

Application of Fuzzy Control for the Energy Storage System in Improving Wind Power Prediction Accuracy

A Li-nu-er A Mu-ti*, CHAO Qin, TU Er-xun Yi Bu-la-yin, LUO Jian-chun

College of Electrical Engineering, Xinjiang University, Urumqi, China

*Corresponding author: alimaytak@sina.cn

Received August 06, 2013; Revised August 27, 2013; Accepted September 05, 2013

Abstract Today the elaboration degree of wind meteorological information far from enough, which leads to the low wind farm wind power prediction accuracy, causing grid scheduling problems, so as to result in instability in power systems easily. This paper selects zinc bromide battery energy storage system for the measurement of improving the forecast accuracy of the wind farms, adopts fuzzy control and sets up fuzzy control rule base for the energy storage system considering the error probability characteristics and the charge state SOC of the energy storage to control the storage charge and discharge power, and does simulation analysis of a wind farm in XinJiang which introduced into the energy storage. At the same time, compared with the traditional control strategy the results indicate that fuzzy control strategy of energy storage system can more effectively improve the wind power short-term forecast accuracy significantly, 80% of the predicted value meet the requirements of the state grid has less than $\pm 25\%$.

Keywords: battery energy storage, wind power prediction accuracy, traditional control strategy, fuzzy control

Cite This Article: A Li-nu-er A Mu-ti, CHAO Qin, TU Er-xun Yi Bu-la-yin, and LUO Jian-chun, "Application of Fuzzy Control for the Energy Storage System in Improving Wind Power Prediction Accuracy." *American Journal of Energy Research* 1, no. 3 (2013): 54-58. doi: 10.12691/ajer-1-3-3.

1. Introduction

With the expansion of the wind power installed capacity, the wind power output prediction error precision brings serious challenge to the stable operation, dispatching and the safety and the quality insurance of the power system [1]. Taking a wind farm in Xinjiang as an example, 2011 wind farm wind power forecast errors are basically within $\pm 50\%$, therefore the State Grid Corporation of China issued documents to specify the wind power forecast error limit within $\pm 25\%$. At present, even though many kinds of intelligent algorithm were presented to increase the wind power prediction accuracy in researches at home and abroad, but due to the limitation of the forecast technology and the characteristics of the wind volatility, the wind power prediction accuracy is still low, which cannot satisfy the state grid requirements.

The development of energy storage technology provides an effective way for the integration large-scale wind power generation and improving the performance of wind power generation [2]. There are a lot of research at home and abroad, article [3] configured the best energy capacity on the goal of suppressing the wind power fluctuation and set up a control strategy for the energy storage. Article [4] set the load "cut peak valley" as the aim configured several energy storage capacity and compared the effect under several kinds of energy storage capacity, but did no assessment for the capacity. Article [5] incorporated battery energy storage into the wind farm to

get the target of improving forecasting precision and put forward four kinds of optimal control strategy to obtain the energy storage system capacity. Article [6] configured sodium sulfur battery energy storage in the wind farm to make wind power forecast error was improved, thus proved the feasibility of energy storage system in the terms of improving wind power prediction accuracy. To sum up, most studies focus on the using energy storage to smooth wind power output power fluctuation, and studies about improving wind power prediction accuracy with energy storage are rare and control strategy and analysis of energy storage is relatively simple.

Therefore, this article configured zinc bromide battery energy storage system in wind farms, considered error change characteristics and the storage charge and discharge power probability characteristics, selected reasonable rated power and rated capacity of energy storage system and controlled the charge and discharge power adopting fuzzy control strategy, at last achieved the goal of improving wind farm output prediction accuracy. At the same time, for a wind farm in Xinjiang with the configuration of energy storage system, the article had carried on simulation analysis to verify the validity and rationality of using energy storage system which adopted fuzzy control strategy to improve the wind power forecast error precision.

2. The Wind-Storage Joint System Frame Structure

The framework structure of the wind joint energy storage system is shown in Figure 1, which mainly includes the wind power generator, transformer, battery charge and discharge controller, battery energy storage system, etc.

This article selected a certain wind power in Xinjiang which configured with energy storage system to do simulation analysis. The total installed capacity of the wind farm is 140MW, which is made of many sets of direct-drive variable pitch and doubly-fed variable pitch wind turbines of 120KW rated capacity. At the same time, in view of zinc bromide battery having the characteristics of high power and energy performance ,scalability and faster response time, simple maintenance requirements and the rate of long cycle life, etc ,this paper choose zinc bromide battery as energy storage system [7,8].

