Research on hydraulic wind turbine main drive system and active yaw control

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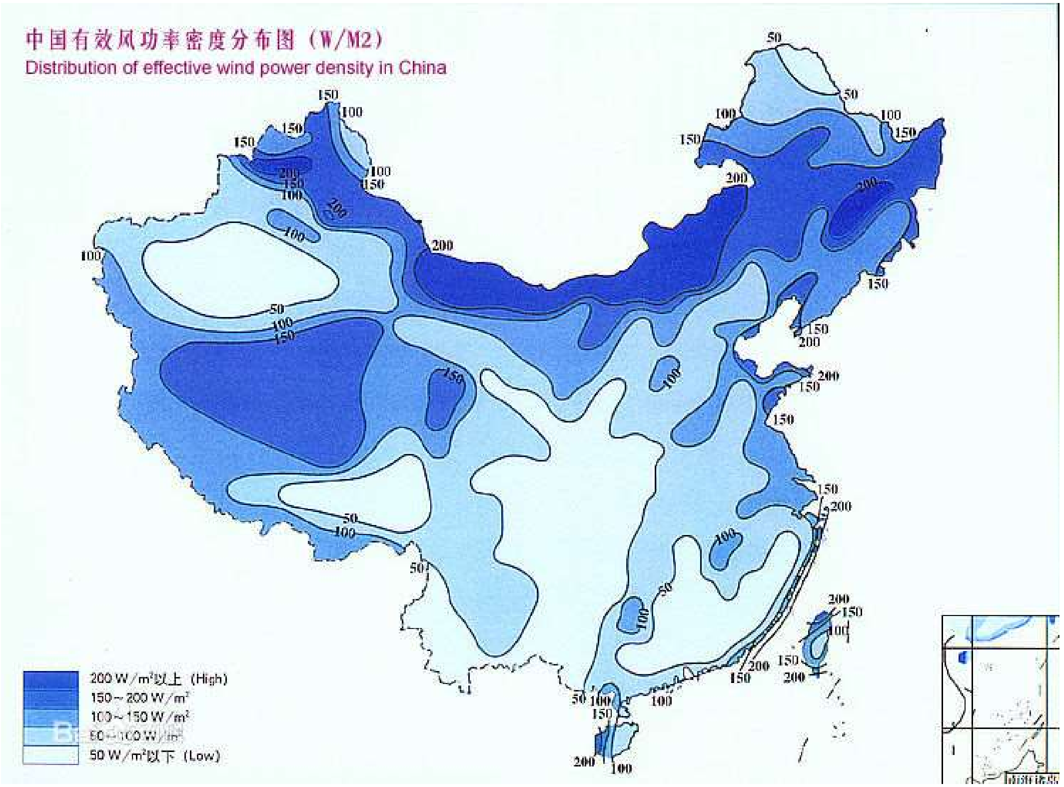
Research on hydraulic wind turbine main drive system and active yaw control

1 Research background

1.1 Wind energy resources

- Land of 10 m height from the ground wind energy resources reserves is about 4.35 billion KW.
- The development and utilization of wind energy reserves is about 750 million KW on the Sea of 10 m height .
- Land of wind energy resources in China are mainly distributed in three north regions (northeast, north, northwest, southeast coast and the islands.

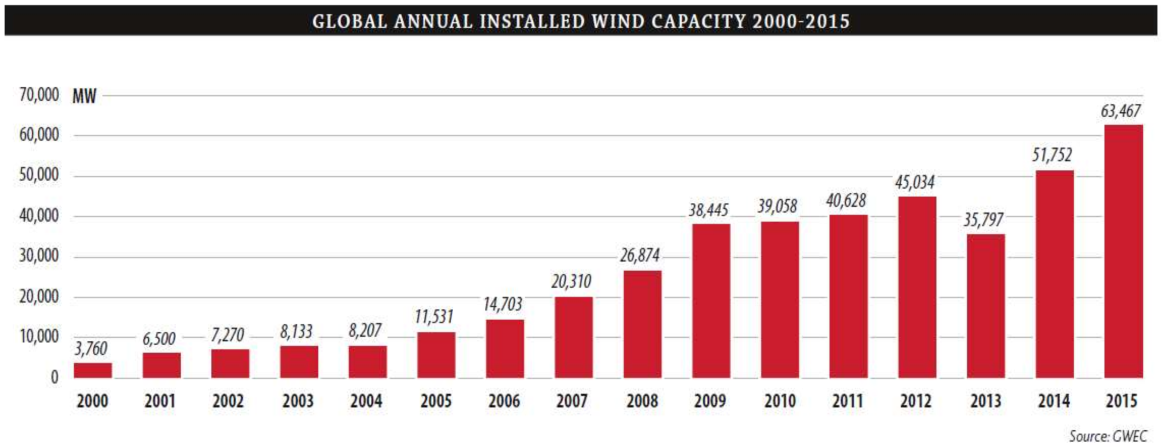


Effective wind power density distribution in our country

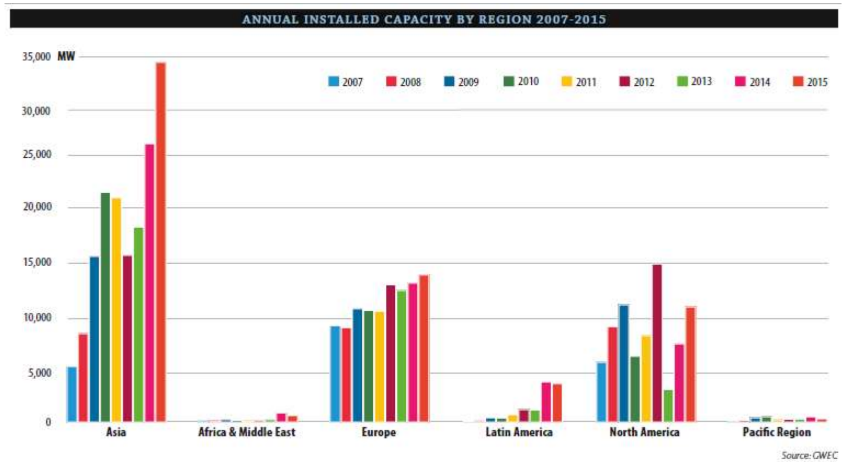
- The wind energy resource is large and widely distributed in China.

1 Research background

1.2 The market demand



GLOBAL ANNUAL INSTALLED WIND CAPACITY 2000-2015



ANNUAL INSTALLED CAPACITY BY REGION 2007-2015

In 2015, the global wind power installed capacity hit a record high. Global new installed capacity of 11715 mw, up 22.64% from a year earlier.

Between 2007 and 2015, Asia, Europe, North America, the installed capacity is higher. In Asia the installed capacity is increasing year by year .

- China is the big country of Asia's abundant wind resource, so wind power generators have a big commercial market.

1 Research background

1.3 National policy

New energy

The 12th five-year plan for public institutions to save energy resources

“The 12th five-year plan for energy conservation and emissions reduction"

About promoting the development of the "Internet +" wisdom energy guidance

Energy industry standardization management approach (trial)

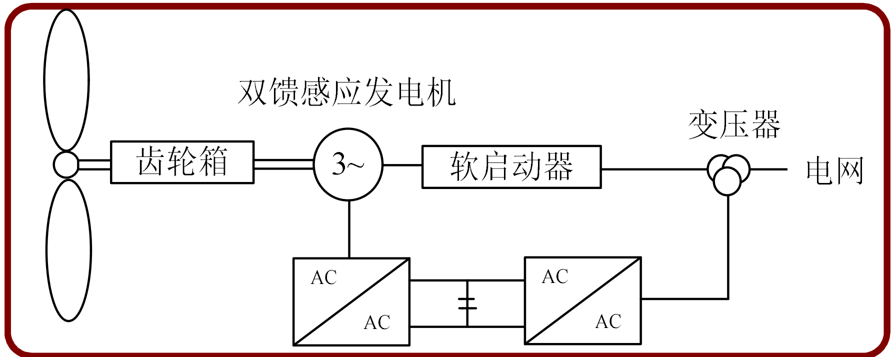
The "rise of green" strategy in hebei province

The 12th five-year plan for national science and technology innovation plan

- It is our duty to follow the Chinese policy of low carbon green environmental protection and develop resource-conserving and environmentally friendly industries.

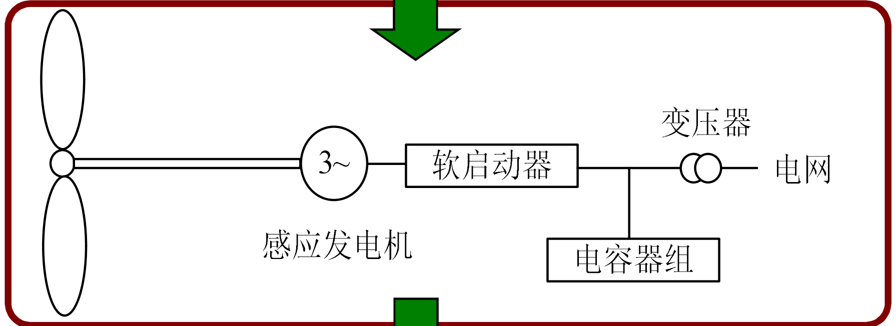
1 Research background

1.4 The traditional wind turbine



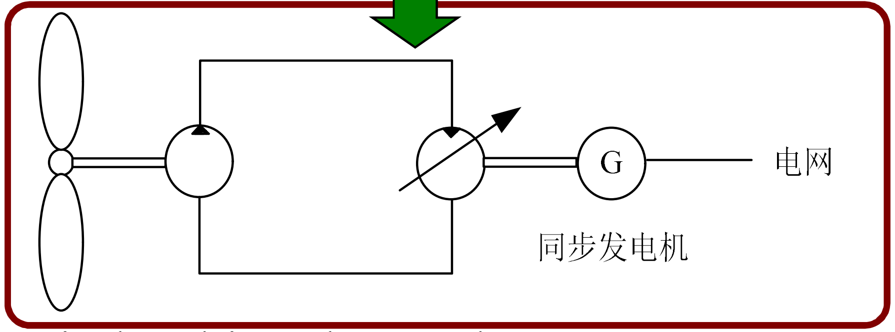
DFIG

Gear box of high failure rate
Tower mass is heavy
Needing rectifier and inverter



PMSM

Tower mass is heavy
Needing rectifier and inverter



HWT

Safe and reliable
Saving tower mass
Omiting the rectifier and inverter

- Compared with traditional wind turbines, hydraulic wind turbines have advantages in safety, energy saving and simpler structure.

1 Research background

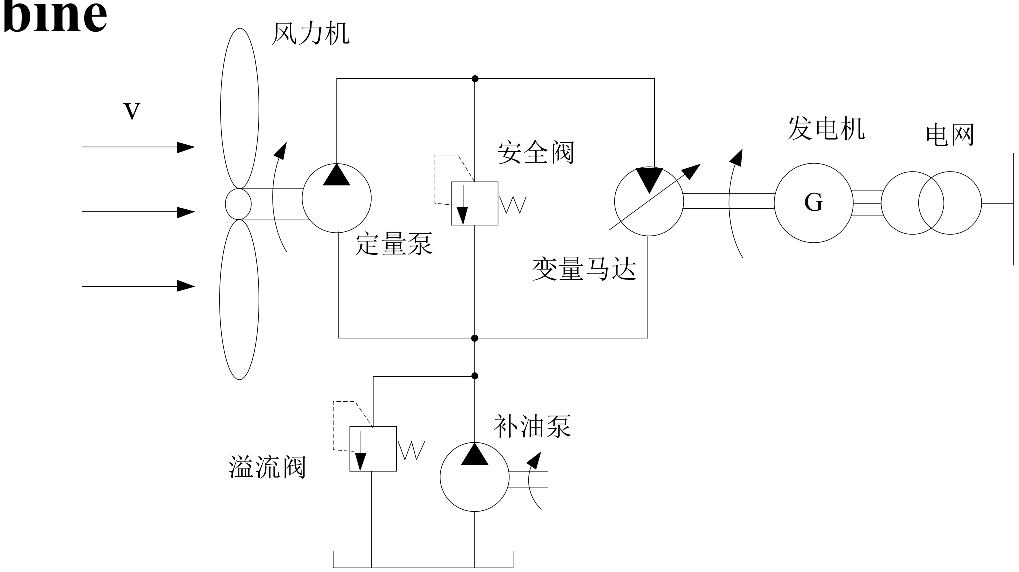
1.5 Advantages of hydraulic wind turbine

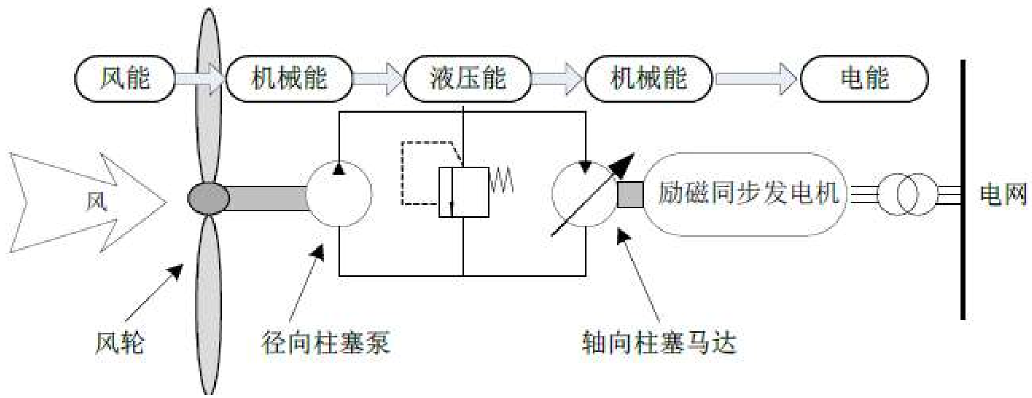
Engineering

1. advanced technology;
2. convenient installation ;
3. advanced structure;
4. Control system is high efficiency.

