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Study on Regulation and Control of Active Wind Power Fluctuations

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ABSTRACT

Wind is random and intermittent. With the increasing proportion of wind power in power system, large-scale wind power will aggravate the imbalance of the active power output in power systems and influence power quality. This study analyzed the natural wind characteristics and broke down the active wind power fluctuation, combined with wind power generation plan. A control method of the active power fluctuation was presented based on energy storage technology. Storage technology and PWM converter technology were applied flexibly, according to the technical rule for connecting wind farm to power system which can bi-directionally adjust the active wind power fluctuation rapidly and accurately and at the same time eliminates the influence of the fluctuation outside the range of active power. The experimental results verify the correctness of the control strategy. It is an effective solution for regulating and controlling wind power fluctuation which can not only improve the quality of active wind power but also save the capacity of the storage system.

Key words: Renewable energy, wind power characteristics, power fluctuation, storage technology, super capacitor

INTRODUCTION

Wind is a green, clean, renewable energy, will be used more widely in the world (Diaz-Gonzalez *et al*., 2012; Luickx *et al*., 2009). The uncertainty and the intermittent of wind power will impact to power grid, result in bad quality of electric energy and unstability of the power system (Aigner *et al*., 2012; Hadjipaschalis *et al*., 2009; Zhang *et al*., 2010).

The random fluctuation of wind speed lead to the inaccurate forecast of wind power. The active wind power fluctuation can be defined as the difference between the wind power prediction and the actual wind power value, it's reasonable but fluctuate greatly (Li *et al*., 2010). In order to obtain the natural wind energy, wind power generators usually work in the maximum power capture mode (Barker and de Mello, 2000). So in the wind power generation process, the power system have to absorb the active wind power fluctuation.

In order to reduce or even eliminate the influence of large scale wind power accessing to the grid, many research scholars provide solutions from different angles. Such as, from the point of wind power prediction, strengthening the accuracy and credibility, building the platform of wind power energy for the active power generation; from the point of power grid dispatching, adjusting the active power of conventional generator, rationally coordinating the hot standby machine, reducing the effects caused by the intermittency and uncertainty of wind power (Ibrahim *et al*., 2008; Teleke *et al*., 2010); from the point of wind farm, in the maximum power capture mode, adding the auxiliary power control system reducing the impact. The auxiliary power control system bases on energy storage technology. The reference (Muyeen *et al*., 2009) controls the wind power fluctuation by ideal battery system, requesting high recycling rate, deal with high fluctuation. The reference (Domachovski and Dzida, 2002) regulates the target value by weighted index method, solve the problem of unbalanced

Table 1: Largest value of normally active wind power fluctuation

	1 min the maximum value of active capacity/MW
Wind farm installed	Power fluctuation/MW
<30	3
30~150	Installed capacity/10
>150	15

power in the power generation process by the double layer capacitors. The reference solves the problem of power fluctuation at 0.1-1 HZ by super capacitor.

The National Electric Net Ltd point out that wind farm should be adjusted with the active power and permit wind power fluctuation in limit in the "Technical regulations of wind farm connected with power system" (Spahic and Balzer, 2005) (Table 1).

This study is on different schemes dealing with wind power fluctuation, focus on the maximal wind energy capture mode, divide the wind power fluctuation into two parts, one is in the range of acceptable and the other is out of the limit, propose a control scheme for active wind power fluctuation. The scheme just need the energy storage system to provide sufficient capacity for the active wind power fluctuation out of limit, with the accuracy and reliability of wind power prediction is increasing day by day, it can effectively reduce the capacity of the energy storage device. Compared with the common energy storage scheme, it can save more cost.

MATERIALS AND METHODS

Character of wind power: Wind is intermittent and volatile, Fig. 1 is the wind speed probability distribution in a certain period of time for a wind farm. The wind speed is mainly from 4-10 m sec^{-1}, the probability is 69.4%; the high and low speed is relatively little. In the middle speed section, the wind power fluctuation is in the limit according to "Technical regulations of wind farm connected with power system", can access to the grid directly. High and low speed is small probability event, so it's easy to generate prediction errors in large range, the active wind power fluctuate greatly (Abbey and Joos, 2007; Yu *et al*., 2011). So, it needs energy storage device to regulate the power fluctuation out of limit.