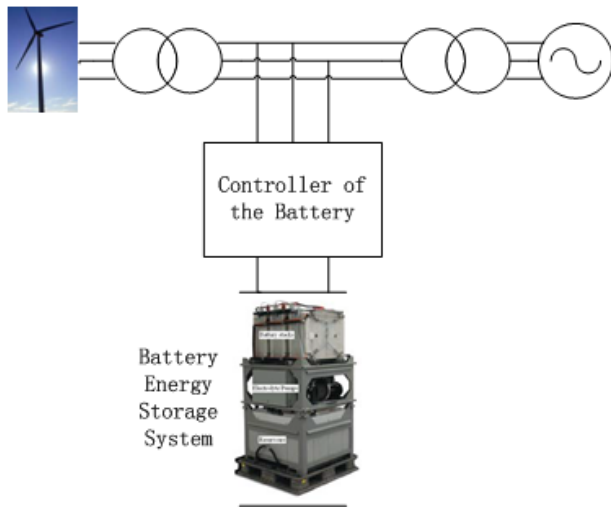


Figure 1. The Wind – Storage System Structure Diagram

Wind turbines are connected to the grid through transformer. Wind farms total power output is equal the combined output power of each wind turbines. Battery energy storage system consists of the serial and parallel connection of large number of batteries. Battery energy storage system is connected to the grid through the transformer, energy storage system collects wind farm power output information by measuring device, energy storage system adjusts charge/discharge current flow through the bidirectional converter and determines charging and discharging state according to the wind farm output conditions.

3. Criterion of the State of Charge of Energy Storage System

Same with all the battery systems, zinc bromide battery energy storage systems rely on batteries energy loss in the current density, generally at the simplest mode of the zinc bromide battery energy storage system ,the loss rate of battery power flow is 15%, and the average efficiency of the battery is 72.25% [9]. The charged state of the battery storage system SOC refers to the ratio of the residual capacity and the total capacity of energy storage system [10,11,12], which is the important basis of setting energy storage system control strategy. The relation between charged state SOC and charge and discharge power P_{es} is shown in formula (1):

$$SOC = SOC_{-1} - \frac{\eta \cdot P_{es,-1}}{4 \cdot E_{\max}} \quad (1)$$

$$\eta = \begin{cases} \eta_{out}, P_{es,-1} > 0 \\ \eta_{in}, P_{es,-1} < 0 \end{cases} \quad (2)$$

The -1 refers to the value at the previous moment, P_{es} $E_{\max}$ refers to the charging and discharging output power of the energy storage system, $E_{\max}$ refers to energy storage system rated capacity, the value of η_{out} is 1.15, the value of η_{in} is 0.85.

4. Control Strategy of Energy Storage System

4.1. Architecture Modeling of Strategy of Energy Storage Control

Energy storage system control structure diagram is shown as Figure 2. The input of the controller is wind power output error P_{error} , the differences of the wind forecast output power $P_{forecast}$ and the wind actual output power P_{actual} , and the charged state SOC, the negative error value means the forecast value is less than the actual value, that the energy storage system should be discharged; Conversely ,when its value is positive, the energy storage system should be charged.

