_{min}, in which the batteries cannot discharge anymore, the hybrid system can no more supply energy deficit. In this case the power deficit must be supplied from the external energy system. The power deficit in this case is called as ' Lack of power', P_{LP}, and can be defined as:

$$P_{LP}(t) = P_{load}(t)\Delta t - (P_G(t)\Delta t + C(t-1) - C_{min})\eta_{inv} \quad (10)$$

Where, $P_G(t)$ and $P_{load}(t)$ are total power and load power requirement. $P_{load}(t)\ \Delta t$ represents total load demand power, and the last term represents the power consumed by the load. In Eq. (10), it is assumed that power generated by the hybrid system during Δt is unchanged. The amount of power discharged until the battery capacity reaches C_{min} , C_{out}, is written as,

$$C_{out} = P_{load}(t)\Delta t - P_G(t)\Delta t\,\eta_{inv} \quad (11)$$

The ratio of lack of power, R_{LP}, for a period T, can be defined as the ratio of total lack of power over the total load required during that period.

$$R_{LP} = \frac{\sum_{t=1}^{T} P_{LP}(t)}{\sum_{t=1}^{T} P_{load}(t)} \quad (12)$$

Using Eq. (12), the design of optimal combination of the hybrid system components is performed.

3.2 Economical Model

For hybrid generation systems the most important concern is to achieve the lowest energy costs, and the economical approach can be the best benchmark of cost analysis. Several methods are used to get different options for energy system; the levelised cost of energy is often the preferred indicator [11]. However, the method is not easy to apply in a practical application because it is very complicated.

In this study, a simple economical model is developed. Let T_i be the output power of the i-th individual generation system that constitutes the hybrid system per *Wh* and *n* be the total number of the generation systems in the hybrid system. Also let E_i be the generation capacity of the i-th individual generation system. The total cost per W*h*, T_{tot} can be expressed as follows.

$$T_{tot} = \sum_{i=1}^{n} T_i E_i + T_{bat} C \tag{13}$$

Where, T_{bat} is the cost of battery per W*h*, and *C* is battery capacity

4 Simulation Results

Fig.1 shows the algorithm of the design of optimal combination. First, it assumes combination of the size of each component of the hybrid system. Using the given data, it calculates the total power generated by the hybrid system. The power is then compared with the power required by the load. During the process P_{LP} is calculated and summed for total period *T*. Finally, R_{LP} is calculated. If the resulting R_{LP} satisfies the required R_{LP}, the assumed combination of the size is a candidate for optimal combination. Among the many candidates, it finds optimal combination by applying the economical model.

The major new and renewable energy sources, such as wind, PV and tide energy, are selected for the simulation. Fig.2 through Fig. 4 shows wind data, solar irradiance data, and tidal current data respectively. The data were acquired for 3 days at somewhere in Jeju island. Design condition is shown in table 1. The load is assumed as 20 W*h* and operates for 24 hours a day. The required R_{LP} is 0, which meet the stand-alone system that need no external supply of energy. For given design conditions the algorithm finds optimal combination of the hybrid system that meet the lowest cost for the generation of the power required by the load.

Table 2 shows the results of optimal sizing for various combinations of hybrid system. It also shows the total generation cost for each combination. The cost of the wind-tide combination is higher most than those of the other combinations. On the other hand, the optimal combination that satisfies the lowest cost is the wind-PV-tide hybrid system. Combination is the lowest cost of hybrid system. The algorithm yields only one combination for the optimum solution, where the cost of W*h* energy is a minimum. These results can be different when the cost of W*h* for each component is changed. However, the algorithm can still find the optimal solution with consistency.

```
1. Input wind, solar, current data
2.  for j=1 to N ▶ N is the assumed number of
sets  for valid combinations
3. Assume combination (E_w, E_PV, E_t)
4. v_n      0 ▶ v_n : the total number of valid
   combinations
5. for i=1 to total period ( total number of
   data set)
6. P_tot      Eq.(8)
7. if P_tot == P_load then
8. P_LP      0
9. end
10 if P_tot  > P_load  then
11.C(t)        Eq.(6)
12. P_LP  ←—— 0
13. end
14. if P_tot < P_load   then
11. C(t) ←——   Eq. (7)
12. P_LP ←—— Eq.(10)
13. end
```

