

A Methodology of Optimal Sizing for Wind Solar Hybrid System

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Abstract - This paper proposes a methodology to perform the optimal sizing of a wind solar hybrid system. The methodology focus at finding the configuration, between a set of systems components to satisfy the desired system reliability requirements, with the lowest possible cost. Due to large number of design setting and the sporadic nature of solar and wind energy sources it become very challenging. In the first step modelling a wind solar hybrid system is considered in the procedure of optimal sizing methodology. While in second step optimum sizing of a system is done according to the loss of power supply probability (LPSP).

Keywords: optimum system sizing; loss of power supply probability; wind; solar; hybrid system

Genetic algorithm is introduced by Xu, Kang, Chang, Cao for selecting type and number of PV, WG and battery to satisfy a constant load demand.

In this context, the present study presents a methodology for the optimal sizing of wind solar hybrid system with storage batteries. The methodology adopted, taken as the ideal approach to suggest, between a set of system components, the type of units and optimal number in terms of economic and technical concepts; the loss of power supply probability (LPSP).

I. INTRODUCTION

The rapid depletion and high capital cost of fossil fuel resources attracted much attention towards urgent search for alternative energy source. Alternative energy source as wind and solar energy are the most favourable option. A common drawback of wind and solar energy is their wind speed characteristic and intermittent solar radiation. The problem is partially overcome by using these systems together with a storage component. These kind of system are known as hybrid system.

In order to efficiently and economically utilize the renewable energy source, an optimum mixture and selection of each component of a wind solar hybrid system is important. The sizing optimization method can help to guarantee the lowest investment and full use of a PV system, WG system and battery bank, so that the hybrid system can work at optimum condition with selected configuration.

Various optimization technique such as probabilistic approach, graphical construction and iteration technique have been recommended by researchers.

Yang et al (2003, 2007) have proposed an iterative optimization technique for the loss of power supply probability model for the wind solar hybrid system. The number selected of the PV modules, wind turbine, and batteries ensures the load demand according to the power reliability requirement and the system cost is minimised.

II. MODELLING OF THE WIND SOLAR HYBRID SYSTEM COMPONENTS

A wind solar hybrid system consists of PV array, Wind turbine, battery bank, inverter, controller and other devices and cable. To satisfy the load demand PV array and wind turbine works together. The maximum available power can be extracted from the PV and Wind power sources depending on battery charger technology. In case of low wind speed or irradiation condition battery bank is used to store the energy surplus and to supply. For a wind solar hybrid system, as shown in Fig.1, three principal subsystems are included, the PV generator, the wind turbine and the battery storage.

A. Modelling of PV generator

Weather data play an important role in PV module performance, especially solar radiation and PV module temperature. The models describing the PV module's maximum power output behaviours are more practical for PV system assessment, as the operation and the performance of PV generator is interested to its maximum power. In this paper, a mathematical model for estimating the power output of PV modules is used.

Using the solar radiation available on the tilted surfaces, the ambient temperature and the data from manufacturers for the PV modules as model inputs, the power output of the PV generator, P_{PV} , can be calculated with the following equations (Markvard, 2000):