Technical

1. flexibility and high reliability;
2. low cost, easy to realize standardization;
3. tracking power easily,
4. wind turbine power series can be realized.

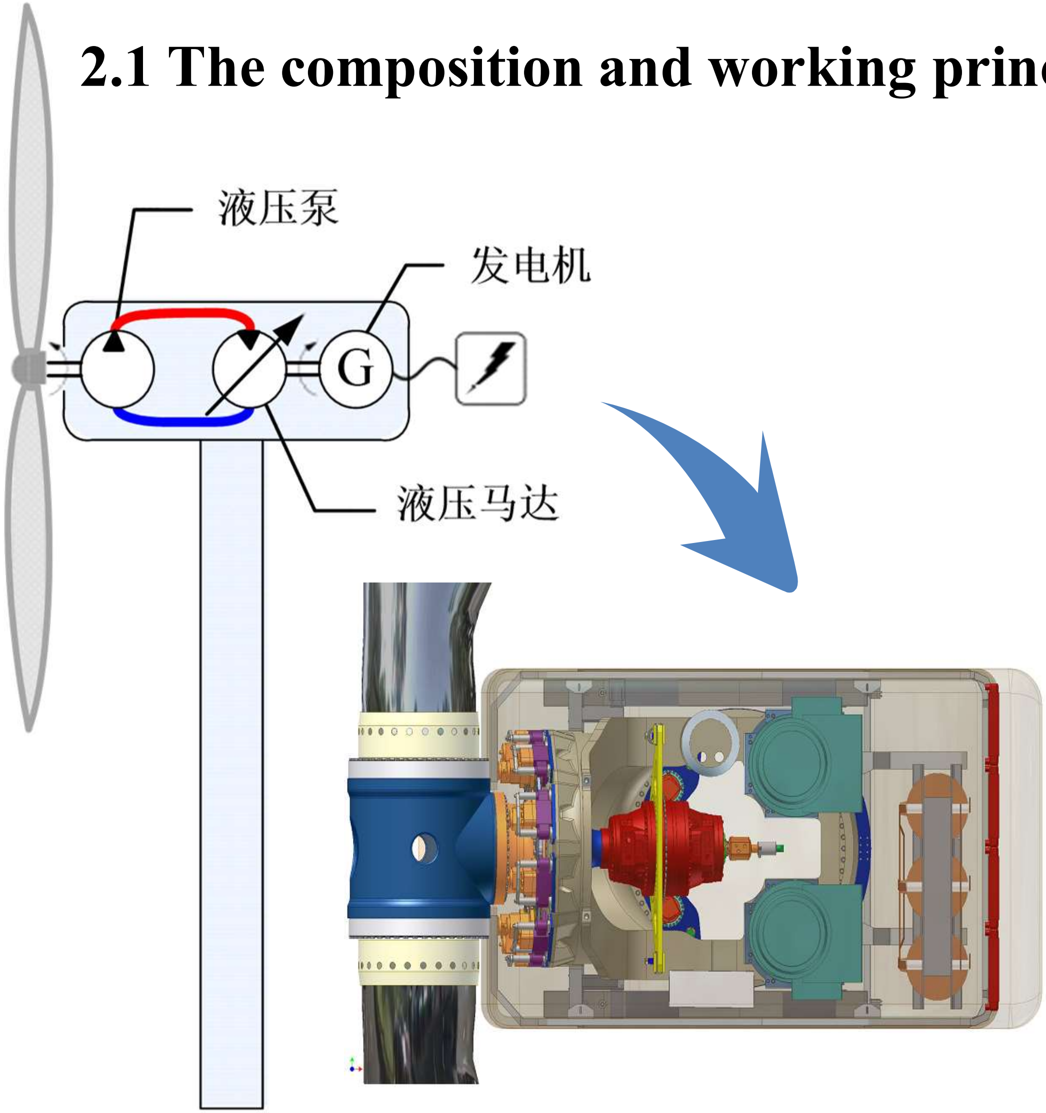




➢ Hydraulic wind turbines have many engineering and technical advantages.

2 Brief introduction and classification

2.1 The composition and working principle



◆ Hydraulic wind turbine (HWT) is consist of wind turbine, a fixed displacement pump-various motor closed hydraulic drive system and synchronous generator.

◆ Wind turbine drives fixed displacement pump to export high pressure oil. Then the oil is exported to motor. Finally, motor drives generator generating electricity.

- The wind turbine drives hydraulic pumps. And the pumps drive motors. Then motors generates electricity.

2 Brief introduction and classification

2.2 Classification

Vertical shaft

Horizontal shaft

According to the blade fixed axis orientation of wind turbine, it can be classified as follows.
（1）Horizontal shaft： it needs adjust orentation timely to keep consistent with wind.
（2）Vertical shaft： it can collect various orentation wind.

- Wind turbines can be classified to horizontal shaft and vertical shaft.

3 Present Condition of Research

3.1 Present Condition of Foreign Research

Chapp drive company

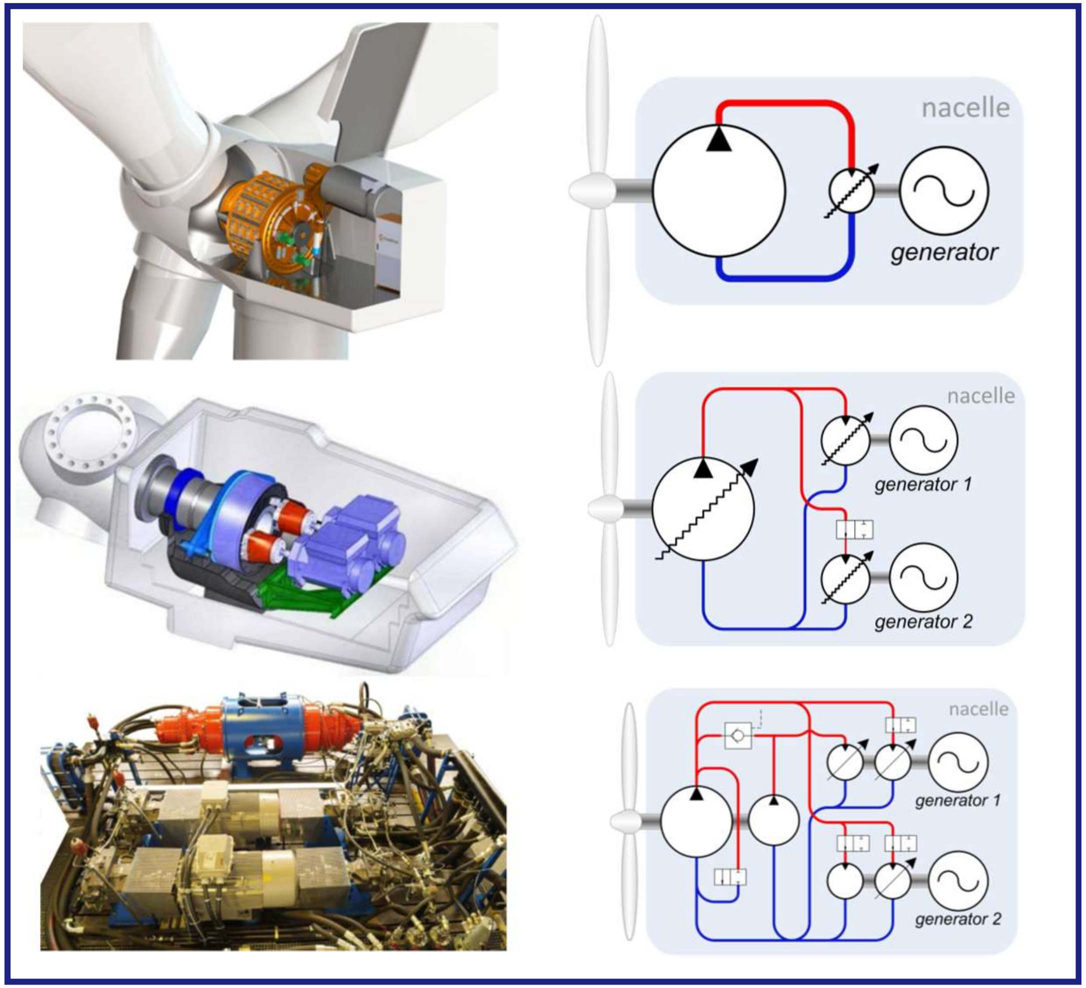
225kW、900kW、5MW types.
3 Europe patents，3.3MW and 6.6MW are under research.

Atos

Using Radial piston pump，purchased by Mitsubishi. 7MW “Sea Angel” was installed in 2015.

RWTH Aachen

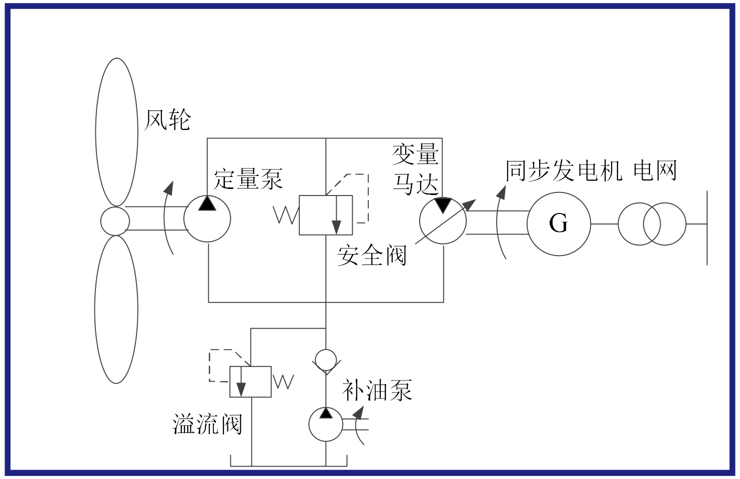
Highest efficiency is 85%，speed control and pressure control .



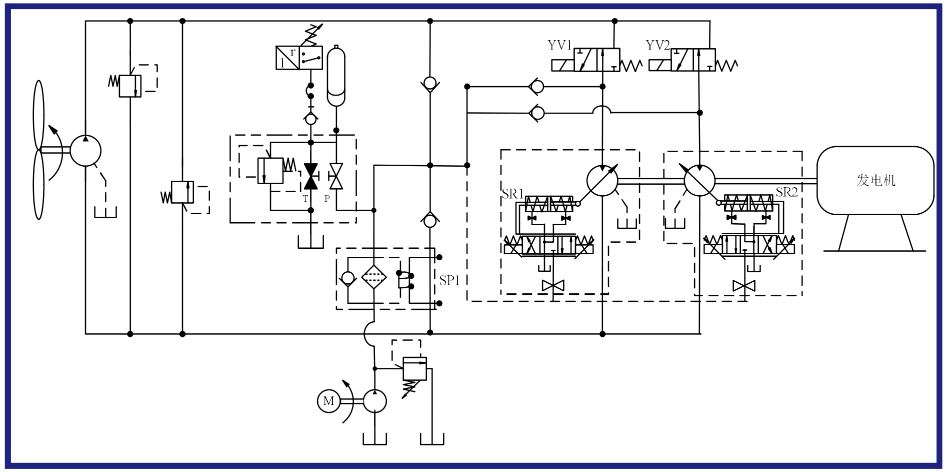
- The three companies did a lot of research on hydraulic wind turbines.