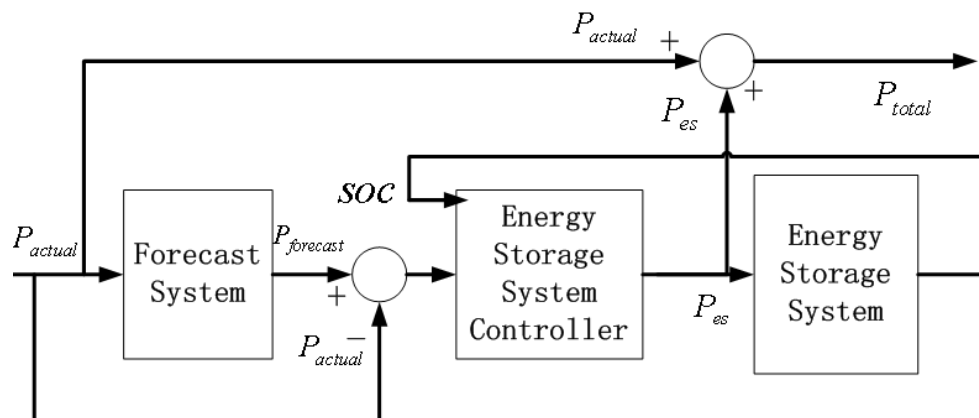


Figure 2. Energy Storage System Control Structure Diagram

The wind farm collects wind real-time actual output power P_{actual} , and then obtains the wind forecast output power $P_{forecast}$ through forecast system. Then it will be passed to energy storage system controller after subtracted from $P_{forecast}$. The energy storage system does judgment for the residual capacity of the energy storage system timely and the energy storage system charged state SOC is calculated according to the formula (1) is sent to the controller, then the controller calculates the charging and discharging power P_{es} of the energy storage system in accordance of the input value of P_{error} and SOC and transmitted to the energy storage system. The sum of the energy storage system charge and discharge power and the wind farm actual power is equal to the total output power value P_{total} .

This paper combined Matlab and Labview, invoked Matlab in the Labview software, set up a storage control structure model, the specific framework is shown in Figure 3. It can be seen from the figure, the Labview collects the information of wind farm actual output power and predicted power input to the controller, then the controller starts the control strategy program and calculates the energy storage system charge and discharge power on the basis of the predicted error value and charged state, at last the power value is sent to the energy storage system.

Energy storage control strategy is reflected in the controller, at present the traditional control strategy is adopted in many researches, this paper proposes a fuzzy control strategy.

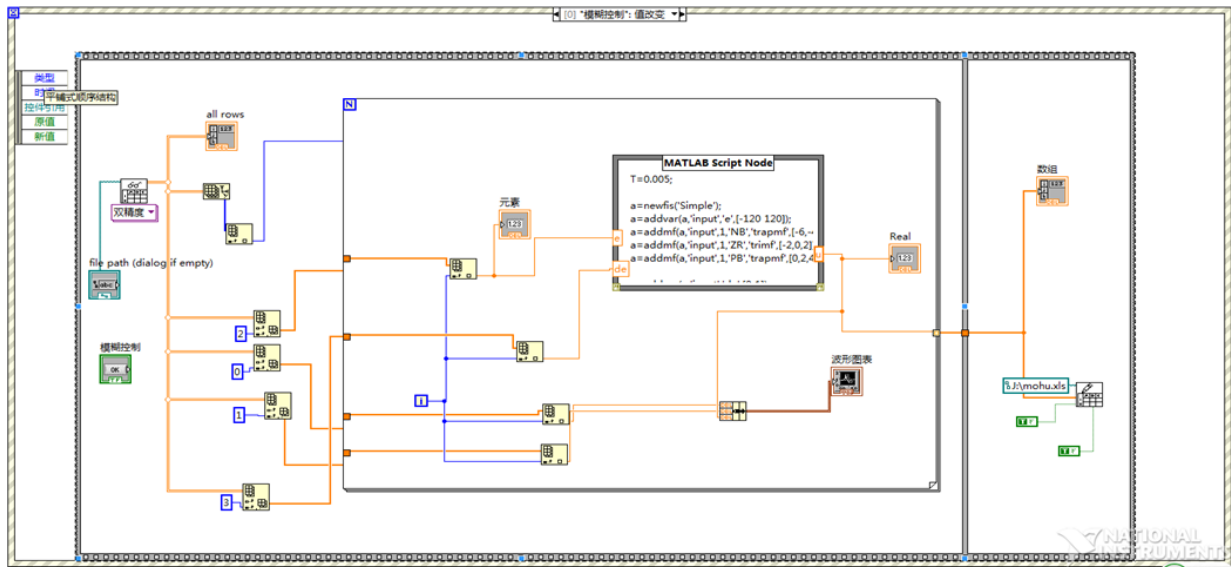


Figure 3. A Model for the Energy Storage System Control Framework

4.2. The Traditional Control Strategy

For the traditional controller, the input is the wind power forecast error and charged state of energy storage, when the energy storage charged state is in saturated condition, the output power of the controller P_{es} is zero; when the energy storage charged state is in unsaturated condition, if the absolute value of the energy storage charge and discharge greater than the energy storage system rated capacity, energy storage system will no longer to charge or discharge and output power P_{es} is equal to the energy storage system rated power P_{rated} .

