

The HSWSO Model for Sizing Hybrid Solar-Wind Power Generation Systems and a Case Study

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ABSTRACT: System reliability under varying weather conditions and the corresponding system cost are the two main concerns for designing hybrid solar-wind power generation systems. This paper introduces the Hybrid Solar-Wind System Optimization Sizing (HSWSO) model, to optimize the capacity sizes of different components of hybrid solar-wind power generation systems employing a battery bank. With the incorporated HSWSO model, the sizing optimization of hybrid systems can be achieved technically and economically according to the system reliability requirements. A project case is chosen and simulated to show the importance and reliability of the HSWSO model for sizing the capacities of wind turbines, PV panel and battery bank of hybrid solar-wind systems. The results give the optimal configurations of the hybrid system with the lowest LCE according to the desired system reliability requirements for the demand load. The weighting relationship among three sizing parameters is discussed accordingly. This paper also investigates the influence of the prices of batteries and PV modules on the optimal sizing and the LCE calculation.

Keywords: hybrid solar-wind, optimization sizing, probability, levelised cost of energy

NOMENCLATURE

h	The tower height of wind turbine, m
C	Battery capacity, Ah
P	Power, W

Greeks

γ	Azimuth angle of the plane, radians
β	Slope angle of the plane, radians

Subscripts

bat	Battery
W	Wind turbine

1. INTRODUCTION

For different regions and locations, climatic conditions, including solar irradiance, wind speed, temperature, and so forth, are always changing. Thus, for electric power production from photovoltaic (PV) modules and wind turbines, there exist instability shortcomings. In order to efficiently and economically utilize renewable energy resources of wind and solar energy applications, the optimum match design sizing method, is very important for solar-wind power generation systems with battery bank. The sizing optimization method can help guarantee the lowest investment with a reasonable and full use of the PV system, wind system and battery bank, so that the system can work at the optimum conditions with the optimal configurations in terms of investment and power reliability requirement of the demand load.

There are number of studies about the optimization sizing of hybrid PV-wind system since the popular utilization of photovoltaic modules and wind turbines after 1980s. There are three main approaches to achieve the optimal configurations of hybrid systems accordingly in terms of technical analysis and economical analysis, i.e. the least square method, the Loss of Power Supply Probability (LPSP) method and the trade-off method.

A novel optimum sizing tool for hybrid solar-wind systems employing a battery bank, the Hybrid Solar-Wind System Optimization Sizing (HSWSO) model, is introduced, which was developed based on the Loss of Power Supply Probability (LPSP) concept and the Levelised Cost of Energy (LCE) concept by the author [1][2][3].

This paper gives the simulation results for one field project, i.e. the optimization sizing of the hybrid system for a communication station at Shanwei of Guangdong province by running the HSWSO program. This project is to supply power for one telecommunication relay station on one remote island. The simulation results provide the optimal configurations of the hybrid system which are identified technically and economically according to the system reliability requirements. The weighting relationship among three sizing parameters is discussed accordingly. In terms of present price standard and two assumed future price standards to predict the future trends, this paper also investigates the influence of the prices of batteries and PV modules on the optimal sizing and the LCE calculation and compares the simulation results.

2. THE HSWSO MODEL

2.1 Hybrid Solar-Wind Power System

A hybrid solar-wind power generation system mainly consists of a PV system, a wind power system, a battery bank, rectifier, inverter, controller, and other accessory equipments and cables. Sometimes the system loads also include one dump load for safety protection.

The power supply from the PV modules and the wind turbine to the demand side, the battery bank and the dump load obey the following priority: first the demand side; second the battery bank; and, lastly, the dump load. In order to predict the hybrid system performance, individual components need to be modeled first and then their mix can be evaluated to meet the load demand.