3 Present condition of research

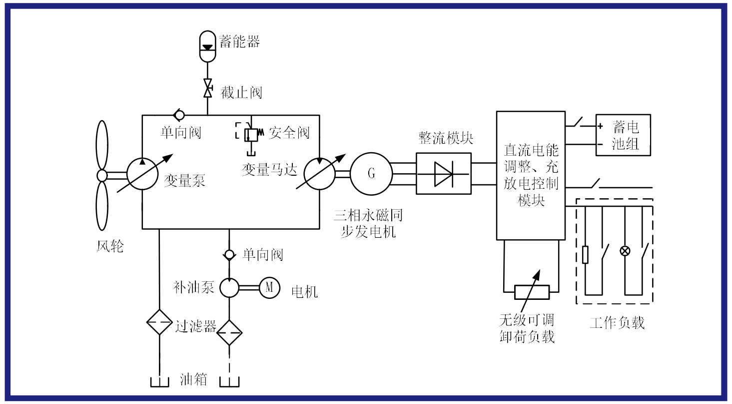
3.2 Present condition of domestic research



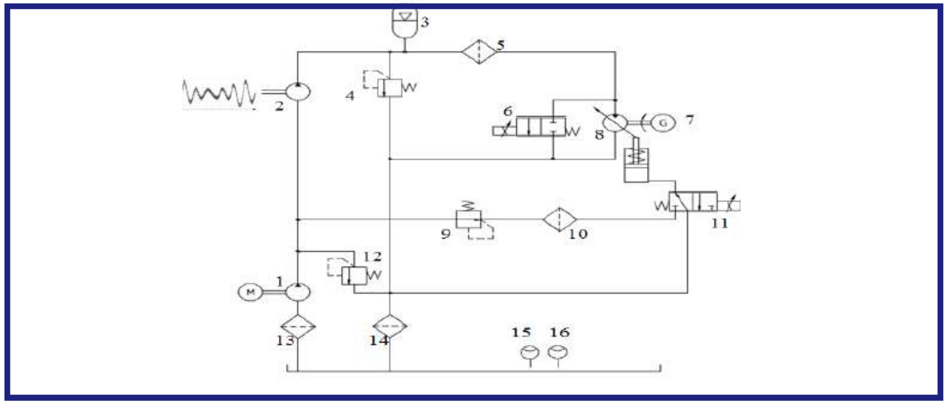
Yanshan University



Dalian university of technology



Zhejiang university

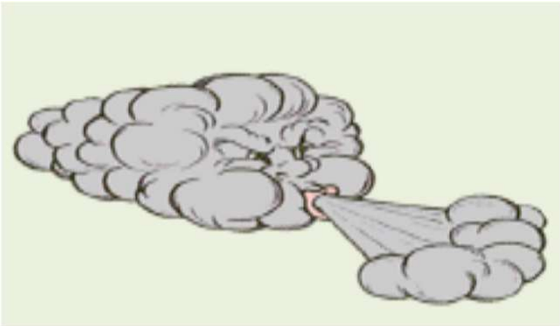


Shanghai Jiao Tong University

- Several Chinese university also did a large amount of work on hydraulic wind turbines.

4 Wind turbine

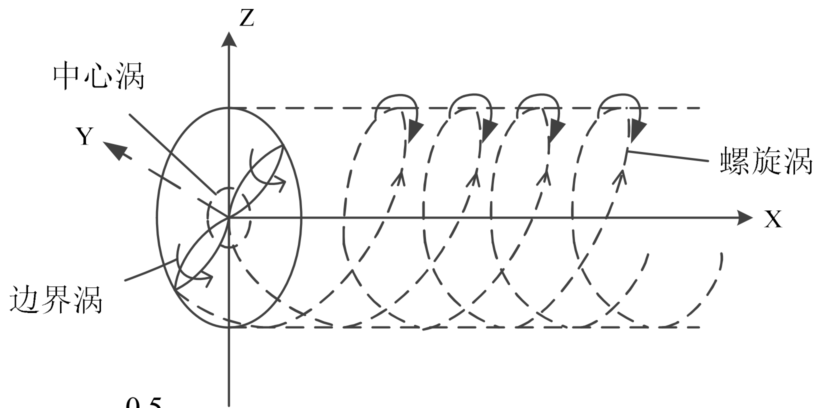
4.1 Wind turbine model

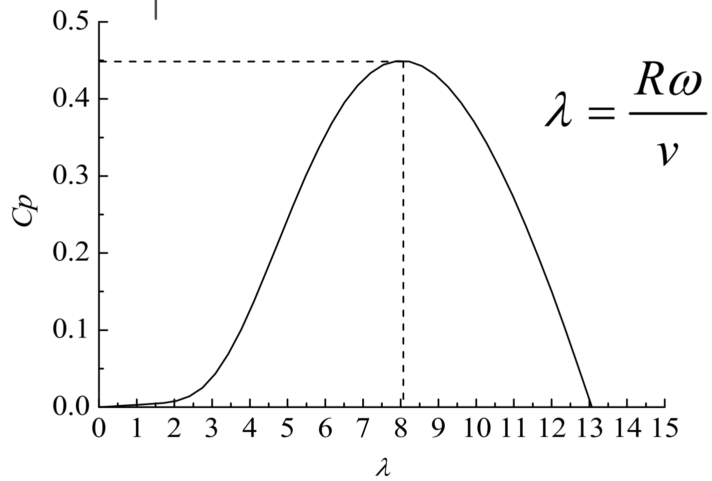


Output power and **pneumatic torque of wind turbine are**

$$P = \frac{1}{2}\rho A C_P(\lambda, \beta) v^3$$

$$T = \frac{P}{\omega}$$



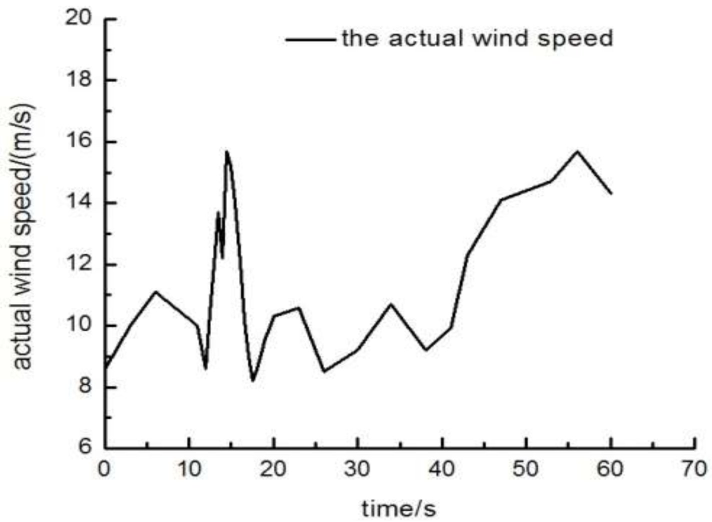


- To improve the generating efficiency, the characteristics of wind turbines are researched.

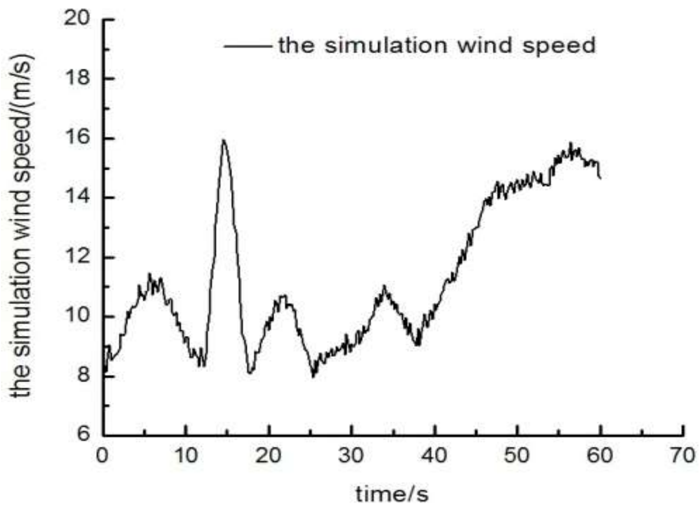
4 Wind turbine

4.2 Wind energy and wind turbine operation area

Although Wind speed has certain randomness , it still has a certain distribution principle. Mathematical method is used to describe wind characteristics. Blow picture is the relevant data in a wind farm.



The actual wind speed curve



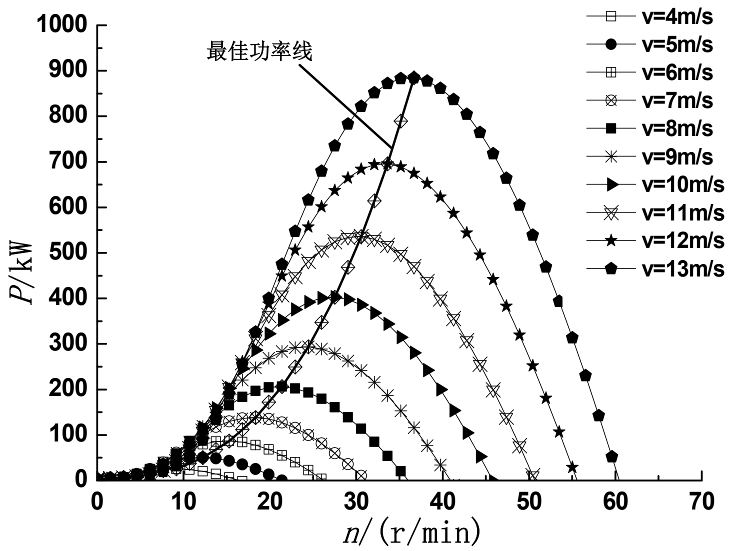
The simulation wind speed curve

- The wind speed model is simplified to a sum of four typical wind speeds: basic wind, intermittent wind, varied wind and random wind.

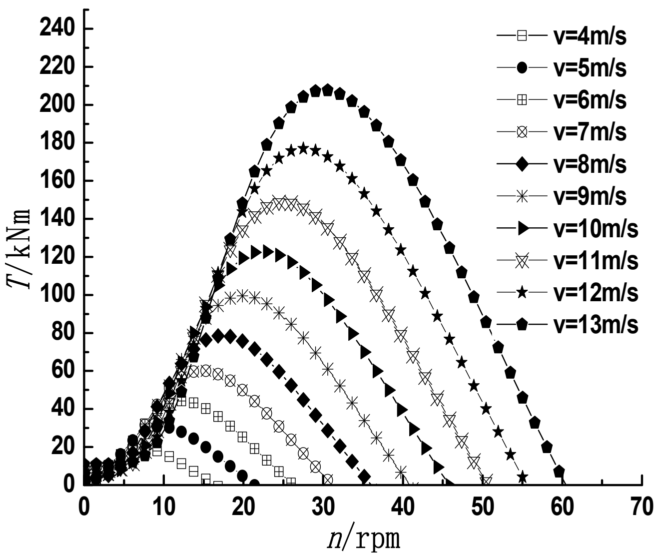
4 Wind turbine

4.2 Wind energy and wind turbine operation area

◆ A study about 850kW wind turbine has been conducted， the relevent curve of wind turbine speed obtained as followed.



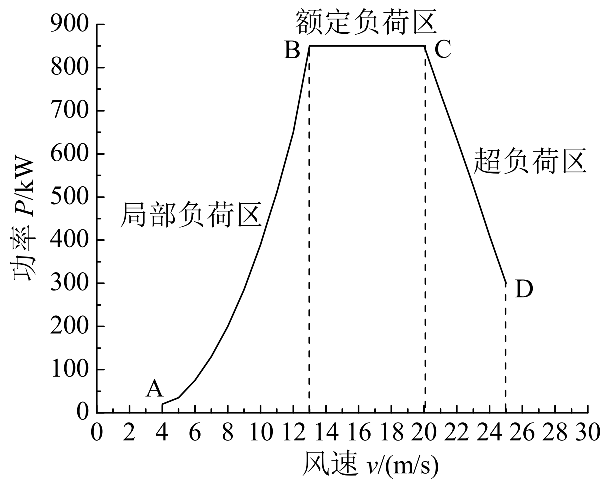
Wind turbine power output characteristic curve



Wind turbine pneumatic torque characteristic curve

➢ A high precision wind turbine model is proposed. (the model accuracy of more than 95 %)

◆ Analyze of running area



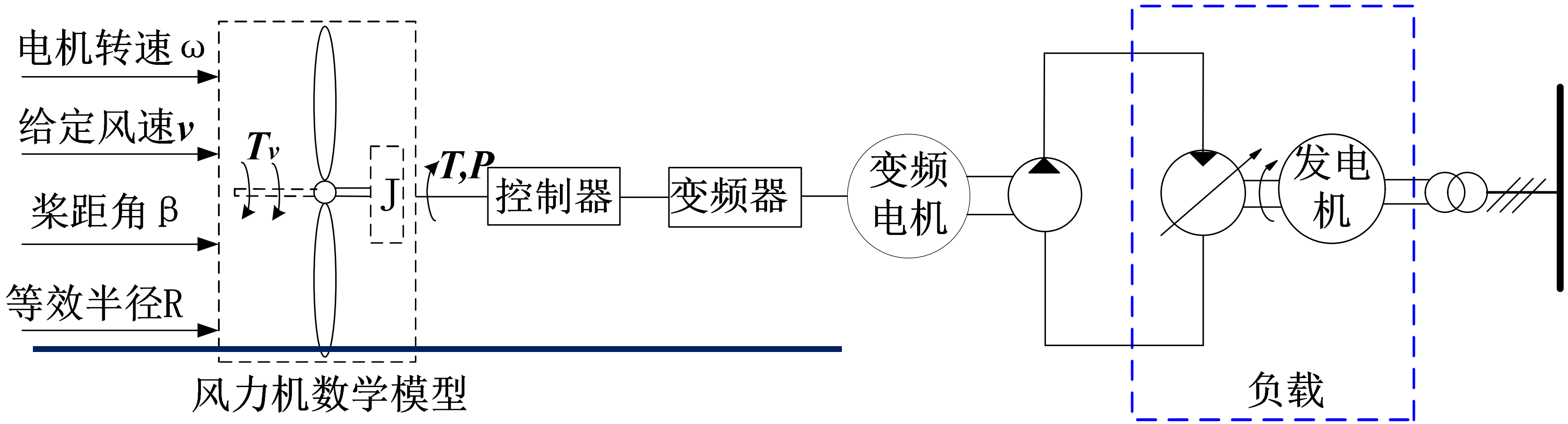
Output power of wind turbine

A~B: **Local load area ;**
B~C: **Rated load area ;**
C~D: **Exceed load area .**

4 Wind turbine

4.3 Wind turbine analog simulation research

There are no actual wind condition in lab. Variable frequency generator simulates wind turbine characteristics.