- Input : P_{error} , soc ;
- Output : P_{es} .

$$P_{es} = \begin{cases} 0 & soc = 0 \& P_{error} < 0 \\ 0 & soc = 1 \& P_{error} > 0 \\ P_{rated} & P_{error} > P_{rated} \& soc \neq 0 \\ -P_{rated} & P_{error} < -P_{rated} \& soc \neq 1 \\ P_{error} & else. \end{cases} \quad (3)$$

4.3. The Fuzzy Control Strategy

4.3.1. Introduction to the Fuzzy Control Strategy

Although traditional control strategy can improve the wind power error precision, but not able to achieve ideal state and to optimize the allocation of the energy storage control system. Therefore, this paper presented a fuzzy control strategy to optimize the charge and discharge output power of the energy storage system according to the energy storage charged state and achieved the purpose of extending the service life of the battery energy storage.

Fuzzy control is to realize control experience using computer, it adopts language control rule directly and does not need to establish accurate mathematical model of the controlled object in the design, thus it makes the control mechanism and strategy are easy to accept, understand and design and it is very applicable for the objects those mathematical model is difficult to get, dynamic characteristics not easy to master and change very significantly. This article adopted fuzzy controller to control the energy storage system output power in the accordance of the wind output power error and charged state of the energy storage system.

4.3.2. Fuzzy Control Rule Table Based on Energy Storage

•Input : P_{error} , soc ;

•Output : P_{es} .

Considering that the energy storage system charged state cannot exceed its rated value, the theory domain of charged state is designed to $[-1,1]$. When the value of SOC is -1, it means the energy storage system have reached its maximum discharge value and couldn't be discharged any more. Likewise, when the SOC value is 1 it means the energy storage system have reached its maximum charge value and couldn't be charged any more.

Fuzzy sets of the input and output of the fuzzy controller are all set to 3 levels {NB (Negative Big), ZO (Zero), PB (Positive Big)} , which are represented for the wind output power error value and charged state and energy storage output power value. Fuzzy control rule table is shown as Table 1.

Table 1. Fuzzy Control Rule Table

Soc e			
	NB	ZO	PB
NB	ZO	ZO	NB
ZO	ZO	ZO	ZO
PB	PB	ZO	ZO

It can be seen from the fuzzy control rule table that when the SOC is Negative Big, the energy storage capacity took the minimum value, the battery energy storage get electric energy from the power grid and only can be charged. When the SOC is Positive Big, the energy storage capacity took the maximum value, the battery energy storage exported electric energy to the power grid and only can be discharged.

5. Analysis and Simulation

This paper did simulation and data analysis based on the wind farm historical forecast data and actual data between October to December of 2011 of a wind farm in Xinjiang using Matlab combined with Labview ,took every 15 minutes as a sampling time interval and set $\pm 25\%$ to be the acceptable range of the error and verified the effectiveness of the energy storage device and its control strategy. The installed capacity of the wind farm is 140MW·h. And based on the research [13], this paper selected 45MW·h as the energy storage rated capacity.

5.1. Wind Farm Output Power Forecast Analysis without Energy Storage System

In order to observe conveniently, this paper chose three months data to do simulation and do statistics to get the error probability histogram, as shown in Figure 4, the horizontal axis shows the wind output error between predicted values and actual values, the vertical axis represents the sampling points numbers.

It can be shown from Figure 4 that the wind output power error obeys the Gaussian distribution which average value of 30MW and standard deviation of 24MW (shown as red outsourcing fall line), most of the wind farm wind power error are within $\pm 50\%$, but the probability of the error which satisfy the state grid

requirements within the $\pm 25\%$ accounts for only 35% and it fails to reach the ideal state and causes larger influence on the stability of the power grid ,and the wind farm need the help of a battery energy storage to limit the wind output error in a given range so as to improve the wind power grid characteristics and enhance the utilization rate and the reliability of wind power.

