

# Research on renewable energy power generation complementarity and storage distribution model

Xiaoxia Wei<sup>1</sup>, Jinfang Zhang

State Grid Energy Research Institute, Future Science and Technology Park North Area, Beiqijia, Changping, Beijing, 102209, P.R. China

E-mail: 20583853@qq.com

**Abstract.** This paper mainly studied the equivalent conversion relationships and model of different “quality” energies in process of multi-energy conversion. In energy interconnection system containing wind turbine, photovoltaic cell and energy storage systems, it gives renewable energy and storage distribution development model, considering comprehensive effect of load demand characteristics on energy utilization mode, multi-objective optimization model is established with objectives of both maximized energy utilization ratio and minimized system operation costs. Then, take Chinese one certain area as scenario, and give out “renewable energy utilization”, “energy transfer” and “total operating cost” three different analyses, according to the connection model. The result is compared with that for traditional energy utilization model. Feasibility of the proposed model is verified with simulation results.

## 1. Introduction

Renewable clean energy has become an important part of the current energy structure, and also an important direction of energy development. As a typical representative of renewable energy, wind and solar energy has been large-scale development and wide application. Because of the energy transmission limitation, “energy” has become main form of use. The renewable energy is vulnerable to external environmental factors, showing a strong gap and volatility, large-scale power grid by safe operation of the power system has a significant negative impact. Many studies have proposed the use of micro-grid in the form of a unified integration of various types of energy and load to form independent and interconnected energy systems to reduce the independent operation of the energy supply system to adverse effects, improve the effective utilization of energy by the system [1].

While the single energy utilization mode and the relatively independent operation mode between energy supply systems will result in the problem of insufficient energy consumption and low utilization rate in the system, resulting in excess of renewable energy and not giving full play to the maximum comprehensive benefits of energy. So this research focused on the characteristics of renewable energy interconnection and the interrelationship of energy storage cooperation, and analysed the problems encountered in the process of cooperation, and proposed a model to improve energy efficiency [2].

Solar and wind energy are pollution-free and environment-friendly. However, due to their intermittent and fluctuating characteristics, their utilization and efficiency are greatly limited. In order to improve the utilization efficiency of solar energy, wind energy and other new energy sources, wind and solar power generation system, wind storage system, light storage power generation system, wind solar storage generation system gradually attract people's attention [3].

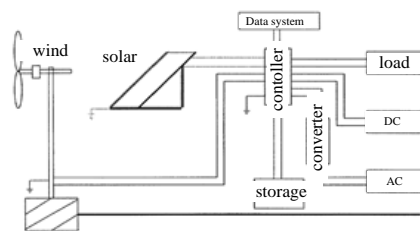


## 2. Renewable energy interconnection characteristics

Wind and solar hybrid power systems are generally used in rural and mountainous areas far away from large power grids. Wind and light power supply systems can hardly provide continuous and stable active power output due to the randomness and fluctuation of wind and solar power. Wind power generation system is using the natural complementarity of wind and solar energy, such as sufficient solar energy in the summer, sufficient wind energy in winter, can greatly reduce the amount of battery in the system, thus improving the system reliability and economy.

Wind-solar hybrid power generation and energy storage system is used to store and release electric energy, which can improve the power output characteristic of the whole wind power generation system, reduce the intermittence and randomness of wind power and photovoltaic power generation and power system requirement real-time balance. Reduce its negative impact on the power grid [4].

From the energy conversion, transmission and utilization process, the transformation and transmission of renewable energy and energy storage, are "energy" form. According to the different demand forms of energy on the load side, the energy needs to be converted into multiple energy forms to match the energy demand of the load side, showed in Figure 1. It can be seen that the equivalent transformation between different "energy" can unite the originally independent energy supply systems and finally form a multi-energy interconnection sharing system, showed in Figure 1. This paper will focus on the process of secondary equivalent conversion between different energies, which is the primary transformation energy model [5,6].