Analog simulation of wind turbine must meet the following three similarconditions
(1) Same wind energy utilization coefficient ; (2) Similar power;
(3) Similar moment of inertia

- Wind turbine simulation method is realized in the above aspects.

5 Hydraulic main drive system

5.1 Quasi-synchronization grid control

Five conditions of connected to Grid

① The same waveform ;

② The same phase sequence ;

③ The same frequency;

④ **The same magnitude ;**

⑤ **In the same phase .**

For the state grid frequency : **50Hz±(0.2)Hz**

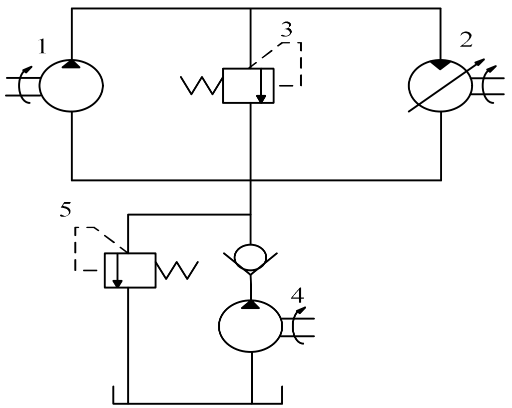
The range of motor speed : **1500 ±6r/min**

Grid control mode: （**Penecon-temporaneous method**）

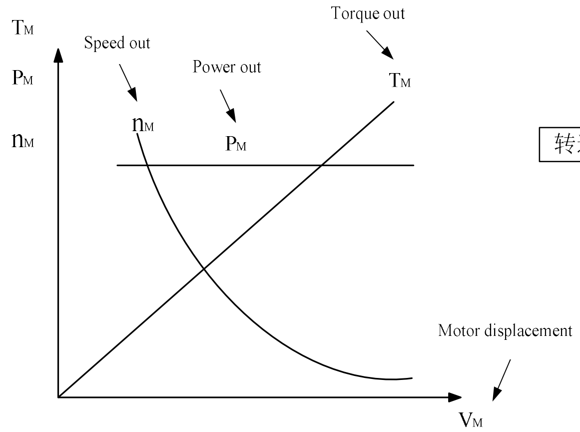
➢ Five conditions are needed in Quasi-synchronization grid control.

2.5 Hydraulic main drive system

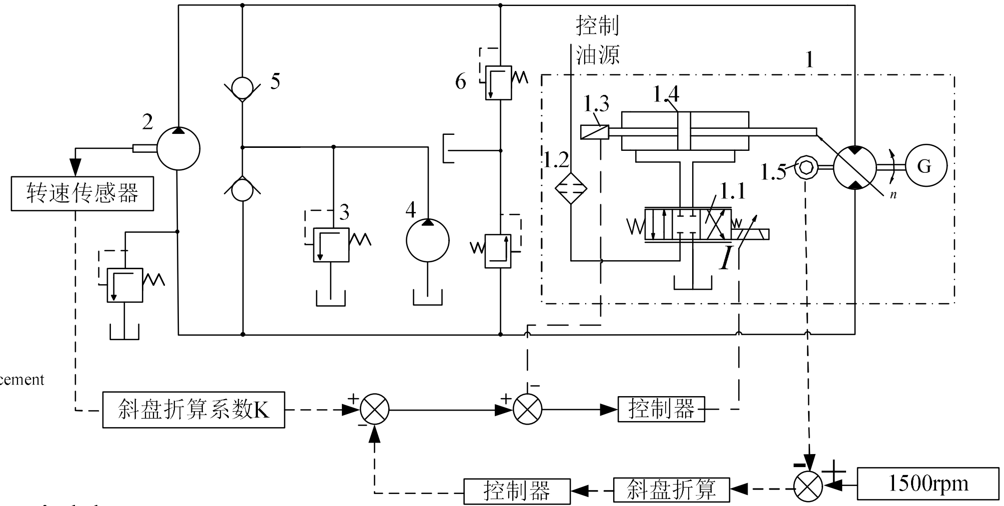
2.5.1 Speed control-Flow steady speed feedback control mode



•Fixed displacement pump- variable motor closed circuit diagram



•Fixed displacement pump- variable operating characteristic curve



•Flow feedback pump- variable motor speed control system schematic

➢The frequency allowable value of ±0.2Hz before connect to grid.

➢synchronous generator speed is 1500±6r / min

➢ Motor displacement reference value is given by the calculation of system.

➢Speed control method of fixed displacement pump-variable motor system and steady flow output control method is researched.

2.5 Hydraulic main drive system

2.5.1 Speed control - Based on the speed of the feedback linearization control mode

◆ **Controlling output option and Tracking target choose**

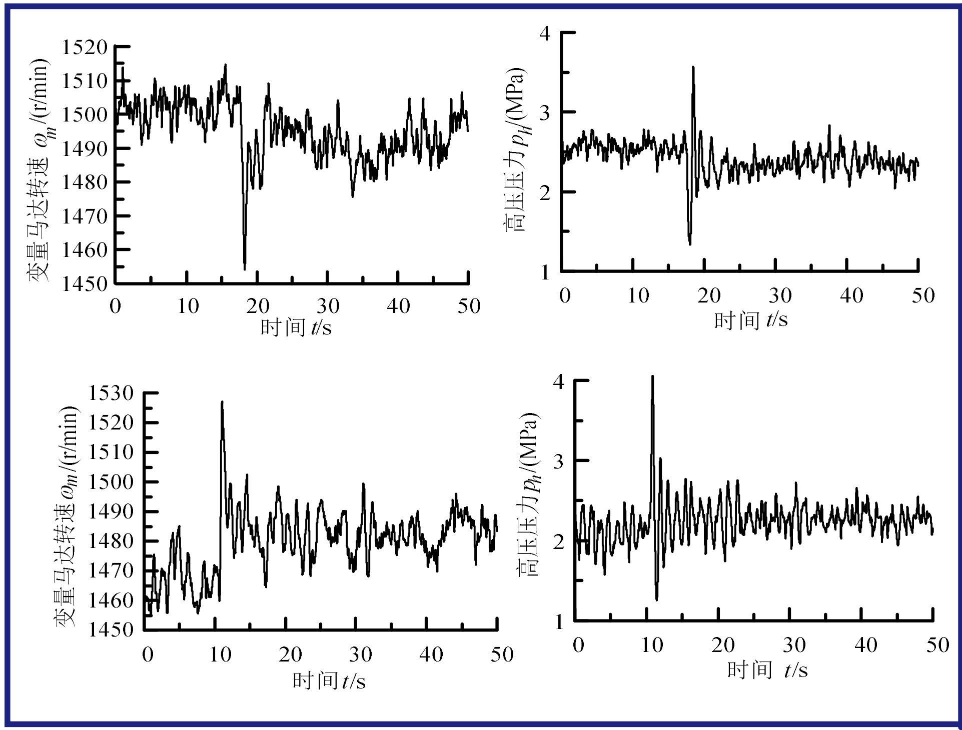
$$y=\begin{cases} h_1(x)=D_p\omega_p p_{h1}=D_p x_1 x_2 \\ h_2(x)=p_{h2}=x_3 \end{cases}$$

$$U_E=\frac{D_p\omega_p-C_{t1}p_{h1}+\left(V_1/\beta D_p\omega_p\right)\left(D_p p_{h1}\dot{\omega}_p-v_1\right)}{K}$$

$$\gamma=\frac{KU_E-C_{t2}p_{h2}-\dfrac{V_2}{\beta}v_2}{K_m\omega_m}$$

$$y_{1d}=K_p\omega_p^3=K_p x_1^3$$

$$y_{2d}=p_{h2d}=\frac{B_m\omega_{md}+T_L}{D_m}$$



Experiment

➢Wind turbine grid-connection control under the condition of changing wind speed is realized.

5 Hydraulic main drive system

5.1 Speed control -Based on dynamic cover control variabl e motorangular speed control

Various motor control law is consist of 3 portion as followed.

(1) Reference value of motor angular
(2) Compensation value of motor angular corresponding to system leaking
(3) Compensation value of motor angular corresponding to system pressure transient adjustment

$$S_1 = \omega_{\mathrm{m}} - \omega_{\mathrm{md}}$$

$$S_2 = p_{\mathrm{h2}} - p_{\mathrm{h2d}}$$

$$\bar{p}_{\mathrm{h2}} = \frac{(-k_1 S_1 + \dot{\omega}_{\mathrm{md}}) J_{\mathrm{m}} + B_{\mathrm{m}} \omega_{\mathrm{m}} + T_{\mathrm{e}}}{K_{\mathrm{m}} \gamma \eta_{\mathrm{mm}}}$$

$$\tau_1 \dot{p}_{\mathrm{h2d}} + p_{\mathrm{h2d}} = \bar{p}_{\mathrm{h2}}$$

Dynamic cover controller

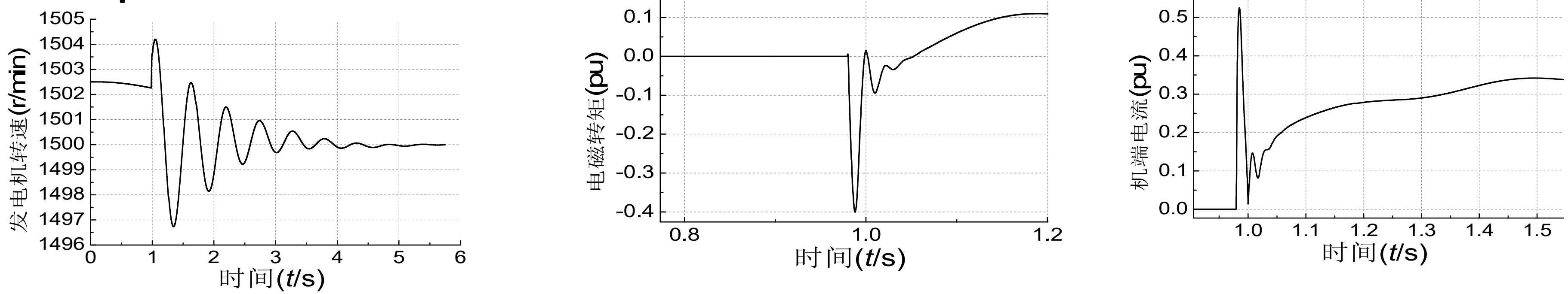
$$\gamma = \frac{D_{\mathrm{p}} \omega_{\mathrm{p}} - C_{\mathrm{tp}} p_{\mathrm{h1}} - (-k_2 S_2 + \dot{p}_{\mathrm{h2d}}) \dfrac{V_{02}}{\beta_{\mathrm{e}}}}{K_{\mathrm{m}} \omega_{\mathrm{m}}} = \frac{D_{\mathrm{p}} \omega_{\mathrm{p}}}{K_{\mathrm{m}} \omega_{\mathrm{m}}} - \frac{C_{\mathrm{tp}} p_{\mathrm{h1}}}{K_{\mathrm{m}} \omega_{\mathrm{m}}} - \frac{(-k_2 S_2 + \dot{p}_{\mathrm{h2d}}) V_{02}}{K_{\mathrm{m}} \omega_{\mathrm{m}} \beta_{\mathrm{e}}}$$

➢Hydraulic system output speed is controlled by the variable motor angle.