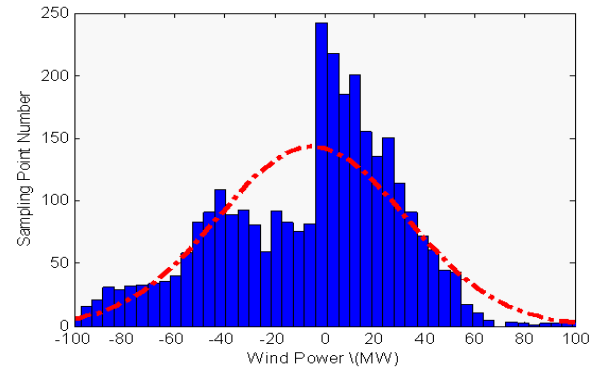


Figure 4. Wind Power Error Probability Histogram

5.2. Prediction Effect of Two Control Strategies with the Energy Storage System

Figure 5 shows the wind output error probability histogram after combining energy storage system into wind farm, shown as in the figure the red curve represents controller using fuzzy control strategy and the green curve represents controller adopting traditional control strategy. It can be seen from the figure that the effect of improving the wind output power error precision with the energy storage system is relatively obvious, especially the energy storage system adopting fuzzy control strategy can make 85% predicted wind power error sampling points limit within $\pm 25\%$ which satisfy the state grid requirements, far more effective than the traditional control strategy.

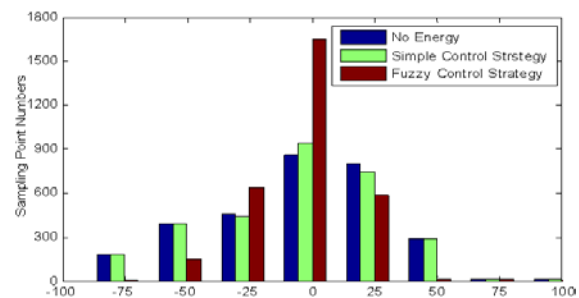


Figure 5. Wind Power Error Probability Histogram with the Energy Storage

5.3. Comparison Analysis of the Two Control Strategies Effects

Table 2 gives the simple summarization for the effects for improving the wind output power error precision of the energy storage control strategies. There shows the ratio T of the error within $\pm 25\%$ to the all errors, the Mean Absolute Error (MAE), the Root Mean Square Error (RMSE), the Maximum Error {MAX(E)} and the Minimum Error {MIN(E)} respectively. From the table we can see that the wind output power error precision is improved obviously with the help of energy storage. Traditional control strategy made 60% forecast points achieve the goal of limiting the error in the state grid

requirements of 25%, while the fuzzy control strategy made 85% forecast points reach the aim of limiting the error in the state grid requirements of 25%. Due to the energy storage system rated capacity is limited, two kinds of control strategies cannot increase the predicted errors of 100% obviously.

Table 2. Effect of Control Strategy

	No Energy Storage	Traditional Control	Fuzzy Control
T	35%	60%	85%
MAE	0.0511	0.0489	0.0302
RMSE	0.379	0.328	0.204
Max(E)	1.0	0.962	0.892
MIN(E)	-1.0	-0.875	-0.821

Figure 6 shows the effect of the energy storage system to improve wind farm output error accuracy. In the figure, the black curve presents the wind farm forecasting power, the blue curve presents the wind farm actual power, the green curve presents the output power with energy storage using traditional control strategy and the red curve presents the output power with energy storage using fuzzy control strategy. The simulation was done based on the wind farms history actual power output data and forecast power output data. From the Figure 6, it can be seen that there exists certain errors between the wind farm actual power and forecast power at the different times, on the one hand, the reason is meteorological information is not enough detailed at present; on the other hand, the reason is the volatile characteristics of wind itself which cause difficult to predict the wind output power. Through designing different control strategies of energy control system to make up the wind power output error. The results show that: when the actual output is lower than forecast output, the energy storage device should be charged; when the actual output is higher than forecast output, the energy storage device should be discharged. Energy storage charge and discharge power is determined by the charged state of energy storage so as to prevent energy storage system over-charging or over-discharging, thus increase the wind farm output power error precision to a large extent. At the same time, it improved energy storage economic value, further validated the rationality of the control strategy proposed in this paper.