2.2 The Components of the HSWSO Model

The HSWSO model is a simulation tool to obtain the optimal configuration of a hybrid solar-wind power generation system employing a battery bank in terms of the LPSP technique and the LCE concept. It includes three models:

1. Modeling of the hybrid solar-wind power generation system, mainly including modeling of the PV system, modeling of wind energy conversion system, modeling of battery bank and the load model;
2. The reliability model based on the LPSP concept;
3. The economic model based on the LCE concept.

There are three main sizing parameters in the simulation, i.e. the capacity of PV system, the rated power of wind system, and the capacity of battery bank. Additionally, the orientations of PV modules and the tower heights of wind turbines are also considered. The optimum configuration can be identified from the set of the above obtained configurations by achieving the lowest Levelised Cost of Energy. The LCE model is incorporated to get the optimal combination of hybrid systems both technically and economically. The LPSP technique, which is considered to be the criteria for sizing, is the probability that an insufficient power supply results when the hybrid system is unable to satisfy the load demand. Using the LPSP objective function, the configurations of a hybrid system which can meet the system reliability requirements can be obtained.

2.3 The Flowchart of the HSWSO Model

The flowchart is illustrated in Fig. 1. For a given load distribution and a desired LPSP value, the system configurations or

combinations can be identified according to the simulation models and the weather data input. The configurations include the number of PV modules, the capacity of wind turbine, the capacity of battery bank, the orientation (γ, β) of PV modules, and the tower height (h) of the wind turbine. All configurations can guarantee the system reliability requirement or the desired system LPSP.

For the desired LPSP value, the optimal configuration can be identified finally from the set of configurations by achieving the lowest Levelised Cost of Energy. This can be performed by applying the LCE model. Thus, the hybrid system can be sized technically and economically according to the system reliability requirements. The three sizing parameters, the hub height of wind turbine, the orientations of PV modules, performance simulation models, costs of hybrid components and applied local weather data all can influence the sizing calculation results. The method can be applied for sizing and evaluating hybrid solar-wind power generation systems.

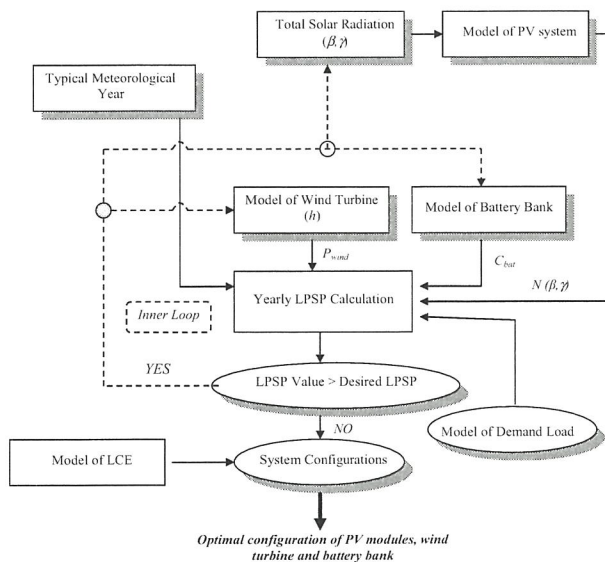


Figure 1: Flow chart of the HSWSO method

3. A CASE STUDY

A case study is carried out for one project, i.e. the optimization sizing and operating characteristics of the hybrid system for a communication station based no Guangdong of China by running the HSWSO program.

This project is to supply power for a telecommunication relay station on a remote island at Shanwei of Guangdong province, China. Its demand load includes 700 W carrier wave (220V AC) and 55 W microwave (24V DC). According to the project requirement and technical considerations, 1000 W is chosen as the demand load.

For the PV array, the optimization starts from 20 PV modules. The panels are facing south with 29.5° inclination angle. Considering the capacity of the demand load, 0.5 kW wind generator is chosen as the starting point with an interval of 0.1 kW. Since the tower heights of wind turbines affect the simulation results significantly, 20 meter is chosen for the tower. All the energy losses F_A in a PV sub-system, including connection loss, wiring loss and other losses, are taken as 5%. The initial price, replacement cost and lifetime of the PV modules, wind system and the battery bank are listed in Table 1. The configuration with the lowest LCE is taken as the optimal one from the set of configurations which guarantee the required reliability of power supply.