When the wind farm works in the maximum wind power capture mode, the characteristics of the wind speed change for wind power output. Such as, Fig. 2a-b are wind speed curve and wind power curve, have the same trend.

Fluctuating wind power decomposition: As shown in Fig. 2b, P represents the real output power and $P_{forecast}$ represents the predicted output power of the wind farm, it's the basis for dispatch order:

$$P_d = |P-P_{forecast}|\ P_d$$

where, P_d is the fluctuating power. According to the "Technical regulations of wind farm connected with power system",

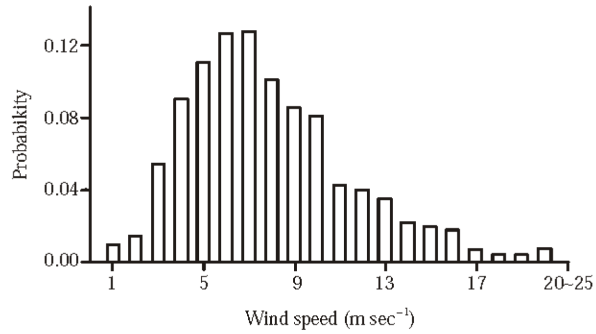

Fig. 1: Wind speed probability diagram of a wind farm

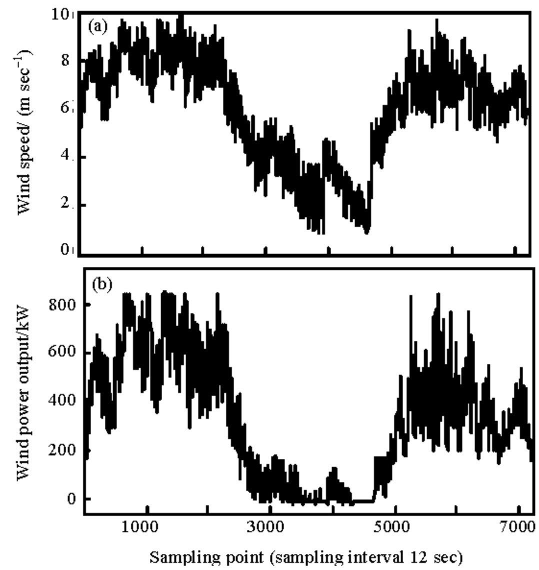

Fig. 2(a-b): Daily, (a) Wind speed and (b) Out put curve of a single wind turbine generator in certain wind farm

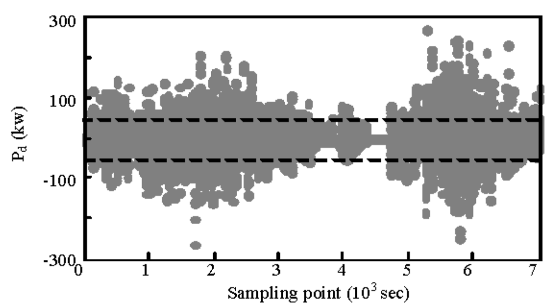

Fig. 3: Power fluctuation (Pd) curve of a wind generator

divide P_d into P_{in} (in the range of acceptance) and P_{out} (out of the range), as shown in Fig. 3.

This decomposition method can make full use of the margin for wind power leaved by grid, saving the energy

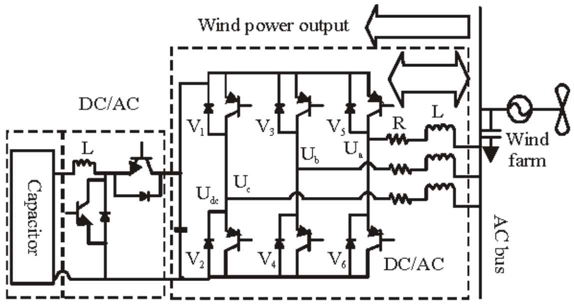

Fig. 4: Power flow and the structure of the control system

storage capacity. As shown in Fig. 3, P_{in} fluctuate small, it's acceptable. And P_{out} fluctuate fast, it's complicated.

Energy storage component selection and energy storage system structure: Decomposing the power fluctuation as shown in Fig. 3, it put forward two demands for the nergy storage element: (1) High power density, dealing with the fast fluctuation and (2) Long cycle life, can deal with active wind power reciprocating.