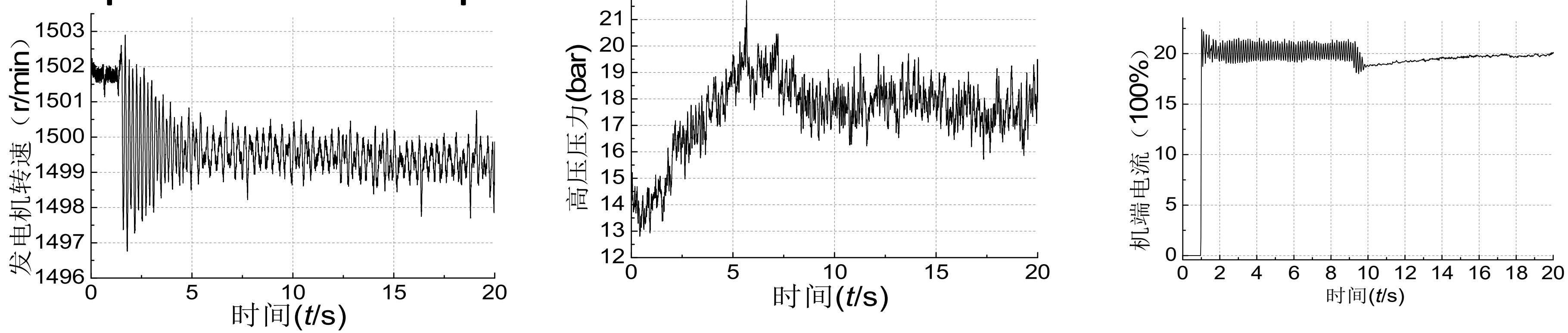
5 Hydraulic main drive system

5.1 Speed control-Experiment and simulation

Grid impact characteristics simulation



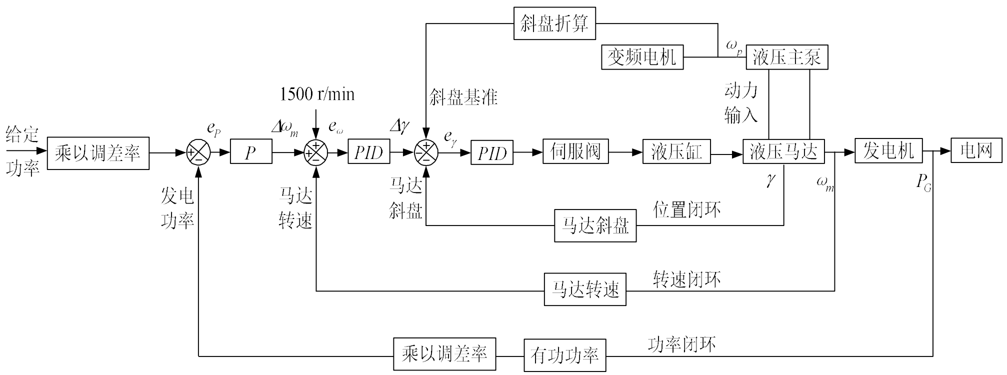
Grid impact characteristic experiment

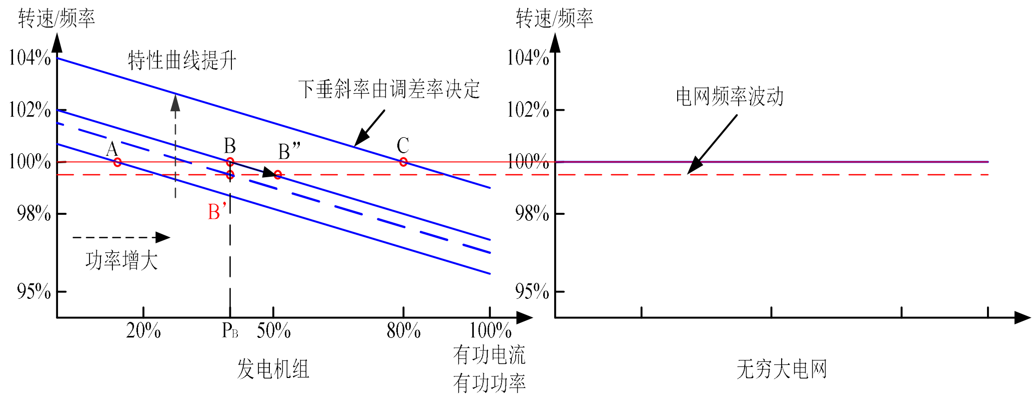


- Voltage and frequency offset have less impact on grid, and a greater influence on the phase angle difference.
- The impact current is small than 30% rated current, and the phase angle impact is about 4 degrees.

5 Hydraulic main drive system

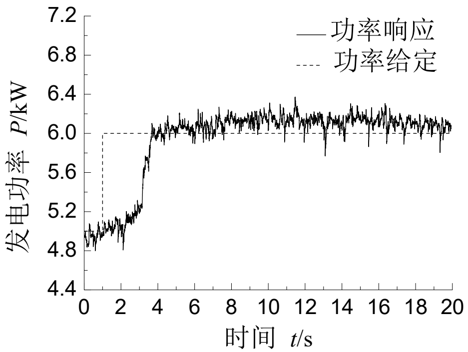
5.2 Main drive system power control—Active power control



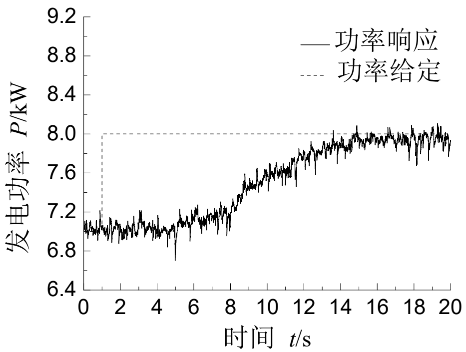


Position closed-loop control；motor speed closed-loop control；power closed-loop control

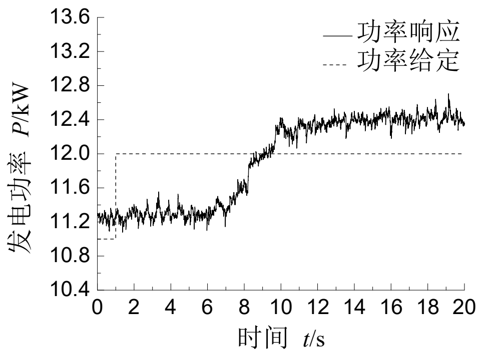
Using **droop characteristic** control scheme to establish the linear relationship between speed and power



a) Rp=500r/min



b) Rp=700r/min



c) Rp=900r/min

P=0.3
I=0.1
Pw=1kW

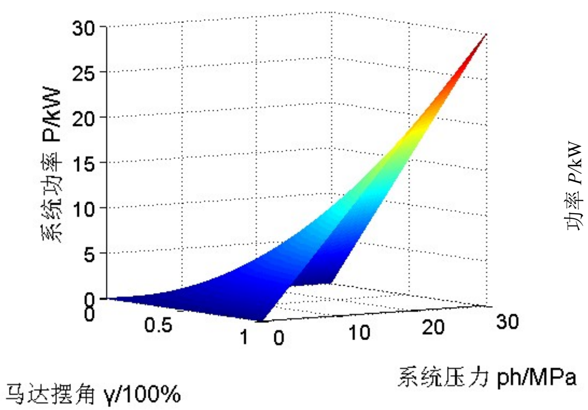
- Power control can be realized by using the droop characteristic method.

5 Hydraulic main drive system

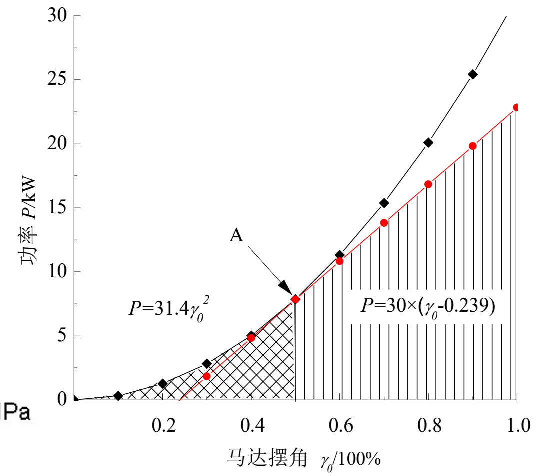
5.2 power control—Active Power Control Online Optimization of Power Controller

The power of the motor angular transfer function： $\frac{p_h}{\gamma}=-\frac{K_m\omega_{m0}/C_t}{(1+\frac{V_0}{C_t\beta_e}s)}$

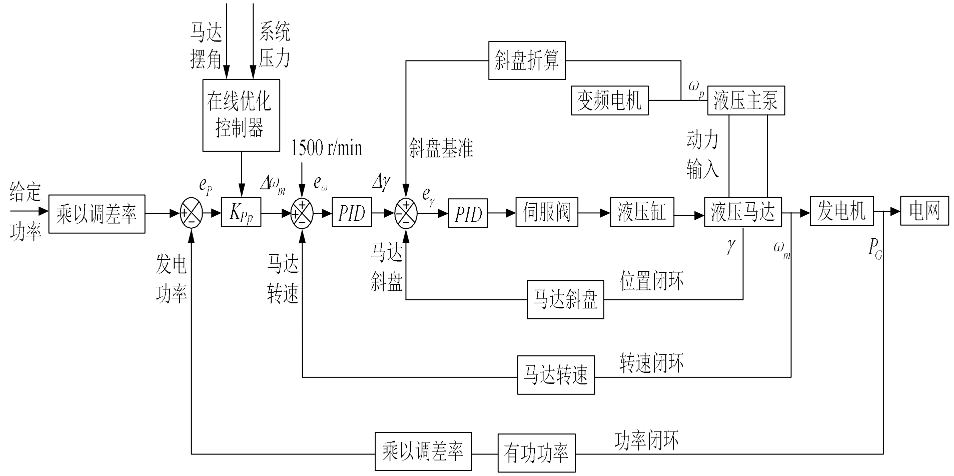
The system pressure of angular transfer function of the motor： $\frac{p_h}{\gamma}=-\frac{K_m\omega_{m0}/C_t}{(1+\frac{V_0}{C_t\beta_e}s)}$



Power three-dimensional workspace



Power up interval

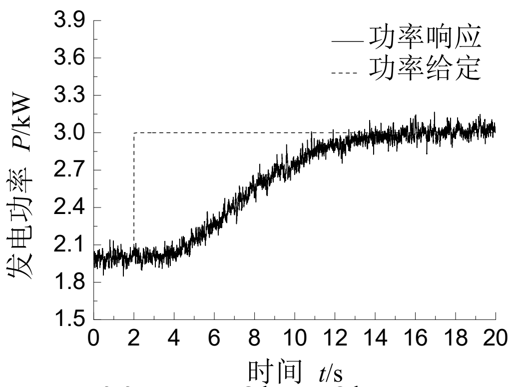


Control block diagram of online optimal power control

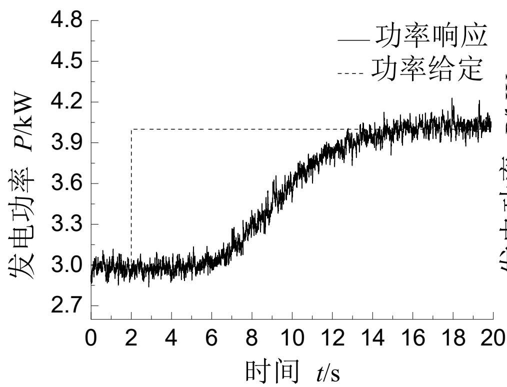
➢ According to the system’s initial pressure and motor’s initial swing angle, the gain value of power control link is determined.

5 Hydraulic main drive system

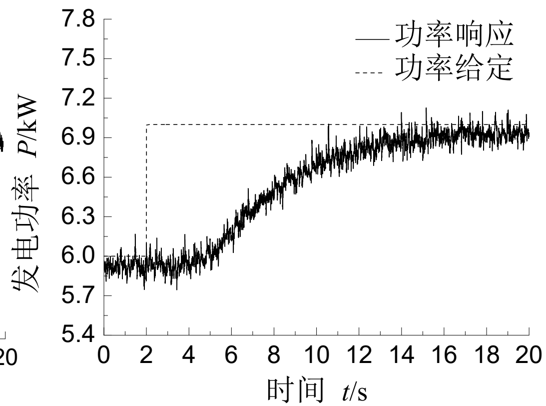
5.2 power control—experimental verification



