# Design of a hybrid solar-wind powered charging station for electric vehicles

Haiying Li, Hao Liu, Aimin Ji, Feng Li, Yongli Jia
College of Metallurgy and Energy Hebei United University
Tangshan, China
lha890508@163.com

***Abstract*—Charging station, as one of the most important aspects of electric vehicle industry, must be able to adapt the fast development of electric vehicles. In this work, a hybrid solar-wind powered charging station was designed to provide electricity for the electric vehicles according to the wind and solar condition of the coastal areas in Tangshan. The key components including wind turbines, PV modules, batteries, an inverter and other controllers were considered. In order to determine the capacities of the components, LPSP was used as a control condition to obtain the configurations achieving the demand energy and the costs of every configuration as the other control condition were calculated to optimize the system. At last, the minimum-cost configuration achieving the demand energy was found as the result of the designation.**

***Keywords—electric vehicle; power station; solar-wind hybrid; optimization***

## I. INTRODUCTION

Electric vehicles play an important role in energy saving and emission reduction of greenhouse gases. Power stations are the power supply places for electric vehicles. The electricity of the power station is supplied by power grid traditionally. A power station with solar-wind hybrid system can save energy and reduce greenhouse emission more deeply.

This solar-wind hybrid system is to be used to provide electricity to a small size electric vehicle in Caofeidian, Tangshan. The voltage for charging the vehicle is 320V, and the current is 30A. It takes three hours to charge the vehicle before it is full. The whole energy used to charge the vehicle is 30 kW·h, so the hybrid system must generate at least the same amount of electricity in a single day. Usually, the electric vehicle is charged at night, so the PV module can generate electricity at daytime and store them in the batteries, and at last provide them to the vehicle at night.

The parameters to be determined was the number of PV modules, the altitude angle of PV modules, the azimuth of PV modules, the number of wind turbines, the height of wind turbines and the capacity of batteries.

In order to optimize the configurations of the hybrid system, loss of power supply probability (LPSP) [1] method was used to determine the parameters above. This method was based on the output of PV modules and wind turbines and the performance of the batteries, calculated the energy provided by the whole system, compared it with the desired energy, and finally found the configurations that achieved the demand energy. Then, the costs of every configuration were calculated and the optimal point was found.

## II. MODEL DESCRIPTIONS

The components of the system were wind turbines, PV modules, batteries, an inverter and other controllers. These components combined together to provide energy, as shown in Fig. 1.

### *A. PV module model*

This model was mainly the method to calculate the output power of PV modules. In this model there were three parameters to be determined: the number of PV modules, the altitude angle of PV modules, and the azimuth of PV modules.

The installation of PV modules should guarantee that the PV modules could receive the most amount of solar radiation. To achieve this purpose, Ecotect Analysis was used to find the altitude angle and azimuth of the PV modules. The best altitude angle and azimuth of the PV modules were 60.7° and 170.2°, respectively. The solar radiation on tilted surface in Tangshan is plotted in Fig. 2. The amount of solar radiation on the tilted PV modules of the whole year is $1.61\times10^6$ W·h/m$^2$.

The output of PV modules was mainly influenced by the solar radiation on the panel surface, the ambient temperature, and the area of PV modules. Equations (1)-(3) were used to calculate the output of the PV modules.

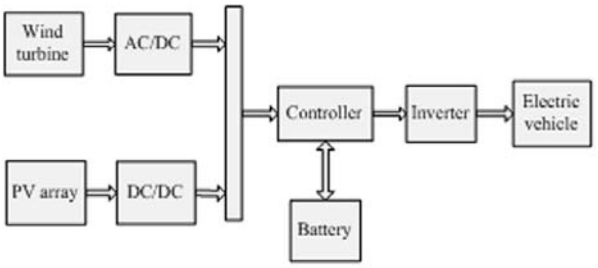

Figure 1. Diagram of the solar-wind hybrid power station

---

Supported by the National Technology Support Program of China (2011BAG02B09)