At the present stage, energy storage technology including flywheel energy storage, superconducting magnetic energy storage, advanced battery energy storage, super capacitor energy storage and pumping energy storage etc. For the characteristics of wind power's fluctuation, this study select super capacitor as storage element, as it has high power destiny and can charge and discharge repeatedly (Abbey and Joos, 2007).

As shown in Fig. 4, it's the energy storage system structure base on super capacitor: The wind generators at different location have different peak and valley value of wind energy. And with the expansion of the scale of wind farm, the different wind generators' fluctuating power can be canceled by each other, so by putting different wind generators (wind farm as shown in Fig. 4) on the same AC bus, then the energy storage system parallel connect with AC bus by AC/DC and DC/DC converters. There is no need to equip energy storage device for very wind generator. It can reduce the storage capacity of the system.

The DC/DC buck-boost converter can control the super capacitor absorb or release the energy. When the wind power is 'too much' for grid, the super absorb the extra energy, when the wind power is 'too little' for grid, the super capacitor release the lack power. And the AC/DC converter make the energy convert between AC and DC. The structure can reduce the amplitude of the wind power fluctuation, enhance the security and reliability of the grid.

System control rule of regulating active wind power fluctuation: Consider that $P_{forecast}$ is the dispatch order, so it's the control objective for output active power. $P_{object} = P_{forecast}$. In the maximum wind energy capture mode of wind farm, the active power control strategy has three kinds of state: The working state, the dormancy state and the off state, as shown in Table 2. P_Δ means active power fluctuation that the grid can accept. P_{cap} means the power that super capacitor can absorb or release.

Table 2: System-level regulation control for active wind power fluctuation

States	Real power fluctuation
Control state	P_d
Dormancy state	$P_d \leq P_\Delta$
Working state	$P_\Delta \leq P_d \leq P_{cap}+P_\Delta$
Off state	$P_{cap}+P_\Delta \leq P_d$

Working state: A scheduling period, when the active power fluctuation P_d exceed the range that the grid can accept P_Δ but less than $P_{cap}+P_\Delta$, the control strategy proposed by this study make the power fluctuation be acceptable.

Dormancy state: A scheduling period, when the active power fluctuation P_d is acceptable (less than P_d), there is no need to use the control strategy. At this time you can check whether the super capacitor is in hot standby state. If the voltage of the capacitor is high or low, you should discharge or charge.

Off state: A scheduling period, when the active wind power fluctuation P_d exceed the energy storage system's capacity (more than $P_{cap}+P_\Delta$), the wind farm abandon wind. Still check the active power output, make the control strategy in standby state.

Control rules for active wind power fluctuation on device: When the active wind power fluctuation control strategy is in working state, the energy storage system works, its object is that limit P_d less than P_Δ. When $P_\Delta<P-P_{forecast}<P_{cap}+P_\Delta$. The energy storage system absorb the extra wind power:

$$\Delta P_\Delta = P-P_{forecast}-P_\Delta$$

When $P_\Delta<P_{forecast}-P<P_{cap}+P_\Delta$, The energy storage system release the vacant power:

$$\Delta P_\Delta = P_{forecast}-P-P_\Delta$$

where, ΔP_Δ is the control objective for energy storage system. If it's realized, the wind farm's output active power can be accepted by the grid.

Coordinated control strategy for active power fluctuation: According to control rules of active power fluctuation, comparing P_d with P_Δ, judge the state of the regulation. When it is in off state or dormancy state, there is no need to regulate the power. And when it is in working state, the control strategy includes two parts as shown in Fig. 5.

One part is the DC/DC buck/boost converter that control the super capacitor absorb or release the energy, the other part is the control of the VSI (AC/DC inverter). The DC/DC converter works according to the power fluctuation control rule, control the super capacitor to absorb or release the objective power ΔP_Δ, make the wind power double-flow. The

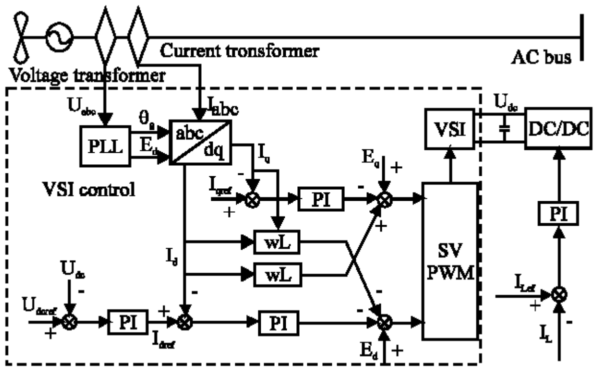

Fig. 5: Control strategy of the wind power fluctuation

Fig. 6: Simple model of RC series circuit

voltage of the capacitor is controlled by the AC/DC inverter, so the wind power flow between the super capacitor and the grid. In the active wind power control strategy, the default control value of passive power is zero. In this case, the super capacitor can be controlled by buck/boost converter to regulate the charge and discharge power. With the two part's coordination, can make the active wind power fluctuation regulate according to the control instruction.