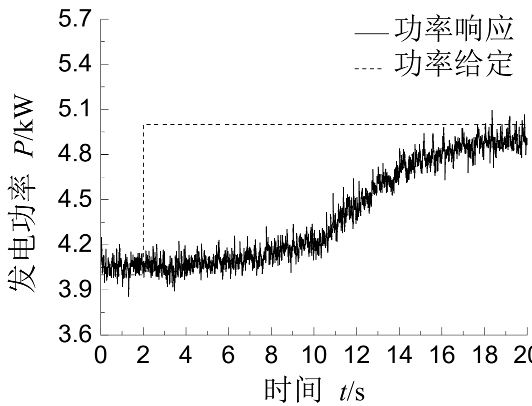
500RPM-2kW-3kW



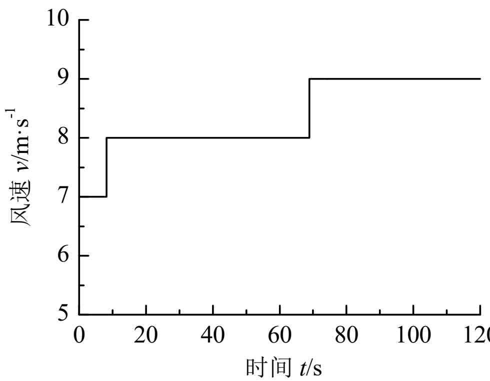
500RPM-3kW-4kW

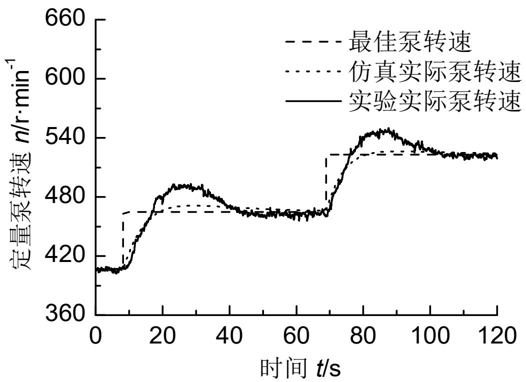


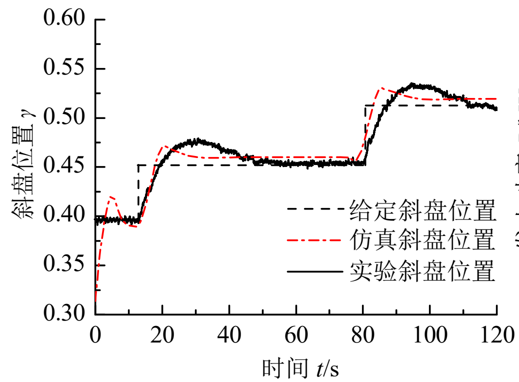
700RPM-6kW-7kW

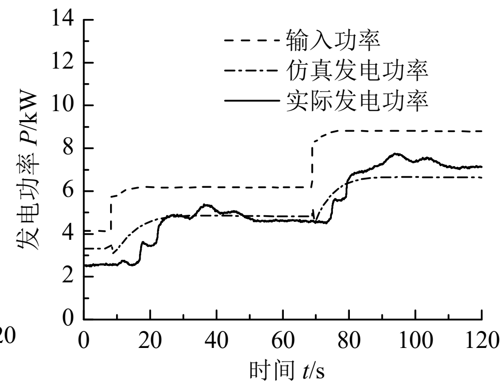


700RPM-4kW-5kW





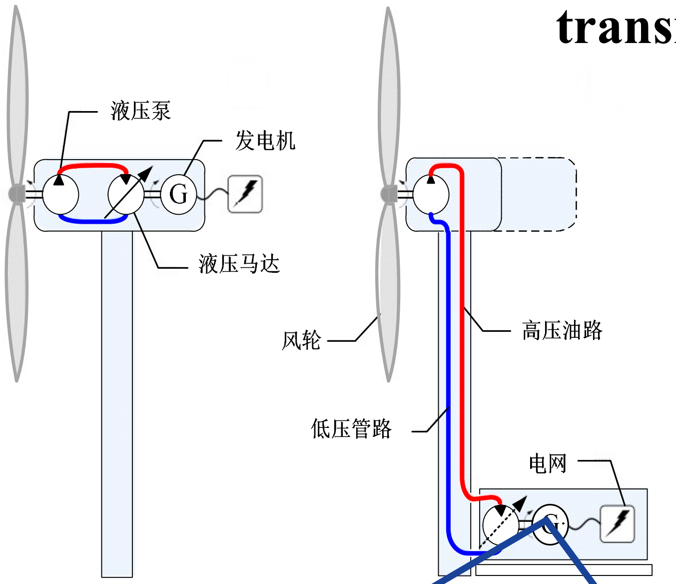


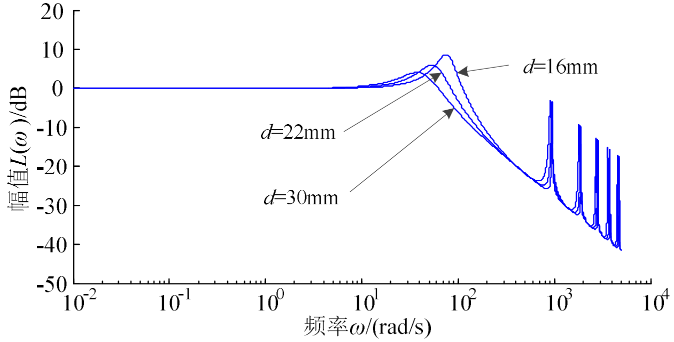


- Under the condition of low wind speed, the optimal control theory is used to realize the power tracking and power smoothing.

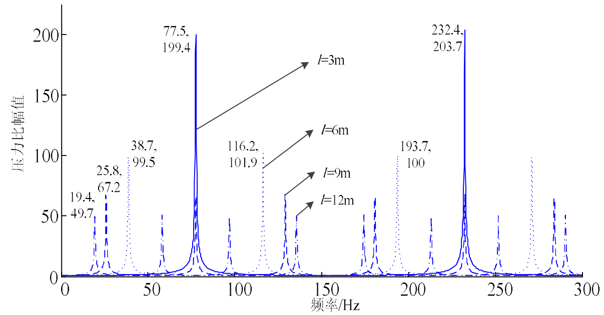
5 Hydraulic main drive system

5.3 Research on the characteristics and the steady speed control of the main transmission system with long pipeline



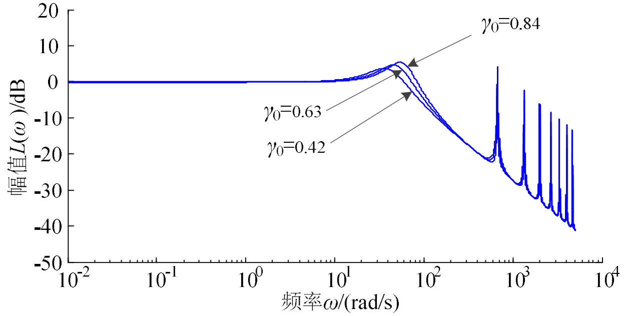


◆Effect of **pipe diameter**

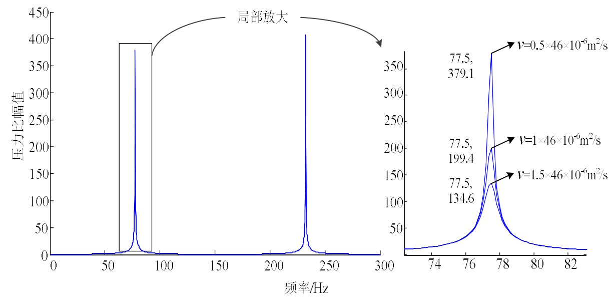


◆Effect of **oil density** on sysytem pressue

With the increase of hydraulic pipeline, the **stiffness** of the system is reduced . So that the unit is more likely to **produce resonance under the random wind frequency excitation.**



◆Effect of **motor swing angle**

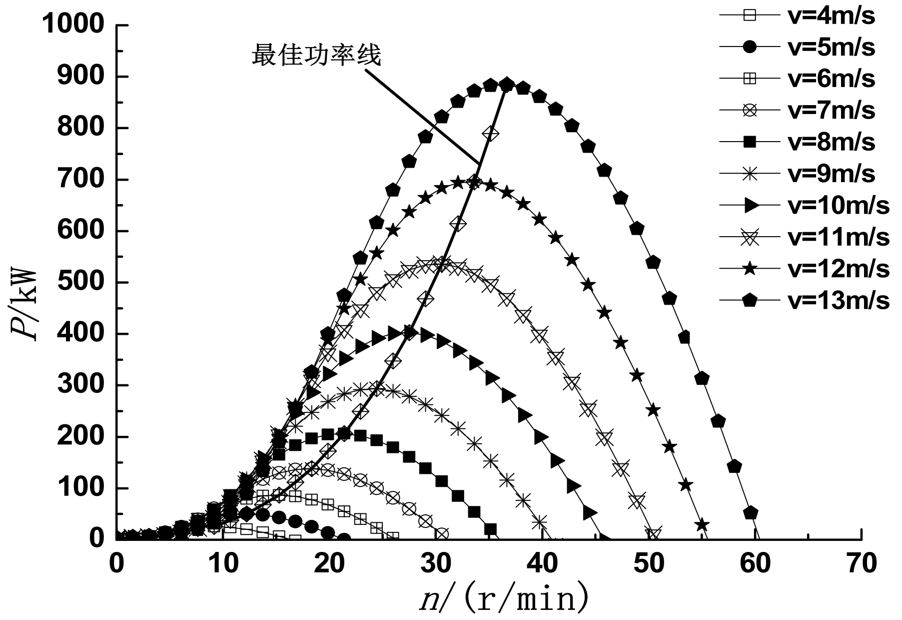


◆Effect of **pipe diameter** on sysytem pressue

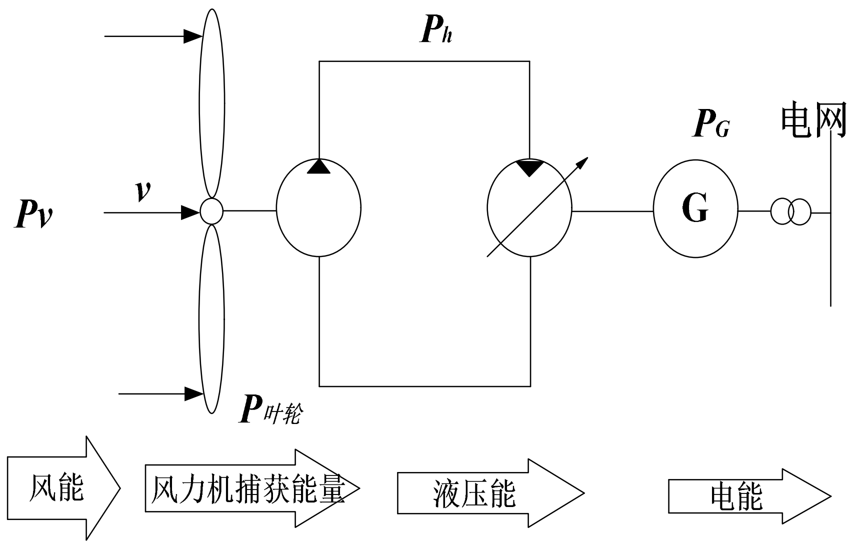
- ➢ The influence of system parameters, including pipe length, diameter and steady speed control strategy are studied.

5 Hydraulic main drive system

5.4 Maximum Power Point Tracking (MPPT)Control —Control target



Wind turbine power output characteristic curve



Energy transfer of HWT

- **Essence: Control wind turbine's rotate speed.**
- **Purpose: Get more energy from wind.**
- The wind turbine can automatically and quickly adjust itself to the maximum power point and operate stably.

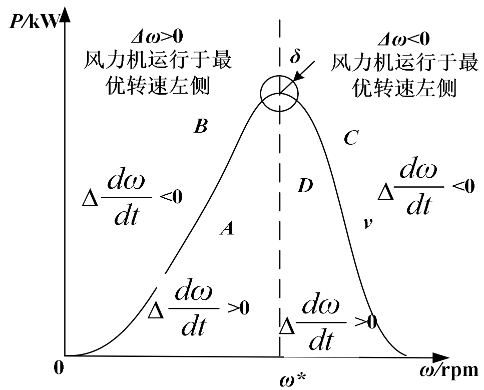
5 Hydraulic main drive system

5.4 MPPT Control —Control method

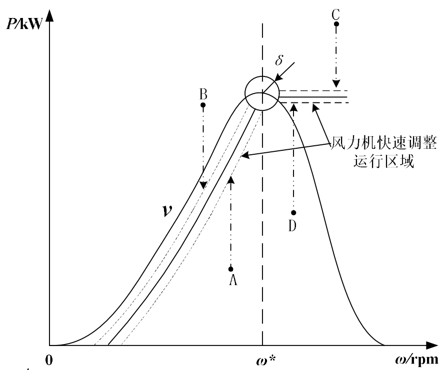
◆MPPT Control Method for Hydraulic Wind Turbine

HWT is different from traditional wind turbine, so MPPT control method is proposed, which divides into the following four steps:

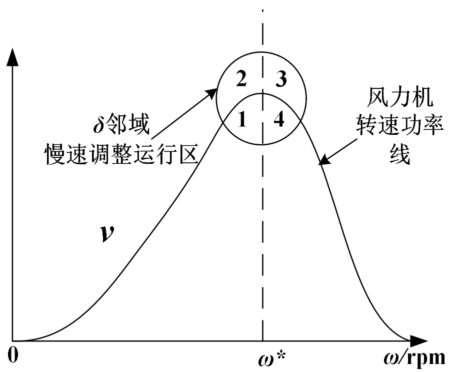
(1)Operation condition judgement(2)Quick adjustment(3) Slow adjustment(4) MPPT result judgement



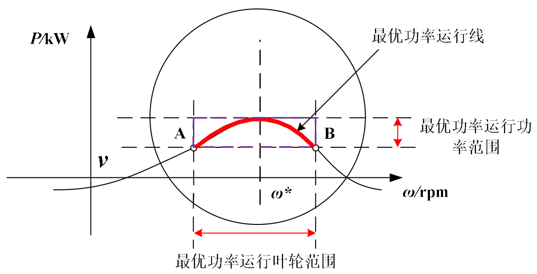
Operation condition judgement



Quick adjustment



Wind turbine slow adjustment



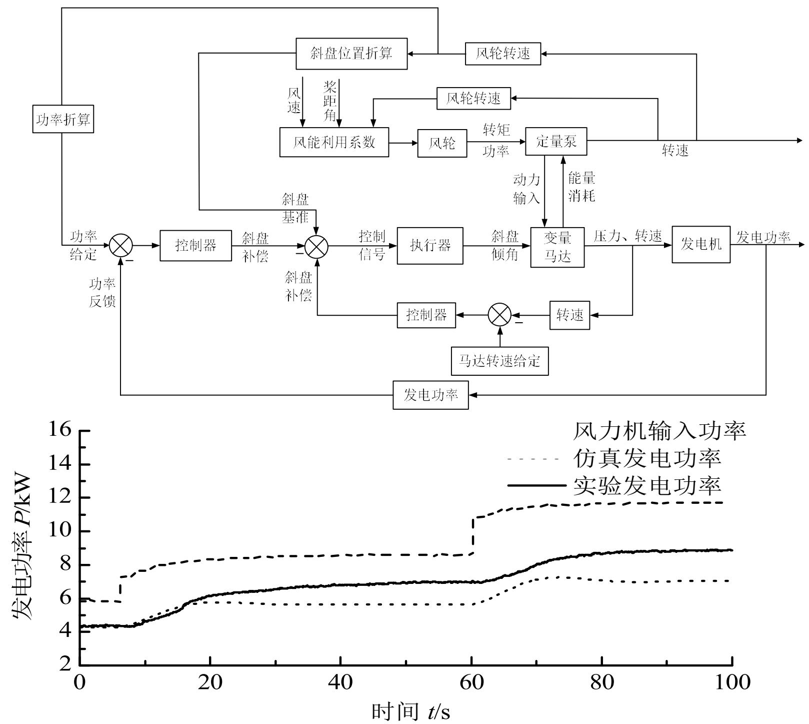
MPPT operating area

➢ A new MPPT control method for HWT is proposed.