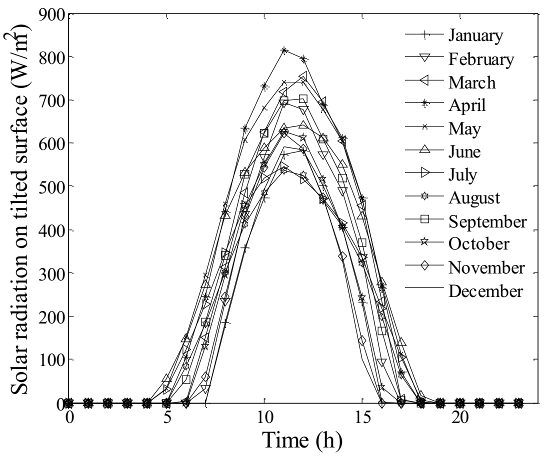

Figure 2. Solar radiation on tilted surface

The output power of PV modules was given below [1]:

$$P_{pv}=\eta A_m G_t \quad (1)$$

where $P_{PV}$ was the output of PV modules (W), $\eta$ the efficiency of PV modules, $A_m$ the area of PV modules (m$^2$), and $G_t$ was the solar radiation on tilted surface (W/m$^2$).

The efficiency of PV modules could be calculated by the following equation [1]:

$$\eta=\eta_r\eta_p\left[1-\beta_t\left(T_c-T_r\right)\right] \quad (2)$$

where $\eta_r$ was the reference efficiency of PV modules, $\eta_p$ the efficiency of maximum power point tracker, $\beta_t$ the temperature coefficient of efficiency, 0.005 [2] was used in this study, $T_c$ the temperature of PV cell ($^oC$), and $T_r$ was the reference temperature of PV cell ($^oC$ ).

The temperature of PV cell could be calculated by the following equation [1]:

$$T_c=T_a+G_t\left(\left(NOCT-20\right)/800\right) \quad (3)$$

where $T_a$ was the ambient temperature ($^oC$), NOCT the normal operating cell temperature ($^oC$ ).

### B. *Wind turbine model*

This model was to calculate the output of wind turbines of the hybrid system. The height of wind turbines and the capacity of wind turbines were to be determined. Wind speed, the height of wind turbines, the capacity of wind turbines and the output curve of wind turbines were the main factors that influenced the performance of wind turbines.

In order to save costs, ten meters was chosen as the height of wind turbines in this power station. The following equation [2] was used to calculate the wind speed at ten meters:

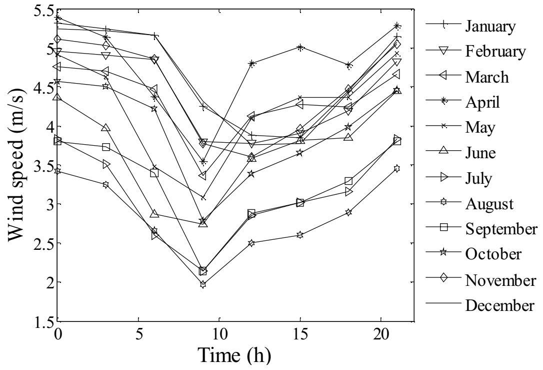

Figure 3. Monthly average three-hour interval wind speed data at ten meters height

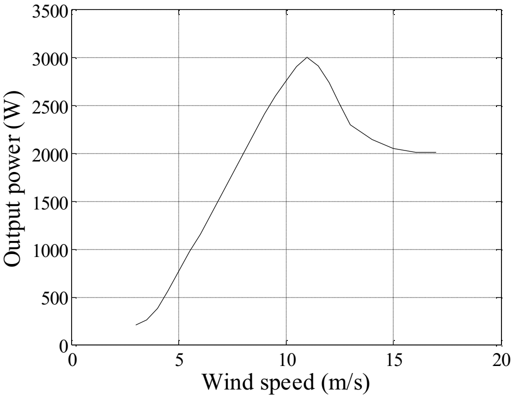

Figure 4. Output curve of wind turbine

$$v=v_0\left(H/H_0\right)^{\alpha} \quad (4)$$

where $v$ was the wind speed at ten meters (m/s), $v_0$ the wind speed at reference height (m/s), $H$ the height of the wind turbine hub (m), here was 10 m, $H_0$ the reference height (m), and $\alpha$ was the wind speed power law coefficient, which was 1/7.