The control strategy of super capacitor energy storage system: The super capacitor's energy density and power density is increasing, it makes the application of the energy storage technology be possible in power system. In order to simplify the analysis, this study adopts a series of RC model for super capacitor, as shown in Fig. 6. In the model, C is the ideal super capacitor, R_{ESR} is the equivalent series resistance. In the process of charge and discharge, the R_{ESR} not only reflects the heat loss within the super capacitor but also reflects when the super capacitor discharge to the load with the change of the current, the voltage of the R_{ESR} is different, so the R_{ESR} is binding on the maximum discharging current.

The transfer function is obtain from the small signal model of the energy storage system shown in Fig. 4, for charge and discharge mode. U_1 represents the voltage of capacitor simplified and U_2 represents the voltage of inverter; C_1 represents the value of the super capacitor and C_2 represent the capacitor in the inverter DC side; U_{c1} represents the voltage of the super capacitor and U_{c2} represents the DC voltage of the inverter; U_{c20} represents the initial value of the super capacitor; R_{s1} represents the internal resistance of the super capacitor and R_{s2} represents the internal resistance of the inverter; I_{L0} represents the initial current value of the inductance; D represents of the duty ratio of PWM.

When the energy storage system release power:

$$U_0 = U_{C2},\ U_i = U_1$$

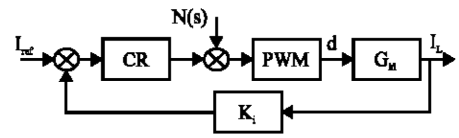

Fig. 7: Current closed-loop control block diagram of DC-DC Buck/Boost converter

the transfer function Gid of control variable D to the inductor current I_L as followed:

$$G_{id} = \frac{(C_1R_{s_1}s+1)[U_{C_{20}}(C_2R_{s_2}s+1)+I_{L_0}R_{s_2}(1-D)]}{M(s)} \qquad (1)$$

When the energy storage system absorb power:

$$U_0 = U_{C1},\ U_i = U_2,$$

the transfer function Gid of control variable D to the inductor current I_L as followed:

$$G_{id} = \frac{(C_1R_{s_1}s+1)[U_{C_{20}}(C_2R_{s_2}s+1)+I_{L_0}R_{s_2}(1-D)]}{M(s)} \qquad (2)$$

$$M(s) = LC_1C_2R_{s_1}R_{s_2}s^3 + (LC_1R_{s_1} + LC_2R_{s_2})s^2 + [L + C_1C_2R_{s_2}(1-D)^2 + C_1C_2R_{s_2}]s + R_{s_1} + R_{s_2}(1-D)^2 \qquad (3)$$

In bidirectional power control, the transfer function of controlled variable D to I_L is the same, Some control system is used to make power double-flow. The control system take the current single ring structure, using PI controller. As shown in Fig. 7, CR represents current controller, the PWM controller transfers the control variable to pulse sequence. The averaged switch model is approximately linear, so it can simplify the PWM control to proportional component, the proportional coefficient is K_{PWM}.

Using DC-DC Buck/Boost converter to control the power of the super capacitor, mainly embodied in the control of the inductance current.In a scheduling period, when the active wind power fluctuation is out of range, the converter absorb the extra power ΔP_Δ by control the inductance current. At this time, the super capacitor is charging; Conversely, the converter release the power ΔP_Δ, the super capacitor is discharging at this time. The specific method is monitor the voltage of the super capacitor U_{cap}. The objective control value of the inductance current is:

$$I_{objective} = \Delta P_\Delta / U_{cap}$$

When the DC/DC buck/boost converter is in working state, it needs to make the U_{cap} in normal range, to make sure the super capacitor to have the ability to provide the difference of active wind power fluctuation, to make sure the wind farm in working state or dormancy state; If there is abnormal situation,

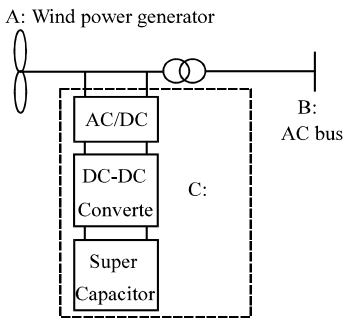

Fig. 8: Experiment structure of active power control

timely removal of network and reports to the dispatching department, ensure the normal operation of the grid and the safety use of the super capacitor.