**Figure 1.** Wind, solar and storage connection system

## 3. Renewable energy and storage distribution development model

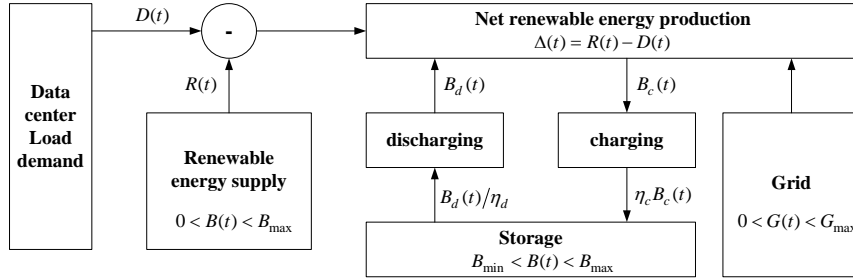
To energy demand, energy demand is treated as a random variable which does not assume any probability distribution. The energy supply, data multi-channel energy centre includes smart grids, storage devices (such as batteries), and new energy sources such as wind energy. The system model is a discrete-time model. From Figure 2, Energy supply and demand model: This paper assumes that energy demand and new energy production are independent of each other a random process[7,8].

At time  $t$ , energy demand is  $D(t)$ , renewable energy production is  $R(t)$ . The net energy supply amount is  $\Delta(t) = R(t) - D(t)$ . The excess renewable energy will be stored in the battery until the battery is fully charged; while new energy can not meet the energy demand will be provided by the grid power and battery.  $G(t)$  is electricity purchased from the grid in order to meet demand, and satisfy the upper and lower boundary  $0 \ll G(t) \ll G_{\max}$ .

The storage battery model and its parameters include energy storage capacity, rated power, and efficiency.  $B_{\max}$  is storage capacity refers, which refers to the battery can store the maximum energy.

The rated power refers to the battery charge and discharge during each charge and discharge the maximum charge, using  $B_{\max}^c$  and  $B_{\max}^d$ . Battery efficiency includes charge efficiency, discharge efficiency and charge-discharge cycle efficiency. The charging efficiency  $\eta_c \in (0,1)$  is the total amount of charging into the battery and the total input energy value. Discharge efficiency  $\eta_d \in (0,1)$  is the effective discharge of the battery and the total energy released by the battery quotient. Battery charge and discharge cycle efficiency of the charge efficiency multiplied by the discharge efficiency,  $\eta = \eta_c \eta_d$ . Although the efficiency of battery charging and discharging will decrease with increasing use time in

actual battery management, efficiency will not change much over a certain period of time. Assuming that the battery charge and discharge efficiency is constant, at time  $t$ , the battery charging amount is  $B(t)$ , charging is  $B_c(t)$ , discharging is  $B_d(t)$ .



**Figure 2.** Renewable energy and storage distribution development model

In order to avoid battery over-discharging, the battery must at least reserve energy at each moment to back up power as a data centre. So, the battery power at each moment must be met  $0 < B(t) < B_{\max}$ . Since the charge and discharge have energy loss, the battery will only charge or discharge at each moment, that is  $t = 0$ , the dynamic update process of the battery power is:

$$B(t+1) = B(t) + \eta_c B_c(t) - B_d(t)/\eta_d \quad (1)$$

Among that,  $0 \leq B_c(t) \leq B_{\max}^c$ ,  $0 \leq B_d(t) \leq B_{\max}^d$ .

The use of renewable energy is vulnerable to the impact of the external environment, the energy output has a great deal of passive, generally can not be with the load demand. In the energy transfer process, energy will be "storage" and "release" two stages of the secondary use. Among them, the energy transfer form of energy storage process can be described as:

$$\begin{cases} B(t+1) = B(t)(1 - \delta_e) + P_{bt}\eta_c \Delta t \\ B(t+1) = B(t)(1 - \delta_e) - P_{bt}\Delta t/\eta_d \end{cases} \quad (2)$$

$B(t)$  is the charging capacity of the energy storage system at time  $t$ .  $B(t+1)$  is the charging capacity of the energy storage system at time  $t+1$ .  $\delta_e$  is self-discharge rate of power storage system.  $P_{bt}$  is the operating power of the power storage system. Positive value is the charging process; the negative value is discharge process.  $\Delta t$  is the gap between  $t$  and  $t+1$ .