5 Hydraulic main drive system

5.4 MPPT Control —Control method

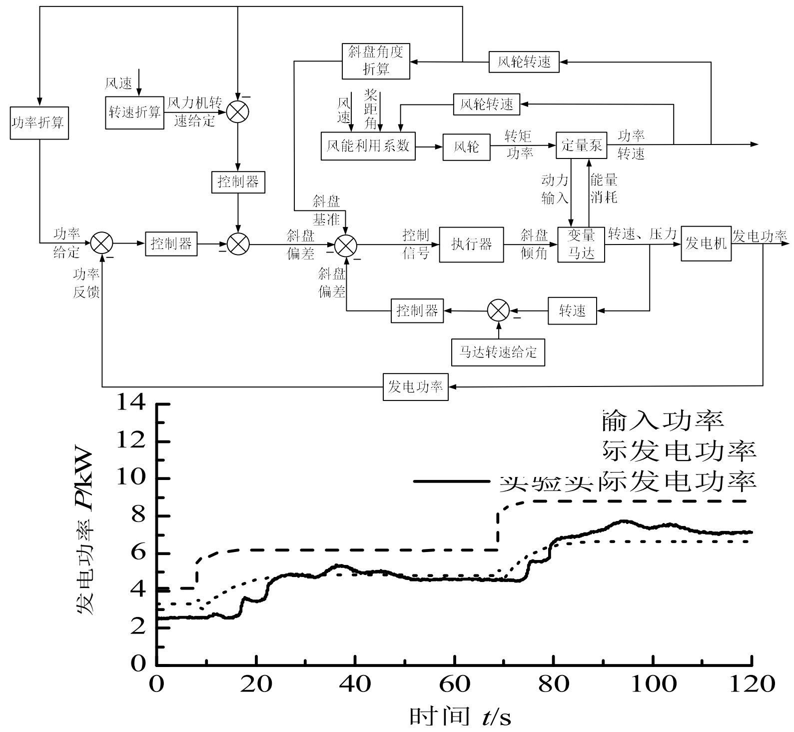
a) Based on wind power



Experiment and simulation results in step wind speed

➢ **Conclusion:** When the tracking process is completed, the final stable point deviates from MPPT.

b) Based on wind power and speed



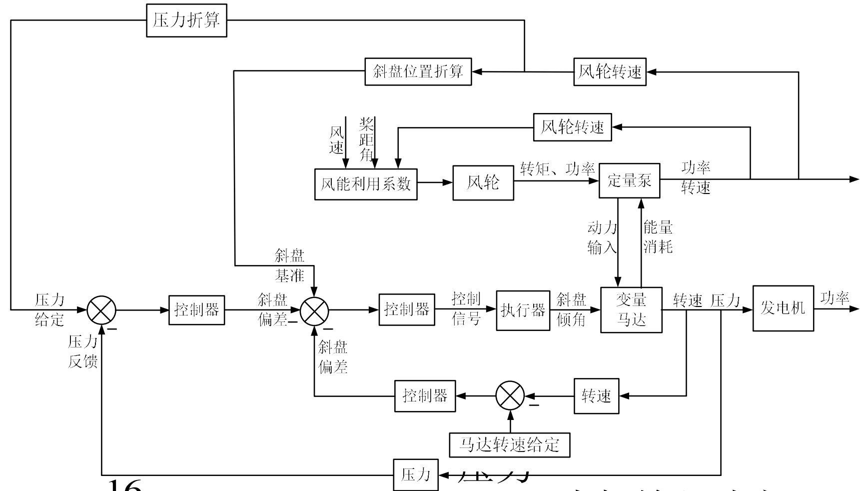
Experiment and simulation results in step wind speed

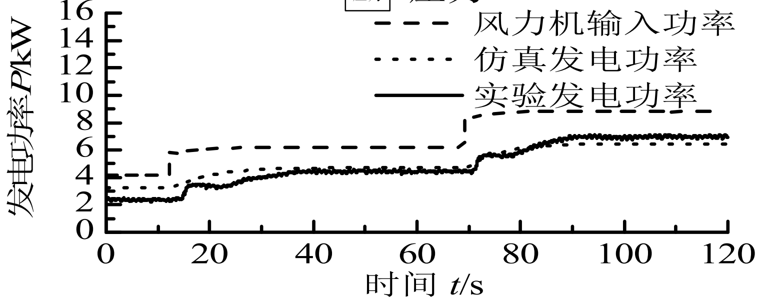
➢ **Conclusion:** The speed control loop is adopted, which overcomes the defect of MPPT control.

5 Hydraulic main drive system

5.4 MPPT Control —Control method

c) Based on system pressure

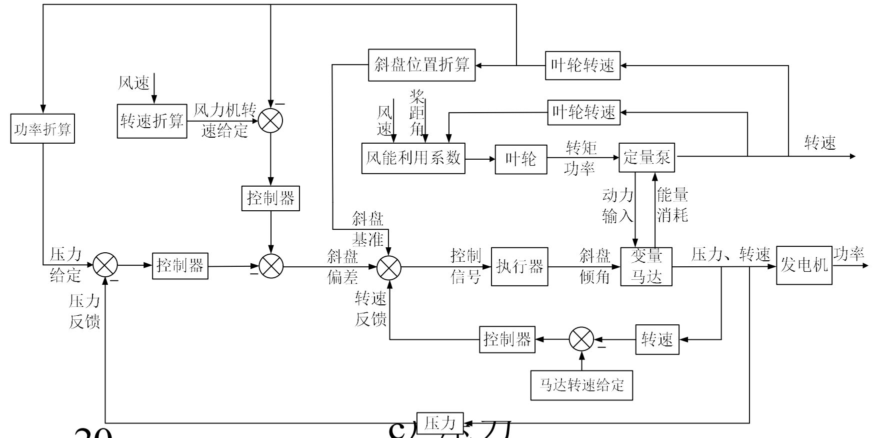


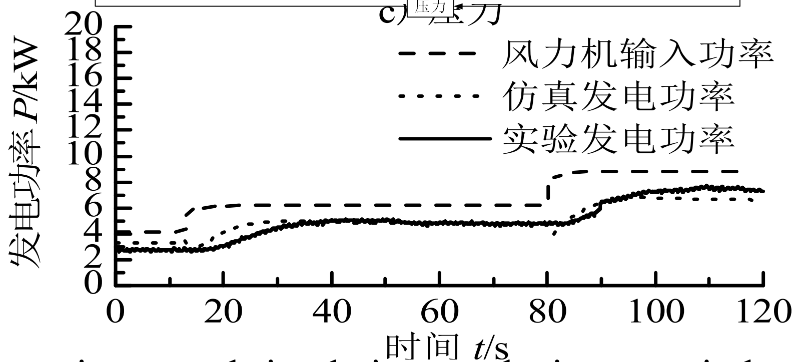


Experiment and simulation results in step wind speed

- **Conclusion:** The system pressure is accurately controlled, but the system also deviates from MPPT.

d) Based on system pressure and wind turbine rotation speed





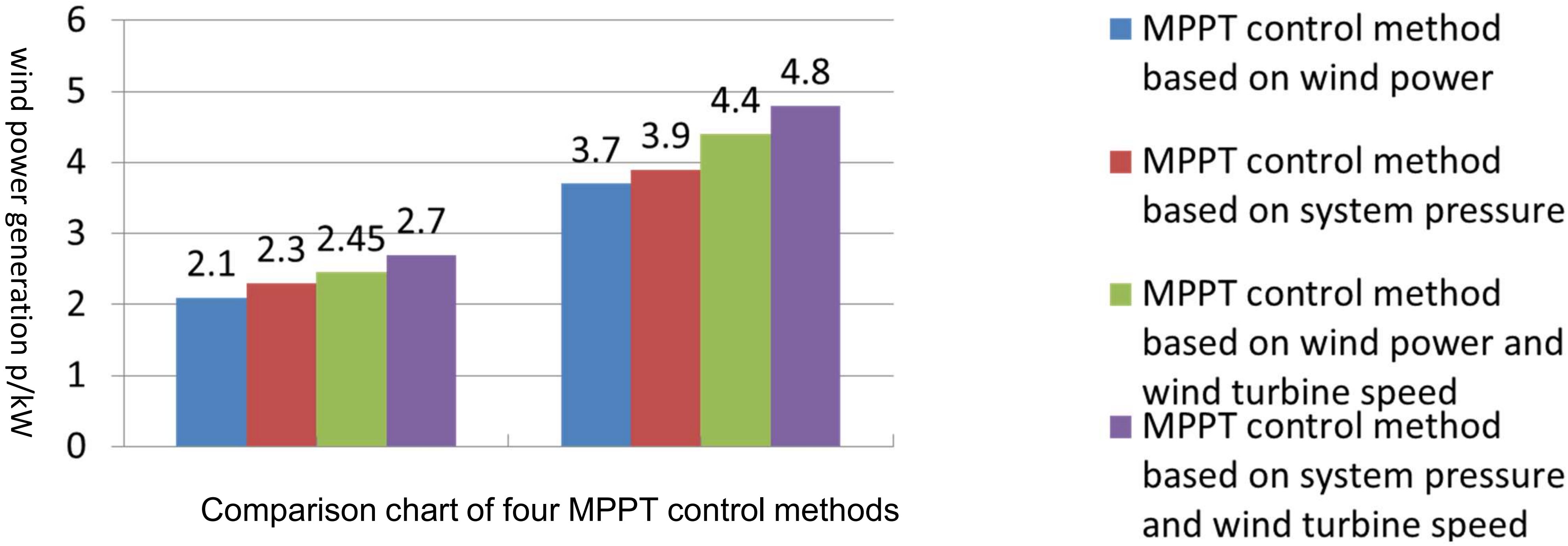
Experiment and simulation results in step wind speed

- **Conclusion:** The system is completely coincident with the MPPT when the tracking process is completed.

5 Hydraulic main drive system

5.4 MPPT Control —Control method

In order to compare the results of four MPPT control methods ,the experimental data is as followed.



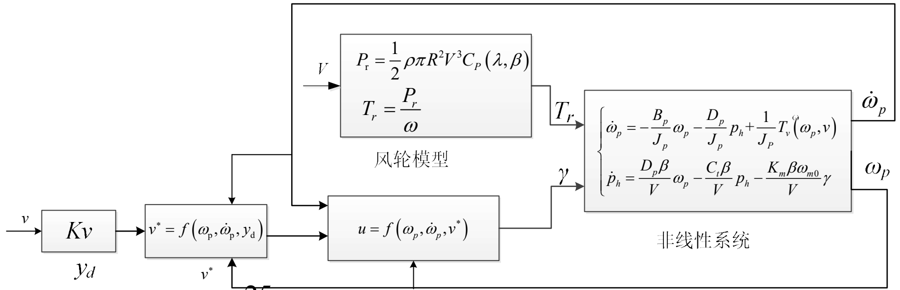
Comparison chart of four MPPT control methods

➢The combination control of system pressure and wind turbine speed shows the best control performance.