Physics experimental structure: The physical experiment model is divided into three parts, as shown in Fig. 8. A: wind power generator(generate power fluctuation), B: AC bus, C: control system for power fluctuation including super capacitor, DC/DC converter and inverter.

Parameters as follow: wind power generator: rated voltage 380 V, rated power: 5 kW; the isolation transformer 5 KVA, 380 v/35 v; inverter: inductance on AC side 3.5 mH, capacitor on DC side: 470 μF, DC/DC converter: inductance on DC side, the rated voltage of the super capacitor is 33 V (normal voltage from 20-80%).

RESULTS AND DISCUSSION

Experimental results: The voltage of inverter DC side is stabilized at 170 V as shown in Fig. 9. It ensures that the real time power of the energy storage system accurately transfer to AC bus.

Simulating reciprocating wind power fluctuations in the experiment as shown in Fig. 10. When the wind power fluctuation power is too high, active power regulating system absorbs active power, when the wind power fluctuation power is too low, active power regulating system releases the vacant active power.

The current control uses PI controller, its transfer function is:

$$G(s) = Kp+Ki/s, Kp = 0.01, Ki = 0.03$$

The response time is 20 msec in the simulation, conversely, the control strategy on changing the pitch angle of the blade is in second class, sometimes it can't make sure the power fluctuation can be accepted by the grid. Therefore, the controller designed by this study can realize fast regulation of wind power.

When the active wind power fluctuate, the energy storage system works. The power transfer to the AC bus is shown in

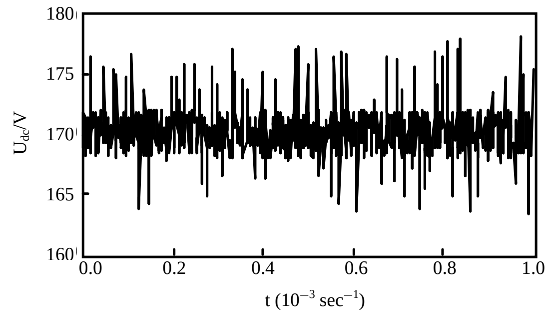

Fig. 9: DC-side voltage curve of the PWM inverter

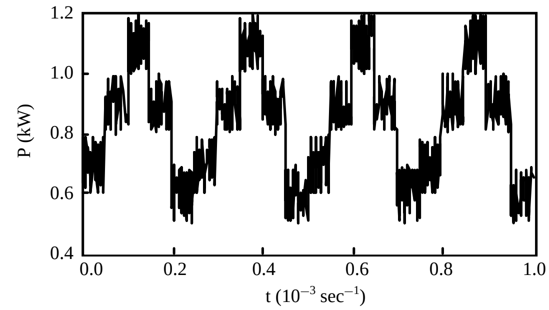

Fig. 10: Simulative curve of the active wind power fluctuation

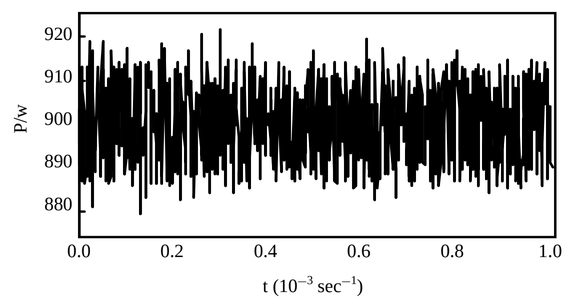

Fig. 11: Regulated curve of active power injected to AC-bus

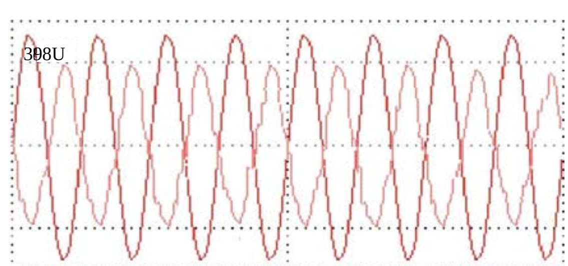

Fig. 12: A-phase voltage and current injected to AC-bus from the high-voltage side of the step-up transformer