Table 1: The initial price, replacement cost and lifespan of the system component

	Initial cost	Replacement cost (per year)	Lifespan (years)
PV modules	3,330 US\$/kW	10 US\$/kW	25
Wind system	2,000 US\$/kW	20 US\$/kW	20
Battery bank	80 US\$/kAh	25 US\$/kAh	4

Note: for the coming simulations, P is the original cost in the above table; P_1 is the cost with the price of batteries to half; and P_2 is the cost when the price of PV modules is decreased to half.

4. SIMULATION RESULTS

The relationships between system reliabilities and system configurations are studied, as well as the relationships between the LCE and system configurations. The optimal configurations of the hybrid system are given accordingly for different desired reliability requirements.

4.1 Reliabilities and System Configurations

Fig. 2, 3 and 4 show the results of the relationship between LPSP values or system reliabilities and system configurations.

Fig. 2 shows the relationships for 1-day-storage battery bank. It's obvious that most configurations of wind turbine and PV modules with low LPSP values (or high system reliabilities) are located in the middle area where combinations have moderate numbers of PV modules and moderate capacity of wind turbines. It also shows that LPSP can reach zero only when the rated power of wind turbine (WT) reaches 10 kW and number of PV modules reaches 270 for alone systems with 1-day-storage battery bank. Among these configurations, the ones meeting the desired LPSP values can be obtained.

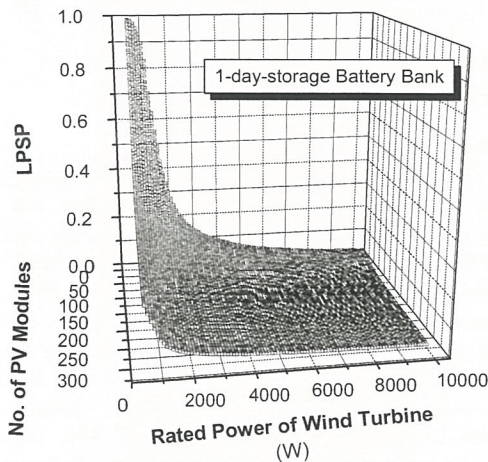


Figure 2: Reliabilities vs. two sizing parameters for 1-day-storage battery bank

For the battery bank with 3-day-storage and 5-day storage, the LPSP values can reach zero very soon with fewer number of PV modules and smaller wind turbine, as shown in Fig. 3 and Fig. 4. It means the hybrid system with more batteries can meet the demand load with less supply failure. According to these simulation results, the reliability can be obtained for different combinations of the hybrid solar-wind system.