$$P_{PV} = \eta_g N A_m G_t$$

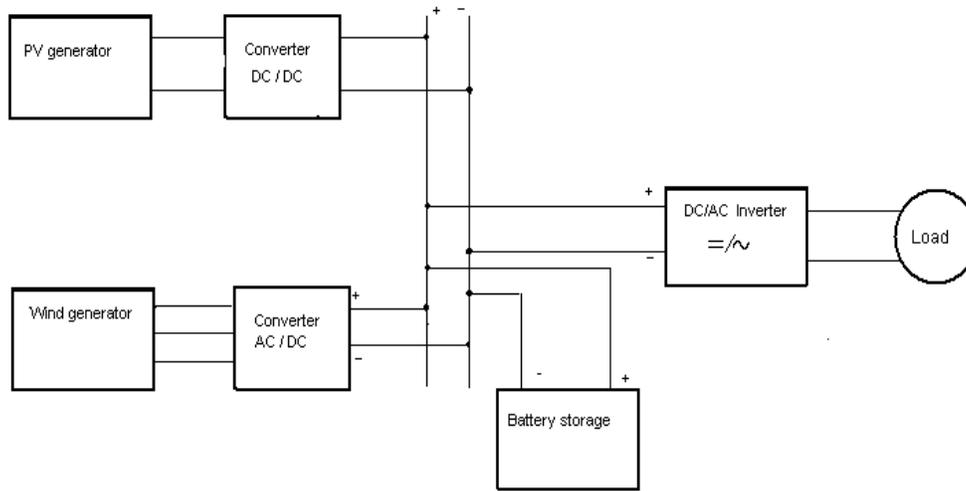


Fig.1 Schematic diagram of hybrid PV/wind system with battery storage

Where, η_g - Instantaneous PV generator efficiency, A_m - Area of a single module used in a system (m^2), G_t - Global irradiance incident on the titled plane (W/m^2), N - Number of modules. All the energy losses in a PV generator, including connection losses, wiring losses and other losses, are assumed to be zero.

The instantaneous PV generator efficiency is expressed by the following equation (Habib et al., 1999)

$$\eta_g = \eta_r \eta_{pt} [1 - \beta_t (T_c - T_r)].$$

Where, η_r - PV generator reference efficiency, η_{pt} - Efficiency of power tracking equipment which is equal to 1 if a perfect maximum power point tracker is used, T_c - Temperature of PV cell ($^{\circ}C$), T_r - PV cell reference

temperature, β_t - Temperature coefficient of efficiency, ranging from 0.004 to 0.006 per $^{\circ}C$ for silicon cells.

Based on the energy balance proposed by (Duffie et al., 1991), the PV cell temperature can be represented as follows:

$$T_c = T_a + G_t \left(\frac{NOCT - 20}{800} \right)$$

Where, T_a - ambient temperature ($^{\circ}C$), (Chedid et al., 1996; Duffie et al., 1991)

Consequently, the instantaneous PV generator efficiency can be expressed as follows:

$$\eta_g = \eta_r \eta_{pt} \left\{ 1 - \beta_t (T_a - T_r) - \beta_t G_t \left(\frac{NOCT - 20}{800} \right) \right\} (1 - \eta_r \eta_{pt})$$

η_{pt} , β_t , $NOCT$, A_m are parameters that depend on the type of module, and given by the manufacturer of the modules.

B. Modelling of wind generator

It is very important for wind solar hybrid system to choose a suitable wind turbine. There are three main factors that determine the power output of a wind turbine, ie, the power output curve (determined by aerodynamics power efficiency, mechanical transmission and converting electricity efficiency) of a chosen WG, the wind speed distribution of a selected site where the wind turbine is installed, and the tower height. (H. Yang et al. 2008).

(Yang et al., 2002; Chedid et al., 1998; Eftichios et al., 2006; Lysen, 1983) taken on that the turbine power curve has a linear, quadratic or cubic form. (Troen et al., 1989; Bueno, 2005) approximate the power curve with a piecewise linear function with a few nodes.

As the installation height of the wind turbine has a large effect on the energy available from the system, the process of adopting of the wind profile for height can be taken into account by using an equation of height adjustment. In this study, the power law is applied for the vertical wind speed profile, as shown in equation below (Ilinka et al., 2003).

$$\frac{V}{V_r} = V_r \left(\frac{H}{H_r} \right)^{\alpha_1}$$

Where, V - Wind speed at hub height H , V_r - Wind speed measured at the reference height H_r and α_1 - Wind speed power law exponent. Wind speed power law expansion which varies from (> 0.10) for very flat land, water or ice to more than 0.25 for heavily forested landscape. The one-seventh power law(0.14) is a good reference number for relatively flat surfaces such as open terrain of grasslands away from tall trees or building (Gipe, 1995).