in Fig. 11. The wind power adjusted basic stabilize in the target value 900 W. The power fluctuation is about 4%, it conforms with the regulation. But the difference with Abbey and Joos (2007) is that the target of this study is not to cancel the power fluctuation but to limit it. So, the energy storage system needn't work always, the capacity of the system is more small and the service life is longer.

In the regulating process, the voltage and the current (A phase as example) on the high voltage side of the step-up transformer is shown in Fig. 12 (the current magnified ten times).

Because the control system add the passive power current control, the target value is zero. So, the phase of the current and voltage is reverse. Obviously after regulation, the output power is smooth.

CONCLUSION

When the wind farm works in the maximum wind power capture mode, the active wind power fluctuation can't be accepted by the grid. This study divide the active wind power fluctuation into two parts and choose super capacitor as energy storage element. Following the control strategy proposed by the study, the active power fluctuation is reduced, enhancing the security and stability of the grid.

REFERENCES

Abbey, C. and G. Joos, 2007. Supercapacitor energy storage for wind energy applications. IEEE Trans. Ind. Applic., 43: 769-776.

Aigner, T., S. Jaehnert, G.L. Doorman and T. Gjengedal, 2012. The effect of large-scale wind power on system balancing in Northern Europe. IEEE Trans. Sustainable Energy, 3: 751-759.

Barker, P.P. and R.W. de Mello, 2000. Determining the impact of distributed generation on power systems. I. Radial distribution systems. Proceedings of the IEEE Power Engineering Society Summer Meeting, Volume 3, July 16-20, 2000, Seattle, WA., USA., pp: 1645-1656.

Diaz-Gonzalez, F., A. Sumper, O. Gomis-Bellmunt and R. Villafafila-Robles, 2012. A review of energy storage technologies for wind power applications. Renewable Sustainable Energy Rev., 16: 2154-2171.

Domachovski, Z. and M. Dzida, 2002. Influence of inlet guide vane control on combined cycle power plant transients. Proceedings of the ASME Turbo Expo 2002: Power for Land, Sea and Air, Volume 1, June 3-6, 2002, Amsterdam, The Netherlands, pp: 953-957.

Hadjipaschalis, I., A. Poullikkas and V. Efthimiou, 2009. Overview of current and future energy storage technologies for electric power applications. Renewable Sustainable Energy Rev., 13: 1513-1522.

Ibrahim, H., A. Ilinca and J. Perron, 2008. Energy storage systems: Characteristics and comparisons. Renewable Sustainable Energy Rev., 12: 1221-1250.

Li, W., G. Joos and J. Belanger, 2010. Real-time simulation of a wind turbine generator coupled with a battery supercapacitor energy storage system. IEEE Trans. Ind. Electron., 57: 1137-1145.

Luickx, P.J., E.D. Delarue and W.D. D'haeseleer, 2009. Effect of the generation mix on wind power introduction. IET Renewable Power Gener., 3: 267-278.

Muyeen, S.M., R. Takahashi, T. Murata and J. Tamura, 2009. Integration of an energy capacitor system with a variable-speed wind generator. IEEE Trans. Energy Convers., 24: 740-749.

Spahic, E. and G. Balzer, 2005. Power fluctuation from a large wind farm. Proceedings of the 2005 International Conference on Future Power Systems, November 18, 2005, Amsterdam, The Netherlands, pp: 6.

Teleke, S., M.E. Baran, S. Bhattacharya and A.Q. Huang, 2010. Optimal control of battery energy storage for wind farm dispatching. IEEE Trans. Energy Convers., 25: 787-794.

Yu, P., Y. Zhao, W. Zhou, H. Sun and C.H. Quan *et al*., 2011. Research on the method based on hybrid energy storage system for balancing fluctuant wind power. Power Syst. Prot. Control, 39: 35-40.

Zhang, L., T. Ye, Y. Xin, F. Han and G. Fan, 2010. Problems and measures of power grid accommodating large scale wind power. Proc. CSEE, 30: 1-9.