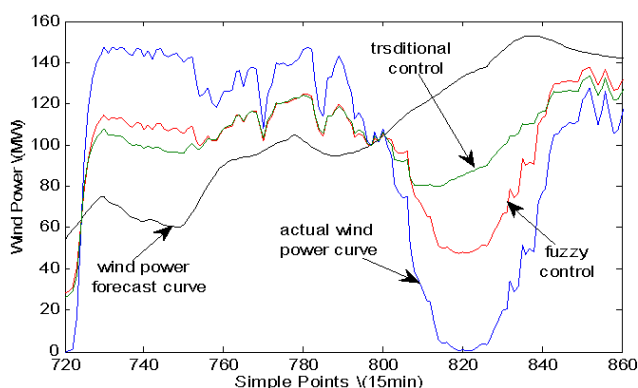


Figure 6. Forecast, Actual and Wind-Energy Output Power

6. Conclusion

According to the analysis discussed above, this paper get the following two conclusions:

(1) Configuring battery energy storage into the wind farm can improve the wind output power error prediction

accuracy and make the total wind power output is more close to the wind the actual output value, thereby increased the safe and stable operation and scheduling of power system.

(2) Energy storage system output power is optimized according to the charged state SOC to make up the wind power error, the energy storage using fuzzy control strategy can improve wind output power error precision more significantly than the energy storage using traditional strategy and will make 85% of forecast points achieve the goal that the error within the limit of $\pm 25\%$. Also, this paper verified the feasibility and rationality of the control strategies adopted in energy storage system.

Fund project

1. The national natural science fund, No.: 51267020; Name: using energy storage technology to improve the wind power short-term forecast accuracy.

2. The ministry of science and technology project" International Science & Technology currency Program of China"; No.: 172013DFG61520; Name: The cooperation research on the key technology of the efficient and reliable wind power generation system.

References

- [1] Jia Hongxin, Zhang Yu, Wang Yufei etc. Energy Storage for Wind Energy Applications [J]. Renewable Energy Resources, 2009, 27(6):10-15.
- [2] Bi Daqiang, Ge Baoming, Chai Jianyun etc. VRB Energy Storage System Based Power Control of Grid Connected Wind Farm [J]. Automation of Electric Power Systems, 2010, 34 (13):72-74.
- [3] E. Manla, A. Nasiri, C. H. Rentel and M. Hughes, "Modeling of Zinc/Bromide Energy Storage for Vehicular Applications"IEEE Transactions on Industrial Electronics, vol. 57, pp. 624-632, 2010,57:624-632.
- [4] LI Bei, GUO Jianbo.A Control Strategy for Battery Energy Storage System to Level Wind Power Output Power Generation System, 2012, 36 (8):38-43.
- [5] Ted K.A.Brekken, Alex Yokochi, Annette von Jouanne and so on. Optimal Energy Storage Sizing and Control for Wind power Applications [J] IEEE Transaction on Sustainable Energy, 2011, 1:69-76.
- [6] E.Manla,A.Nasiri, C.H. Rentel and M. Hughes, "Modeling of Zinc/Bromide Energy Storage for Vehicular Applications" IEEE Transactions on Industrial Electronics, vol. 57, pp. 624-632, 2010.
- [7] Ali Esmaili, Adel Nasiri.Energy Storage for Short-Term and Long-Term Wind Energy Support[C].36th Annual Conference on IEEE Industrial Electronics Society: IEEE, 2010: 3281-3284.
- [8] E. Manla, A. Nasiri, C. H. Rentel and M. Hughes,"Modeling of Zinc/Bromide Energy Storage for Vehicular Applications"IEEE Transactions on Industrial Electronics, vol. 57, pp. 624-632, 2010.
- [9] Handbook of Electrochemistry, C. G. Zoski, Ed. Amsterdam,The Netherlands: Elsevier BV, 2007.
- [10] Wang Chengshan, Yu Bo, Xiao Jun etc. Sizing of Energy Storage System for Output Smoothing of Renewable Energy Systems [J]. Proceeding of the CSEE, 2012, 32 (16):3-4.
- [11] S. Teleke, M. Baran, S. Bhattacharya, and A. Huang, "Optimal control of battery energy storage for wind farm dispatching," IEEE Trans. Energy Convers., vol. 25, no. 3, pp. 787-794, Sep. 2010.
- [12] S. Teleke, M. Baran, A. Huang, S. Bhattacharya, and L. Anderson, "Control strategies for battery energy storage for wind farm dispatching," IEEE Trans. Energy Convers. vol. 24, no. 3, pp. 725-732, Jun. 2009.
- [13] Liang Liang, Li Jianlin, Hui Dong. Optimization Configuration for Capacity of Energy Storage System in Large-scale Wind Farm [J]. High Voltage Engineering, 2011, 37(4):930-936.