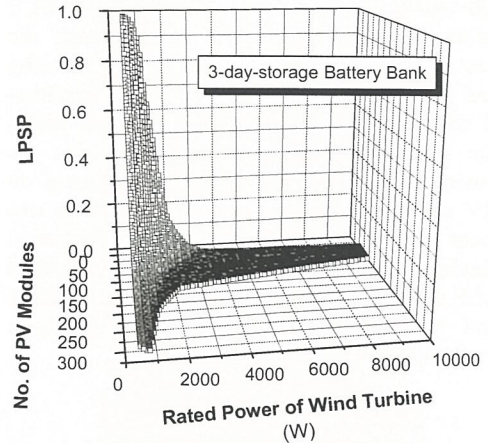


Figure 3: Reliabilities vs. two sizing parameters for 3-day-storage battery bank

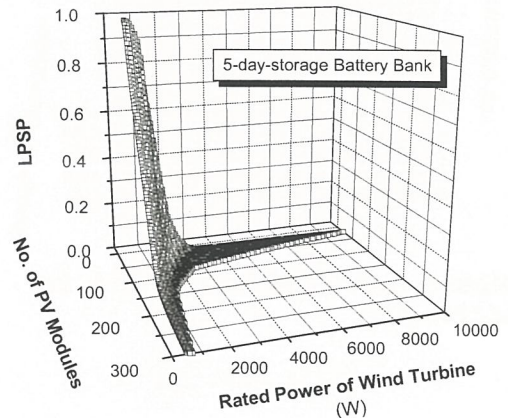


Figure 4: Reliabilities vs. two sizing parameters for 5-day-storage battery bank

4.2 LCE and System Configurations

The configurations meeting different desired LPSP requirements are obtained technically. After the technical process, the Levelised Cost of Energy (LCE) is utilized as the economic benchmark. The simulation results are demonstrated, and the relationships between the LCE and system configurations are analyzed. As shown in Figures 5, 6 and 7, the curves of the LCE for those configurations meeting the desired LPSPs are plotted. Obviously, one point with the minimum LCE value occurs in each curve which means the best configuration for one certain LPSP value and one certain battery bank. This configuration is considered as the optimal one which meets the system reliability requirement with the lowest LCE value. The grey dashed curves on XY surfaces give the configurations which can meet the system reliability requirements. Having a deeper look into figures, the lowest LCE is found when the capacity of wind turbine and the number of PV modules are both moderate.

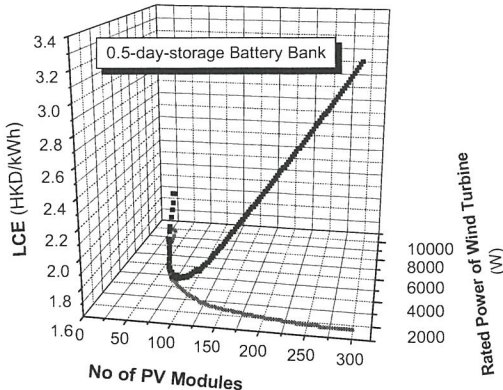


Figure 5: LCE vs. system configurations for an LPSP of 5%

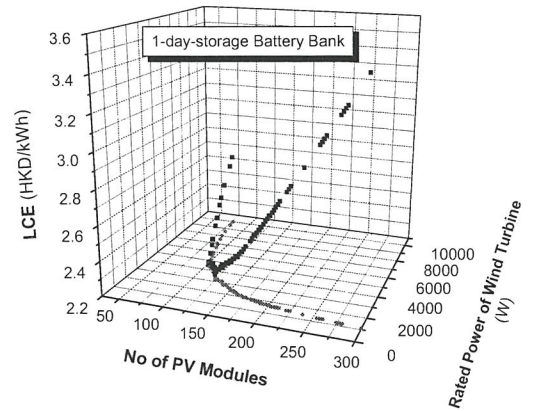


Figure 6: LCE vs. system configurations for an LPSP of 1%

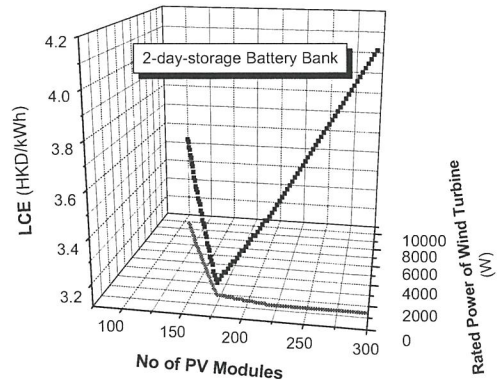


Figure 7: LCE vs. system configurations for an LPSP of 0%

4.5 Sizing Optimization

The minimum Levelised Costs of Energy for different employed battery numbers are given in Fig.8. The best configuration for an LPSP of 5% happens when the battery bank only employs 10 batteries which mean 50% capacity of one day's power consumption by the demand side. The battery bank is weighty in the LCE calculation. Fewer batteries are suitable for low reliable requirement systems with lower cost. For an LPSP of 1%, the configurations with 0.5-day-storage battery bank cannot meet the reliability requirement, but the configurations with more than 1-day-

storage battery bank can. Similarly, the optimal configuration is the system with the fewest batteries of 1-day-storage battery bank as battery is very expensive with short lifespan. The optimal combination for 100% reliability system comes with 2-day-storage battery bank, and only the configuration with more than 1.5-day-storage battery bank can meet this reliability requirement.