C. Modelling of Battery Storage

$$C_{bat}(t) = C_{bat}(t-1) \cdot (1 - \sigma) + \left(E_{PV}(t) + E_{WG}(t) - \frac{E_L(t)}{\eta_{inv}} \right) \eta_{bat}$$

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as:

$$C_{bat}(t) = C_{bat}(t-1) \cdot (1 - \sigma) - \left(\frac{E_L(t)}{\eta_{inv}} - (E_{PV}(t) + E_{WG}(t)) \right)$$

Where, $C_{bat}(t)$ and $C_{bat}(t-1)$ are the available battery bank capacity (Wh) at hour t and $t-1$, respectively; η_{bat} = the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and while charging, the efficiency is 0.65 to 0.85 depending on the charging current) (Bin et al., 2003), σ = self-discharge rate of the battery bank. The manufacturer documentation gives a self-discharge of 25 % over six months for a storage temperature of 20 °C, that is to say 0.14 % per day (Markvart et al., 2003). $E_{PV}(t)$ and $E_{WG}(t)$ are the energy generated by PV and wind generators, respectively; $E_L(t)$ = the load demand at hour t and η_{inv} = the inverter efficiency (in this study it is considered as constant, 92%). At any hour, the storage capacity is subject to the following constraints:

$$C_{bat\ min} \leq C_{bat}(t) \leq C_{bat\ max}$$

Where $C_{bat\ max}$ and $C_{bat\ min}$ are the maximum and minimum allowable storage capacity.

Using for $C_{bat\ max}$ the storage nominal capacity C_{batn} , then

$$C_{bat\ min} = DOD \cdot C_{batn}$$

Where DOD (%) represents the maximum permissible depth of battery discharge.

III. MODELLING OF SYSTEM RELIABILITY

Power reliability analysis has been considered as an important step in system design process, because of the intermittent solar radiation and wind speed characteristics. Several approaches are used to achieve the optimal configurations of hybrid systems in term of technical analysis. Between these methods, we find the least square

To regulate system voltage and to supply power to load in case of low wind speed or low solar radiation, a battery bank is used which is usually made of the lead-acid type to store surplus electrical energy. During the charging process, when the total output of PV and wind generators is greater than the load demand, ie when power generation cannot satisfy load demand requirement, the available battery bank capacity at hour t can be described by (Bogdan et al., 1996.; Bin et al., 2003):

method applied by (Kellogg et al., 1996; Borowy et al., 1994), the trade-off method (Elhadidy et al., 1999; Gavanidou et al., 1993) and the technical approach also called loss of power supply probability (LPSP) (Abouzahr et al., 1990, 1991; Hongxing et al., 2002; Yang et al., 2002;).

LPSP is defined as the probability that an insufficient power supply results when the hybrid system (PV module, wind turbine and battery storage) is unable to satisfy the load demand (Yang et al., 2003). A LPSP of 0 means the load will always be satisfied, and LPSP of 1 means that the load will never satisfied (H. Yang et al. 2008). Loss of power supply probability (LPSP) is a statistical parameter to measure of the system performance for an assumed or known load distribution.

In this paper the probabilistic approach is used to calculate the LPSP in order to avoid computational burden thus PLSP is defined as follows: (Mr. Sandeep V Karemore, Mr Shubhash Y Kamdi).

$$LPSP = \frac{\sum_{t=0}^T Power\ failure\ time}{T}$$

$$LPSP = \frac{\sum_{t=0}^T Power\ available - Power\ needed}{T}$$

Where

T = No. of hours in the study with hourly weather data input. The power failure time is defined as that time the load is not satisfied when the power generated by both the wind turbine and PV array is insufficient and battery storage is depleted.

A. System size optimization

The required number of WGs, PV module and batteries for a given load demand are calculated as follows:

Calculate the hourly energy output from individual wind generator and PV module for a typical year using wind speed and solar insolation of the site. In order to match the generation with the given hourly load of a year, different combination of wind generator and PV module is used. There will be energy deficit during several consecutive hours in between the hours of excess energy generation for each of the combination. This cluster of energy deficit cannot be supplies by renewable sources. The combination

of wind generator and PV module is selected which minimizes the maximum deficit. The amount of maximum deficit is used to determine the storage size ie. the size of the battery. Loss of power supply probability (LPSP) and 10-years total cost of the hybrid renewable power system are calculated for each of these combination. Optimal combination is selected based on desired LPSP and minimum total cost of the system.