#### 4. The optimal algorithm of investment and operation cost for the cooperative system of renewable energy and storage

The objective function of the optimization design is to reduce the investment and operating costs while satisfying the performance indexes. The reliability cost and the environmental treatment cost can be added in order to minimize the total cost of the system[9,10]. After considering the investment and operating costs and environmental management costs according to the target function, this model can be described as:

$$C = \sum_{i=1}^2 \sum_{j=1}^{M_j} C_{ij} P_j + \sum_{i=1}^2 u(P_i) + k_{coe} P_{eens} + e_i \left( \sum_{t=1}^{8760} P_g P_{gridt} + \sum_{k=1}^n \beta_k \alpha_k Q_{gridk} \right) \quad (3)$$

Among them,  $i$  is the different kinds of energy,  $i=1,2$ , which refers to wind and solar.  $M_j$ ,  $C_i$ ,  $P_i$  refers to number, cost and output power.  $u(P_i)$  is operation cost,  $k_{coe}$  is compensation factor.  $P_{eens}$  is less than system power perdition.  $e_i = 0,1$  refer to isolated power system operation and connection to the power line.  $P_g$  is the parallel line price.  $P_{gridt}$  the grid power supply capacity.  $\alpha_k$ ,  $\beta_k$ ,  $Q_{gridk}$  refer to pollution emission factors, pollutant treatment charges and its emission amount.

Considering the boundary condition, power balance limit refers to the wind power; solar power system output power coupled with the power output of the power grid is equal to the user's electricity load. That is:

$$P_{DG} + P_{grid} = P_L \quad (4)$$

Among them,  $P_L$  is total power load.

The power output can not larger than the maximum transmission capacity. And at the same time, wind and solar power needs capacity boundary. That is:

$$\begin{cases} P_{grid} \leq P_{g \max} \\ P_{DG} \leq P_{DG \max} \end{cases} \quad (5)$$

Among them,  $P_{g \max}$ ,  $P_{DG \max}$  refer to maximum transmission capacity and maximum distributed power capacity. For the solar and wind power system has certain fault. So the system must have a certain degree of power supply reliability. The out-of-load probability is the ratio of the terminal time to the total supply time in the statistic time, which is usually less than 2%.

## 5. Analysis of the result of the cooperation of renewable energy and energy storage

Take Chinese one special area as example, to the wind power, photovoltaic power generation system, CCHP system and various types of energy storage system based energy system, the maximum power output of wind power system is 200 kW; the maximum power output of PV system is 200 kW; the maximum power output of CCHP is 200 kW; the maximum cooling power of 300kW; battery maximum charge and discharge power of 100kW; storage system maximum operating power of 200kW.

The mode 1: Considering the CCHP continuous supply system adopts the coupling operation mode of "heat-set" to meet the cooling load demand in the system, the demand of the power load is supplied by other distributed power supply.

The mode2: Renewable energy quota energy storage, the provision of electrical energy supply.

The three operating modes are compared: "renewable energy utilization", "energy transfer" and "total operating cost".

### 5.1. Renewable energy utilization

In mode 1, renewable energy will be converted into electricity as the form of a single use, so in this mode of operation, the excess energy can not be forced to abandon, resulting in short of energy use. Since the wind and solar energy are renewable energy sources, and the system operation and maintenance costs are low, are 0.11 yuan / (kW · h) and 0.08 yuan / (kW · h) respectively. The renewable energy operating cost of mode 1 is 229.89 yuan. Compared with the operating mode 1, the utilization of renewable energy in the system can be increased by 11.5%, and the running cost of the system is increased to 264.45 yuan.

In mode 1, the cooling load demand of the system is all supplied by the CCHP co-supply system in the coupled operation mode of "heat-set", and the same amount of cooling load demand is satisfied with respect to the mode 2. The cost of CCHP energy loss is 2.03 yuan. Resulting in higher operating costs of the system, which will increase the operating cost of 425.38 yuan, the mode 2 operating cost of the system can be reduced by 390.82 yuan, showed in Table 1.