These results may change for different types of PV modules, wind turbines and batteries, and different costs of equipments. The heights of wind turbines and orientations of PV modules also influence the simulation results. Increasing the number of PV panels and capacity of wind turbine can be a better choice than just increasing the number of batteries since batteries are much more expensive with short lifespan. But, for high reliable systems, too few batteries cannot meet the reliability requirements, which causes high cost because too many PV modules or too large wind turbines are required. Higher reliable systems are quite more expensive than lower requirement systems. Choosing an optimal system configuration according to system reliability requirements can help save investments and avoid blind capital spending.

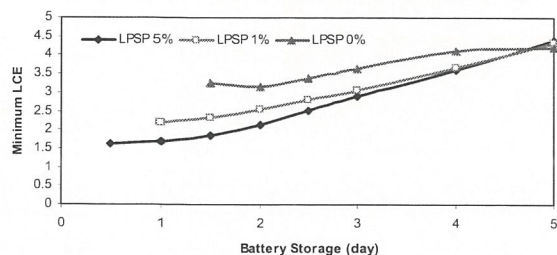


Figure 8: The lowest LCE and the capacity of battery bank

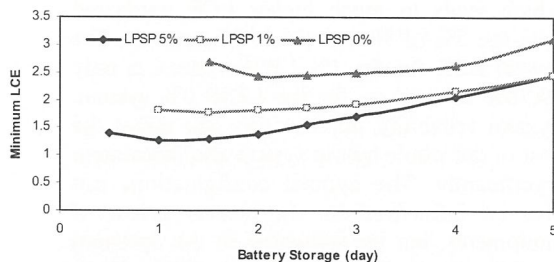


Figure 9: The lowest LCE and capacity of battery bank for the assumption P1

4.6 Results for Other Two Assumptions

Presently, the price of wind turbines is competitive compared with other energy resources, which means the potential space for their prices is limited. But, PV Modules and batteries can own large potential drop in prices with new technologies coming ahead. Two assumptions are made for further analysis accordingly. The simulation results: for an LPSP of 0%, the minimum costs can be reduced to be 76.63% (P1) and 76.99% (P2) of the present one (P) respectively. Meanwhile, for the LPSP of 5%, the costs can be reduced to 78.74% and 80.72% respectively while the optimal configuration for P1 is also changed to the one with fewer batteries. Similar results are obtained for $LPSP = 1\%$ case. The simulation results of the lowest LCE for the first assumption P1 are demonstrated in Fig. 9.

5 CONCLUSIONS

The HSWSO model is introduced to optimize the sizing of the hybrid solar-wind power generation system employing a battery bank. A hybrid solar-wind system is simulated by running the HSWSO program, and its relationships with system configurations are also analyzed. The optimal configurations of the hybrid system are obtained in terms of different desired system reliability requirements and the LCE.

For the system with 0% LPSP, more batteries and more PV modules are needed, but less capacity of wind turbine is necessary,

which leads to much higher LCE compared with the 5% LPSP and 1% LPSP systems. The lowest LCE for the 1% LPSP system is only 69.75% of the one for the LPSP 0% system. System reliability requirements can affect the cost of the whole hybrid system and investment significantly. The optimal configurations can also be influenced by the present prices of equipments, but the influence on the optimum configurations is insignificant. The future trends of equipment prices will affect the optimization simulation results.

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