TABLE I SPECIFICATION OF PV MODULE

Type	Monocrystalline silicon
Short circuit voltage	37.8 V
Short circuit current	8.89 A
Maximum power voltage	31.2 V
Maximum power current	8.18 A
Maximum power rating	255 W
NOCT	45.7 C

TABLE II SPECIFICATION OF WIND TURBINE

Power	1000 W
Cut in wind speed	2.5 m/s
Rated wind speed	10 m/s
Maximum wind velocity	40 m/s
H _{low}	11 m
H _{high}	35 m

TABLE III SPECIFICATION OF BATTERY

Battery model	Fullriver AGM
Voltage	12 V
Capacity	415 Ah
Price	1032 (\$)

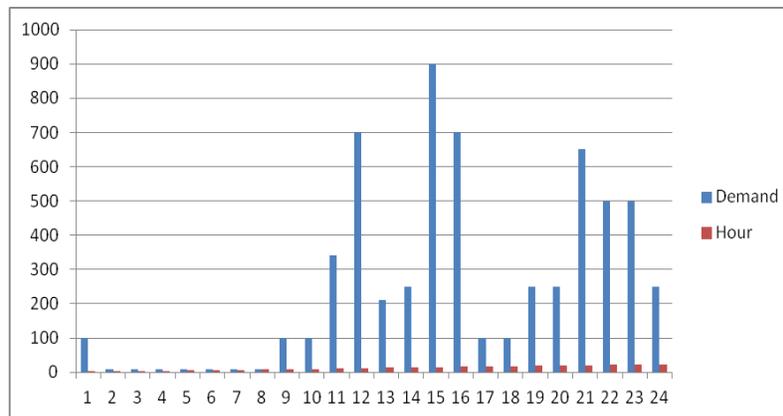


Fig.2 Hourly Load of a day

IV. RESULTS AND DISCUSSION

A combination of different wind generator and PV module was used to match the energy generation with the load. There was energy deficit in each group of consecutive

hours of excess generation, for each of these combinations. Maximum amount of deficit in a cluster among these was determined by calculating the total amount of energy deficit in each of these clusters throughout the year. A simple table was created for this calculation. The first column shows the

energy generation of PV module, second column shows the energy generation of WG and third column shows the demand. In the next column total energy generation by WG and PV module is shown. In the next column difference between generation and demand is found negative sign before the energy difference indicates the deficit. In the last

column total energy deficit in this group is calculated. It is impossible for renewable energy to meet these deficit directly, for this purpose we need a storage system i.e. batteries. The excess energy generated by this system could store by charging the battery.

TABLE IV CALCULATION OF TOTAL ENERGY DEFICIT

PV Gen. (V)	WG Gen.(W)	Demand (W)	Total Gen.	Difference between Gen. & Demand	Deficit	Total deficit
61.26	1.2	200	206	6.76	0	
38.99	1.5	200	209.13	9.23	0	
61.67	2.63	700	72.45	-627.54	-627.54	
61.63	2.5	500	0	-461.56	-461.56	
59.77	2.8	500	0	-500	-500	
43.38	2.85	300	0	-300	-300	
73.192	1.15	200	0	-200	-200	
69.14	1.23	10	0	-10	-10	
57.14	1.58	10	0	-10	-10	
59.166	1.46	10	59.35	49.35	0	
						2109.1

TABLE V COMBINATION OF WG, PV AND BATTERY BANK

WG No.	PV No.	Battery No.	Total cost(US\$)	LPSP
1	20	4	11936	0.113
1	21	4	12206	0.1091
1	25	4	13286	0.0463
1	28	4	14096	0.0218
1	30	4	14636	0.0009
1	33	4	15446	0
1	34	4	15716	0
1	35	4	15986	0
2	20	4	14336	0.217
2	25	5	16720	0.1347
2	33	6	19914	0.152

Total cost (including capital cost and maintenance cost, replacement cost and operation cost) and LPSP were calculated for each of these combinations. Total lifetime of the system is calculated to be 20 years. The system was sized for loss of power supply probability of zero i.e. the load will always satisfy the demand. The number of WG, PV, and battery were found 1, 33 and 4 that satisfy LPSP of zero value with minimum cost.

V. CONCLUSION

The optimal sizing of wind solar hybrid system with battery storage, using an optimization model has been presented in this work. Loss of power supply probability LPSP concept is used to configure the system reliability. The combination of components with the lowest levelised cost of energy is considered as the economical optimal configuration.

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