**Table 1.** Renewable energy utilization type under different modes

	Energy supply(kW·h)		Utilization (kW·h)		Utilization(%)
	solar	wind	Supply	cooling	
Mode1			2355.19	-	85.48
Mode2	972.54	1782.73	2355.19	314.14	96.88

### 5.2. Energy transfer

In mode 2, with the energy equivalent substitution relationship, according to the load demand system, use the different type of energy to storage, and form into the energy transfer. In the TOU price under the guidance of the flexibility to change their operating conditions, and priority to participate in scheduling, the valley of the energy transfer to the peak hours to use. The renewable energy efficiency will be increased by 3.11%. In order to satisfy the same amount of load demand, the mode 1 is mainly depending on CCHP system (energy loss is 2608.71kW·h), and needing to buy extra power at high price (the total energy amount is 27.5kW·h), which can make the operation cost as 550.43yuan, showed in Table2.

**Table 2.** Energy transfer structure

Transfer		Energy structure	
Power (kW·h)	Cooling(kW·h)	Renewable energy (kW·h)	Extra grid power (kW·h)
800	1620	85.95	1555.65

### 5.3. Total operating cost

Mode 1 is short of renewable energy utilization, operating costs are relatively low, showed in Table 3. To the CCHP supply, mode 1 adopts heat decision of electricity, with higher energy consumption and operating costs. In the energy price guidance of mode 2, form the timing of the transfer, and the operation of the system to add a certain operating costs. Mode 1 will be surplus of electricity sent to large power grids, and achieved a certain income, but can not offset the high cost of the system inputs.

**Table 3.** Costs under two modes

project		Operation cost (yuan)	
		Mode 1	Mode2
wind		152.09	196.10
Photovoltaic		77.80	77.80
CCHP		1676.81	358.54
Energy transfer	Power	-	32
	Cooling	-	32.40
Power connection	Extra sending	693.92	-
	buying	13.92	264.46
synthesize cost		1226.69	961.30

## 6. Conclusion

This paper analysed different energy equivalent transmission relation. Construct renewable energy and storage distribution development model. And realize the multi-energy connection. Through the comparison with traditional modes, this paper verified the model reasonable and advantage. The main conclusions are:

- Through the energy equivalent, it can enhance system utilization to the renewable energy, and reduce the system operation cost.
- Realize the adjustment jointed, can enhance the renewable energy utilization and reduce the energy exchange of different energy, can increase system operation economic efficiency.
- Through the energy in different forms of energy in the timing of the transfer, to a certain extent, reduce the operating costs of the system.

The example gives three "renewable energy utilization", "energy transfer" and "total operating cost" characteristics, compared with traditional energy utilization model, which can showed that the cooperation of renewable and storage has better efficiency.

## Reference

- [1] Ji Y, Ai Q and Xie D 2010 *Power System Technology* vol **34** 15-23
- [2] Zhu X, Han X Q and Qin W P 2015 *Renewable and Sustainable Energy Reviews* vol **42** 453-463
- [3] Zhang H Y, Li S D 2011 *Research on micro grid*. Beijing, China: Tsinghua University 595-598
- [4] Wu X, Yin X G and Song X 2013 *Energy and Power Engineering* **4** 142-149
- [5] Xu J, Sui J and Li B *Energy* **35** 4361-67
- [6] Cho H, Smith A D and Mago P 2014 *Applied Energy* **136** 168-185
- [7] Luo F, Wei G, Xu X and Lu Y 2016 *Journal of Computational and Theoretical Nanoscience* vol **13** 1933-38
- [8] Zhang D and Wang J 2016 *Dianwang Jishu/Power System Technology* **40** 451-458
- [9] Ming W, Jian S, Liu H, Yang L and Yu J 2014 *POWERCON 2014 - 2014 International Conference on Power System Technology: Towards Green, Efficient and Smart Power System, Proceedings* 3361-65
- [10] Zeng Z, Zhao R, Yang H and Tang S 2014 *Renewable and Sustainable Energy Reviews* 701-718