Fig. 1. Optimal design algorithm

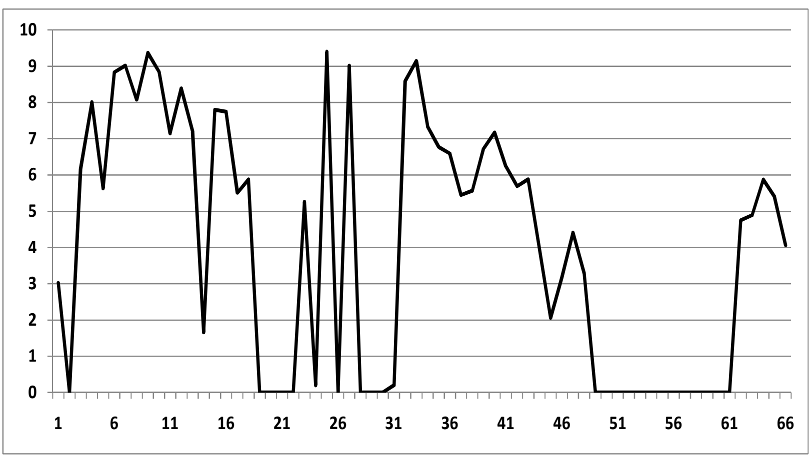

Fig. 2. Wind data

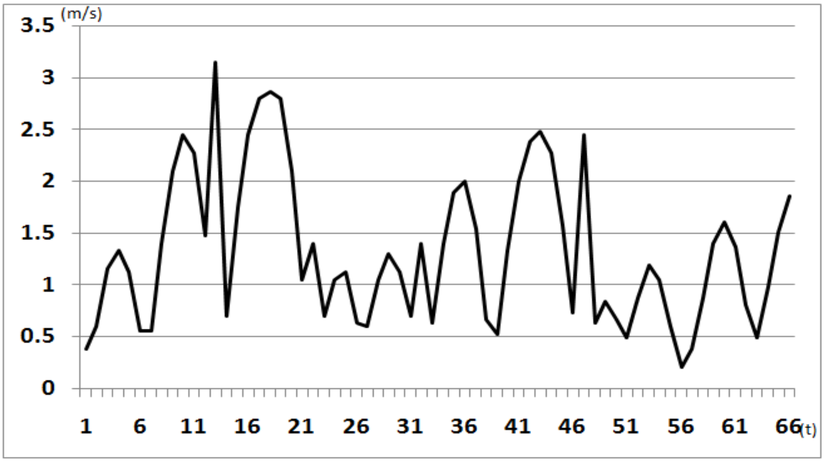

Fig. 3. Current data

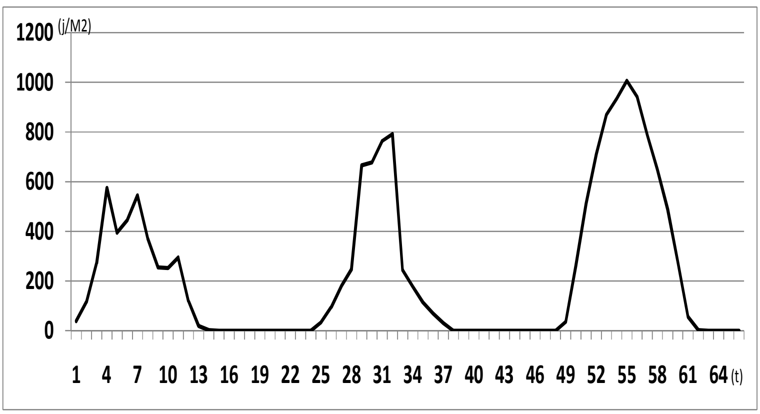

Fig. 4. Irradiance data

Table 1. Design Conditions

Type	Unit size	Total size	Cost (Won/kWh)
Wind	5 W	To be designed	105
PV	30 W	//	640
Tide	5 W	//	201
Battery	5 Wh	//	320
Wind	5 W	20 Wh	-