The monthly average three-hour interval wind speed data at ten meters height is shown in Fig. 3.

The output curve of the wind turbine could be obtained from the manufacture. Based on the output curve, four cubic equations could be found using the method of least squares, so the power output of the wind turbine could be calculated. The output curve is shown in Fig. 4.

### C. *Battery model*

Power generated directly by wind turbines and PV modules is unstable, and usually can’t meet the demand desirably. So the batteries were used to store the excess energy when the energy generated by wind turbines and PV modules was more than the demand energy and supply energy to the load when the energy generated by wind turbines and PV modules was less than the demand energy.

This model was to describe the state of batteries of charging and discharging processes and the energy supply conditions when cooperating with wind turbines and PV modules. The capacity of batteries was to be determined in this model.

In charging process, the state of batteries could be expressed by the equation below [2]:

$$C_{bat}(t)=C_{bat}(t\text{-}1)(1\text{-}\sigma)+\left(E_{pv}(t)+E_{w}(t)\text{-}E_{load}(t)/\eta_{inv}\right)\eta_{bat} \tag{5}$$

In discharging process, the state of batteries could be expressed by the equation below [2]:

$$C_{bat}(t)=C_{bat}(t\text{-}1)(1\text{-}\sigma)\text{-}\left(E_{load}(t)/\eta_{inv}\text{-}\left(E_{pv}(t)+E_{pv}(t)\right)\right) \tag{6}$$

where $C_{bat}(t)$ was the energy stored in the batteries at the time t, $C_{bat}(t\text{-}1)$ the energy stored in the batteries at the time t-1, $\sigma$ the battery self-discharge rate, $E_{pv}(t)$, $E_{w}(t)$ and $E_{load}(t)$ the energy generated by PV modules, the energy generated by wind turbines and the demand energy at the time t, respectively, $\eta_{inv}$ the efficiency of the inverter, 0.9 was used in this study, and $\eta_{bat}$ was the battery efficiency, 0.8 was used during charging process and 1 was used during discharging process[2].

The energy stored in the batteries must meet the constraints below [2]:

$$C_{bat\,min} \le C_{bat}(t) \le C_{bat\,max} \tag{7}$$

where $C_{bat\,min}$ and $C_{bat\,max}$ was the minimum and maximum energy stored in the batteries. $C_{bat\,max}$ was equal to the nominal capacity of batteries and $C_{bat\,min}$ could be calculated as follows [3]:

$$C_{bat\,min}=(1\text{-}DOD)C_{bat\,n} \tag{8}$$

where $C_{bat\,n}$ was the nominal capacity of batteries, DOD the depth of discharge of batteries, 70% was used in this study.

## III. SYSTEM RELIABILITY

LPSP method was used to assess the reliability of the hybrid system. LPSP could be expressed as follows [1]:

$$LPSP=DE/E_{load} \tag{9}$$

where $LPSP$ was the loss of power supply probability, $DE$ the total deficit energy, $E_{load}$ the total demand energy.

$DE$ could be calculated as follows:

$$DE(t)=DE(t\text{-}1)+E_{load}(t)\text{-}E_{tot}(t) \tag{10}$$

where $DE(t)$ and $DE(t\text{-}1)$ was the deficit energy at the time t and t-1, respectively, $E_{load}(t)$ the demand energy in the time t, $E_{tot}(t)$ the sum of the energy generated by wind turbines and PV modules and the available energy stored in batteries, it could be calculated by the equation below:

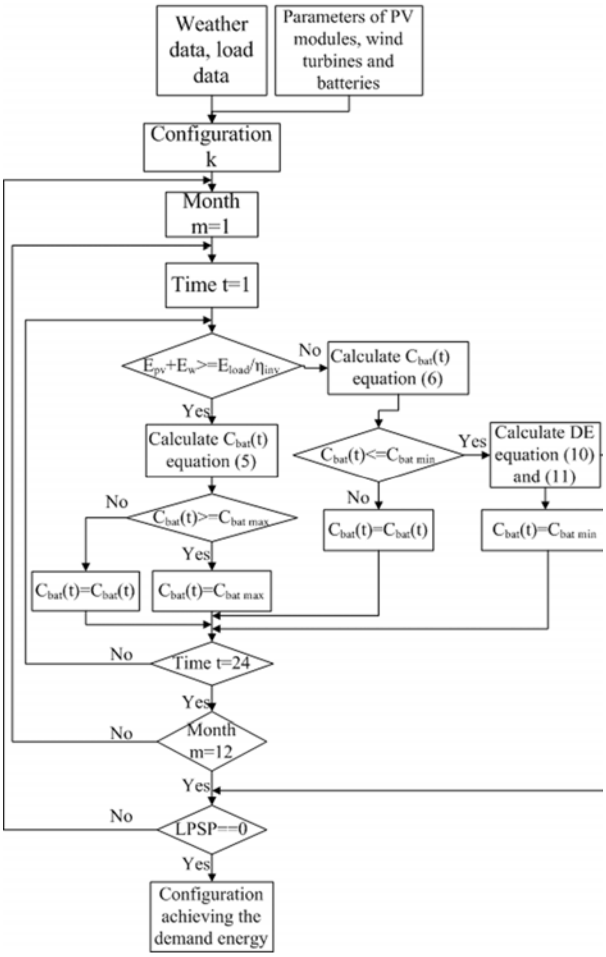

Figure 5. Calculation process

TABLE I. PARAMETERS OF WIND TURBINES

| Type | Rated power (kW) | Max power (kW) | Output voltage (V) | Rated wind speed (m/s) |
|---|---|---|---|---|
| HF4.0-2000W | 2 | 3 | 96 | 8 |

TABLE II. PARAMETERS OF PV MODULES

| Type | Open circuit voltage (V) | Short circuit current (A) | Working voltage (V) | Working current (A) | Peak power (W) | Cell dimensions (mm) | Cells per module | Module efficiency | NOCT (°C) | Conditions (STC) |
|---|---|---|---|---|---|---|---|---|---|---|
| TEP667201 | 44.568 | 8.12 | 37.08 | 7.56 | 280 | 156×156 | 72 | > 13.3% | 46 | AM 1.5<br>$1000\ \mathrm{W/m^2}$ $25\ ^{\circ}\mathrm{C}$ |

TABLE III. PARAMETERS OF BATTERIES

| Type | Nominal capacity (AH) | Charge voltage (V) | Discharge cut-off voltage (V) | Standard charge/discharge current (A) | Self-discharge rate (monthly) | Cycle life with 70%DOD (times) |
|---|---|---|---|---|---|---|
| SE100AHA | 100 | 3.6 | 2.0 | 0.3C | 3% | 3000 |

$$E_{tot}(t)=((E_{pv}(t)+E_w(t))+C_{bat}(t-1)(1-\sigma)-C_{bat\,min})\eta_{inv} \qquad (11)$$

With the equations above, the LPSP of the whole year could be calculated. If it was zero, it meant that there was no deficit energy throughout the year and the hybrid system had a high reliability.

According to the calculation process based on Matlab shown in Fig. 5, the configurations achieving the energy demand could be obtained.

## IV. RESULTS

The electric vehicle was charged from eight to eleven at night. So the demand power was 10 kW between eight and eleven and zero at other times.

The parameters of wind turbines, PV modules and batteries used in this study are shown in Table 1, Table 2 and Table 3, respectively.

After compiling the program with the equations and parameters above, the result can be seen in Fig. 6. Every point on the surface represented a configuration that achieved the demand energy with LPSP equal to 0.