Table 2. Results of optimal combinations

combination	Size				cost (won)	remarks
	wind (*W*)	PV(*W*)	tide(*W*)	battery(*W*h)		
Wind-PV	100	60	-	145	95.3	-
Wind-Tide	5	-	270	135	100.43	-
PV-Tide	-	30	105	95	71.65	-
Wind-PV-Tide	40	30	45	80	58.45	optimal

5 Conclusion

In this paper, method for design of optimal combination for hybrid renewable generation system has been studied. A simple mathematical modeling for typical new and renewable energy resources such as wind, PV, tidal energy resources were developed. Using the models, the method of designing the optimal combination of the hybrid system was developed. The method is based on R_{LP} (Ratio of Lack of Power) and economical model. This aims at finding the configuration, among a set of system components that meets the desired system requirements, with the lowest value of the energy cost. The method was applied to hybrid wind-PV-tide generation system. The availability of the methodology was successfully demonstrated with the field data acquired from sets of experiments.

Acknowledgement. Following are results of a study on the "Human Resource Development Center for Economic Region Leading Industry" Project, supported by the Ministry of Education, Science & Tehnology(MEST) and the National Research Foundation of Korea(NRF).

References

1. Kellogg, W., Nehrir, M.H., Venkataramanan, G., Gerez, V.: Optimal unit sizing for a hybrid PV/wind generating system. Electric Power System Research 39, 35–38 (1996)
2. Chedid, R., Saliba, Y.: Optimization and control of autonomous renewable energy systems. Int. J. Energy Res. 20, 609–624 (1996)
3. Karaki, S.H., Chedid, R.B., Ramadan, R.: Probabilistic performance assessment of autonomous solar-wind energy conversion systems. IEEE Trans. Energy Conv. 14, 766–772 (1999)
4. Bagul, A.D., Salameh, Z.M., Borowy, B.: Sizing of stand-alone hybrid PV/wind system using a three-event probabilistic density approximation. Solar Energy 56, 323–335 (1996)
5. Musgrove, A.R.D.: The optimization of hybrid energy conversion system using the dynamic programming model – RAPSODY. Int. J. Energy Res. 12, 447–457 (1988)

6. Yokoyama, R., Ito, K., Yuasa, Y.: Multi-objective optimal unit sizing of hybrid power generation systems utilizing PV and wind energy. J. Solar Energy Eng. 116, 167–173 (1994)
7. Yang, H.X., Burnett, J., Lu, L.: Weather data and probability analysis of hybrid photovoltaic wind power generation systems in Hong Kong. Renewable Energy 28, 1813–1824 (2003)
8. Beyer, H.G., Langer, C.: A method for the identification of configurations of PV/wind hybrid systems for the reliable supply of small loads. Solar Energy 57, 381–391 (1996)
9. Protogeropoulos, C., Brinkworth, B.J., Marshall, R.H.: Sizing and techno-economical optimization for hybrid solar PV/wind power systems with battery storage. Int. J. Energy Res. 21, 465–479 (1997)
10. Diaf, S., Diaf, D., Belhamel, M., Haddadi, M., Louche, A.: A methodlogy for optimal sizing of autonomous hybrid PV/wind system. Energy Policy 35, 5708–5718 (2007)
11. Nelson, D.B., Nehrir, M.H., Wang, C.: Unit Sizing of Stand Alone Hybrid Wind /PV/Fuel Cell Power Generation Systems. IEEE Power Engineering Society General Meeting 3, 2116–2122 (2005)