In order to chose the best configuration, the costs of every configuration needed to be calculated. In this study, a simple method was used to calculate the costs of the system. The costs of PV modules, wind turbines and batteries were 32000 yuan/kW, 24000 yuan/kW [4] and 8 yuan/AH, respectively. So the total costs of the hybrid system could be expressed by the following equation:

$$C_{tot}=32000C_{pv}+24000C_w+8C_b \qquad (12)$$

where $C_{tot}$ was the total costs of the hybrid system (yuan), $C_{pv}$ the capacity of the PV modules (kW), $C_w$ the capacity of the wind turbines (kW), and $C_b$ was the capacity of the batteries (AH).

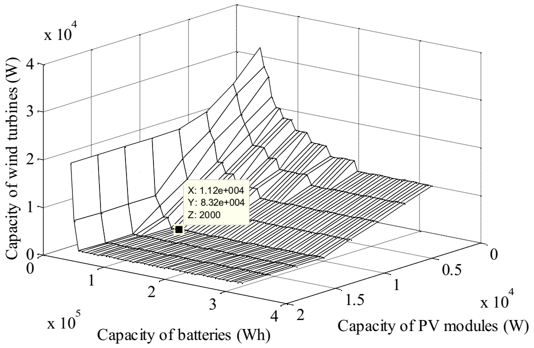

Figure 6. Configurations achieving the demand energy

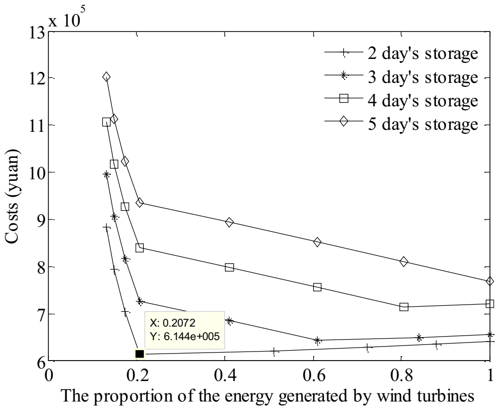

Figure 7. The relation between costs and configurations

Fig. 7 shows the relation between costs and the ratio of output energy from wind turbines and the total output energy of every configuration shown in Fig. 6.

It was to be found that the costs of the hybrid system rose rapidly with the increasing capacity of batteries, and varied with different capacities of PV modules and wind turbine. When the energy generated by wind turbines accounted for 20% of the whole energy generated by the hybrid system, the costs were $6.144\times10^5$ yuan, which was the least compared with the costs of other configurations. The point of the same configuration in Fig. 6 shows that the capacity of PV modules, wind turbines and batteries is 11.2 kW, 2 kW and 83.2 kW·h, respectively.

## V. CONCLUSION

In this paper, a power station with solar-wind hybrid system was designed to provide energy to electric vehicles. Based on the calculation, an optimized configuration with minimum costs and a LPSP equal to zero was chosen. From the calculation and optimization process, it can be concluded that, aiming at a specific load model, both PV modules and wind turbines can achieve the demand energy alone, but usually the costs are higher than hybrid system and there exists more instabilities.

The development of renewable energy can make a big progress of energy saving. Combined with electric vehicle, the solar-wind hybrid power station will improve the situations of energy use and pollutant gas emission in traffic field.

# REFERENCES

[1] S. Diaf, G. Notton, M. Belhamel, M. Haddadi, A. Louche, "Design and techno-economical optimization for hybrid PV/wind system under various meteorological conditions", Applied Energy, vol. 85, pp. 968～987, 2008.

[2] S. Diaf, D. Diaf, M. Belhamel, M. Haddadi, A. Louche, "A methodology for optimal sizing of autonomous hybrid PV/wind system", Energy Policy, vol. 35, pp. 5708～5718, 2007.

[3] Hongxing Yang, Lin Lu, Wei Zhou, "A novel optimization sizing model for hybrid solar-wind power generation system", Solar Energy, vol. 81, pp. 76～84, 2007.

[4] Yongping Yang, Distributed Energy System. Beijing, Chemical Industry Press, 2011.