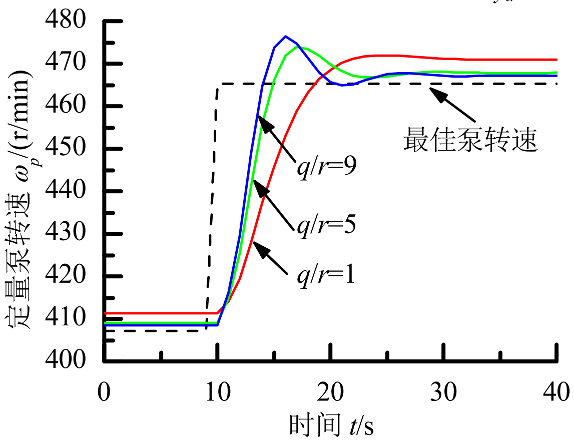
5 Hydraulic main drive system

5.4 MPPT Control —Control method

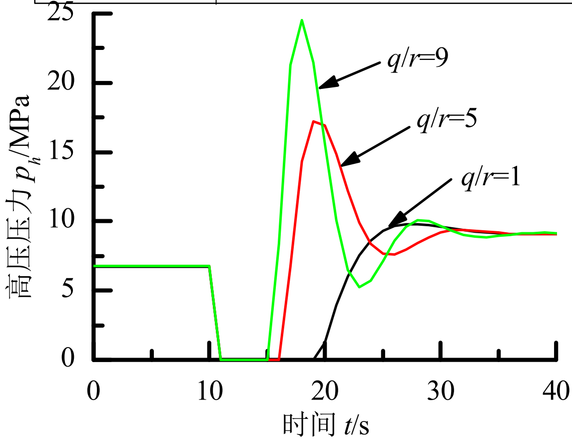
e) Based on wind turbine using feedback linearization method



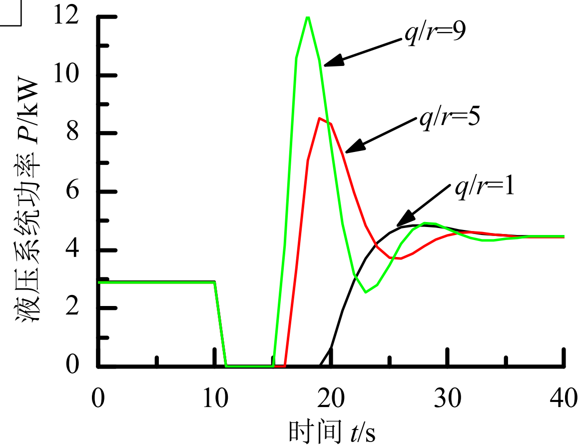
Simulation modal



Quantitative pump speed response curve



System pressure curve



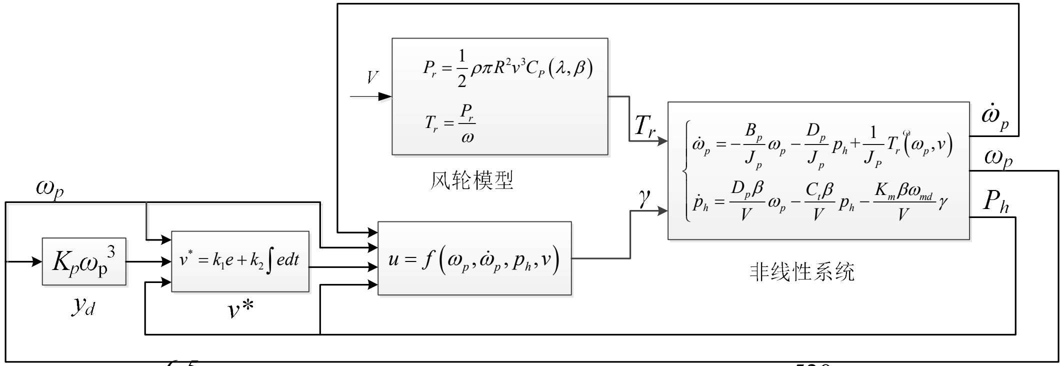
System frequency curve

- The tracking accuracy of the system increases with the increase of the ratio of q to r, but the output power is relatively large.

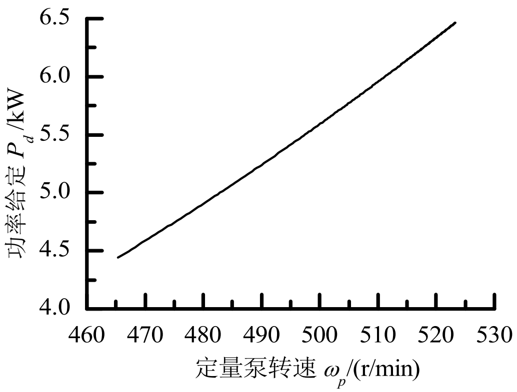
5 Hydraulic main drive system

5.4 MPPT Control —Control method

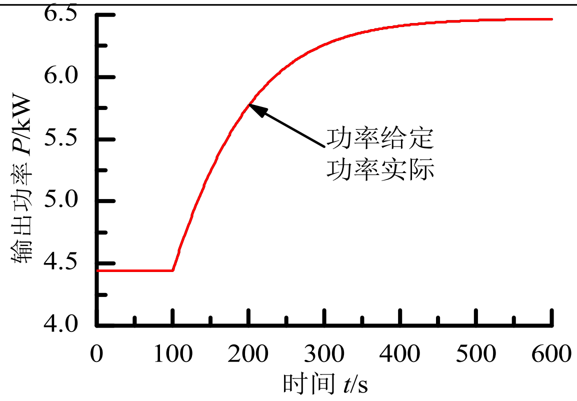
e) Based on output power using feedback linearization method



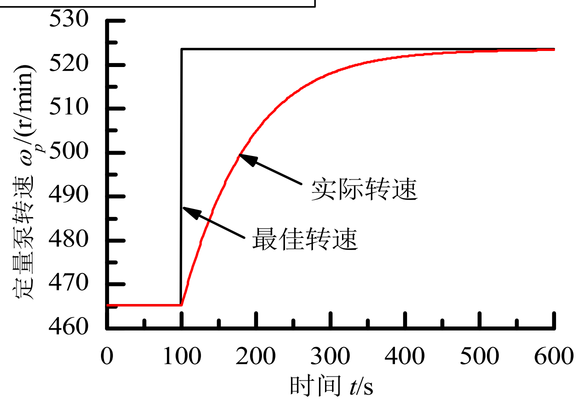
Simulation model



Quantitative pump speed response curve



System pressure curve

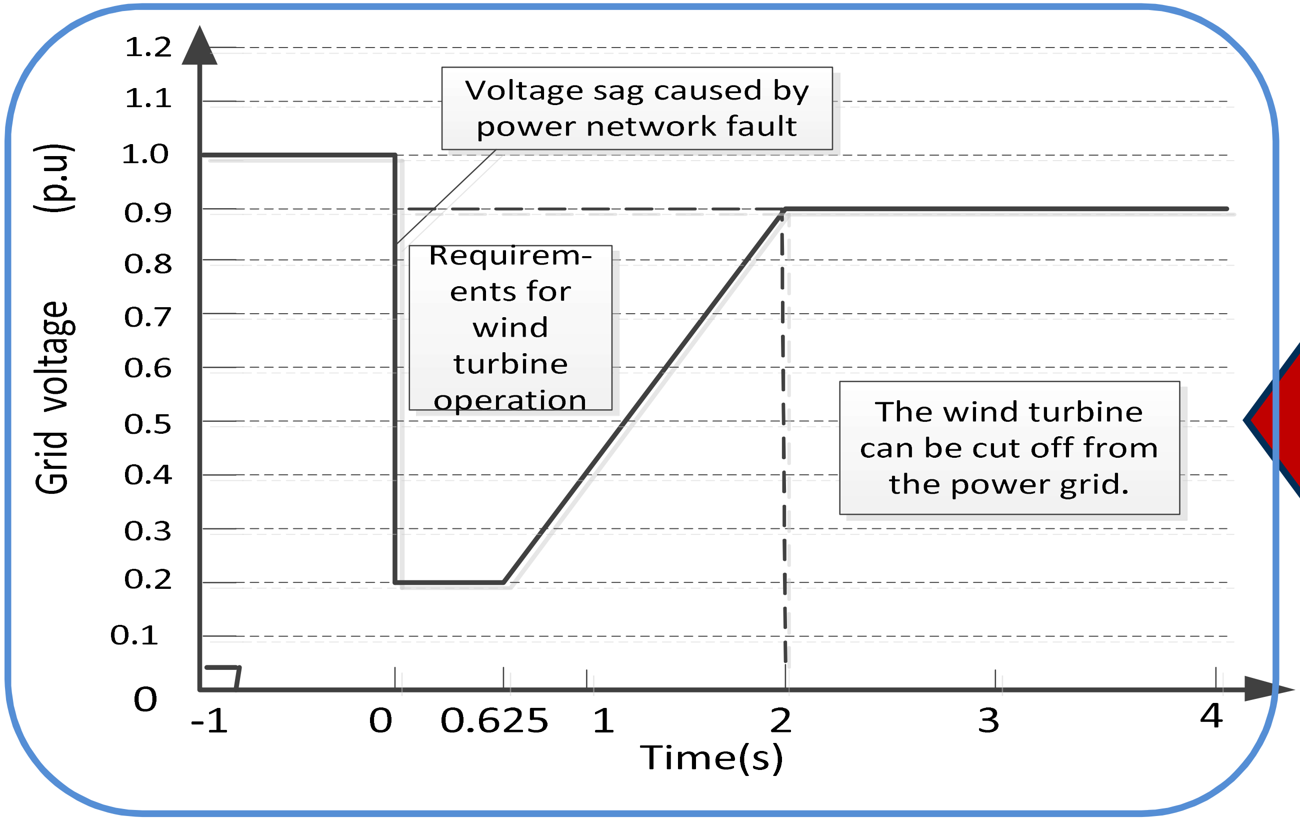


System frequency curve

- The tracking time is longer, but the output power is relatively stable and it is easy to be accepted by the power grid.

6 Low voltage ride through

6.1 Research background



Wind turbines should be able to maintain the low voltage ride through capability of 0.625 seconds when the voltage drop to 20% rated voltage.

The wind farm and the network voltage can be recovered to 90% of the rated voltage in 2 seconds after the fall, the wind power unit should have the ability to run in uninterrupted power grid.

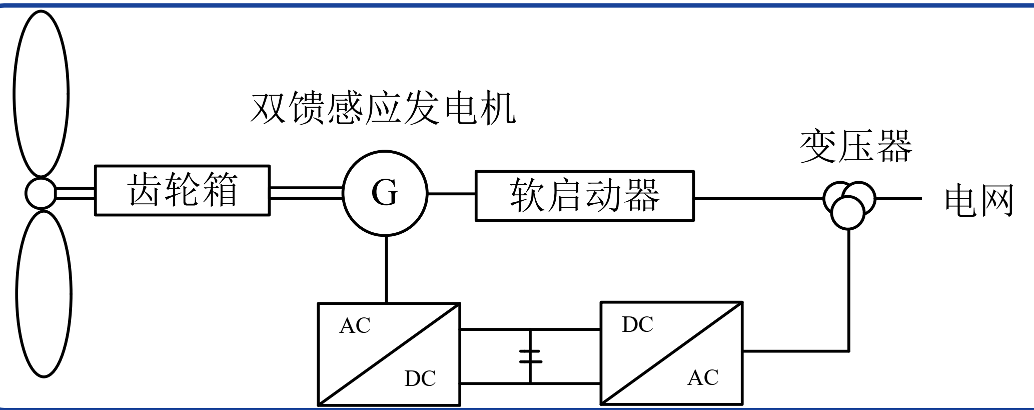
During the power grid fault period without cutting out of the wind turbine, the active power in the fault should be removed after the power of at least 10% of the rated power / second change to the state before the fault.

LVRT specifications for wind turbines in China

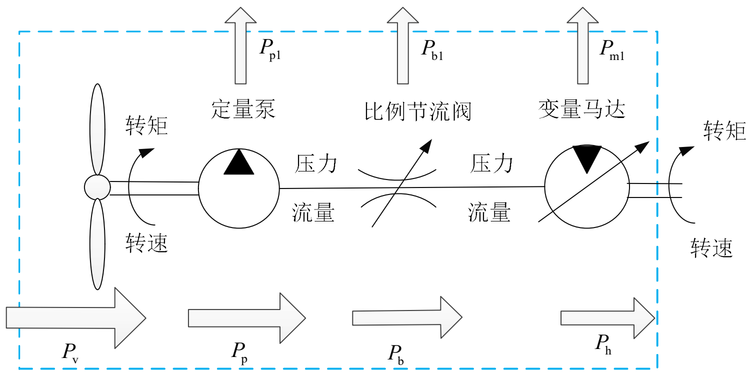
- The LVRT are different from countries to countries and here Chinese LVRT is taken as the standard.

6 Low voltage ride through

6.1 Research background



DFIG is mostly used Crowbar protection circuit to decrease the rotor current converter, **which cannot be adopted in HWT.**



Power loss:

(1) Fixed displacement pump: $P_{p1}=p_{h1}D_p\omega_p(1-\eta_{pv})$

(2) Proportional throttle valve: $P_{b1}=Q_b(p_{h1}-p_{h2})$

(3)Various motor: $P_{m1}=p_{h2}K_m\gamma\omega_m(1-\eta_{mv})$

- **Self-preservation**—Adjust hydraulic transmission power quickly.
- **Not to take off power grid**—Ensure steady speed output.
- **Support**—Steadily provide reactive power.

6 Low voltage ride through

6.2 Coupling analysis of hydraulic system

The hydraulic main driving system mathematical model

(1)Fixed-displacement pump

$$Q_{\mathrm{p}} = D_{\mathrm{p}}\omega_{\mathrm{p}} - C_{\mathrm{tp}}p_{\mathrm{h1}}$$

$$\dot{\omega}_{\mathrm{p}} = \frac{1}{J_{\mathrm{p}}}(T_{\mathrm{w}} - \frac{D_{\mathrm{p}}p_{\mathrm{h1}}}{\eta_{\mathrm{mp}}} - B_{\mathrm{p}}\omega_{\mathrm{p}})$$

(2)proportional throttle valve

$$X_{\mathrm{v}} = KU_{\mathrm{E}}$$

$$Q_{\mathrm{b}} = C_{\mathrm{d}}WX_{\mathrm{v}}\sqrt{\frac{2}{\rho}(p_{\mathrm{h1}} - p_{\mathrm{h2}})} = C_{\mathrm{d}}WX_{\mathrm{v}}\sqrt{\frac{2p_{\mathrm{L}}}{\rho}}$$

(3)Various motor

$$Q_{\mathrm{m}} = K_{\mathrm{m}}\gamma\omega_{\mathrm{m}} + C_{\mathrm{tm}}p_{\mathrm{h2}}$$

$$\dot{\omega}_{\mathrm{m}} = \frac{1}{J_{\mathrm{m}}}(K_{\mathrm{m}}\gamma p_{\mathrm{h2}}\eta_{\mathrm{mm}} - B_{\mathrm{m}}\omega_{\mathrm{m}} - T_{\mathrm{e}})$$

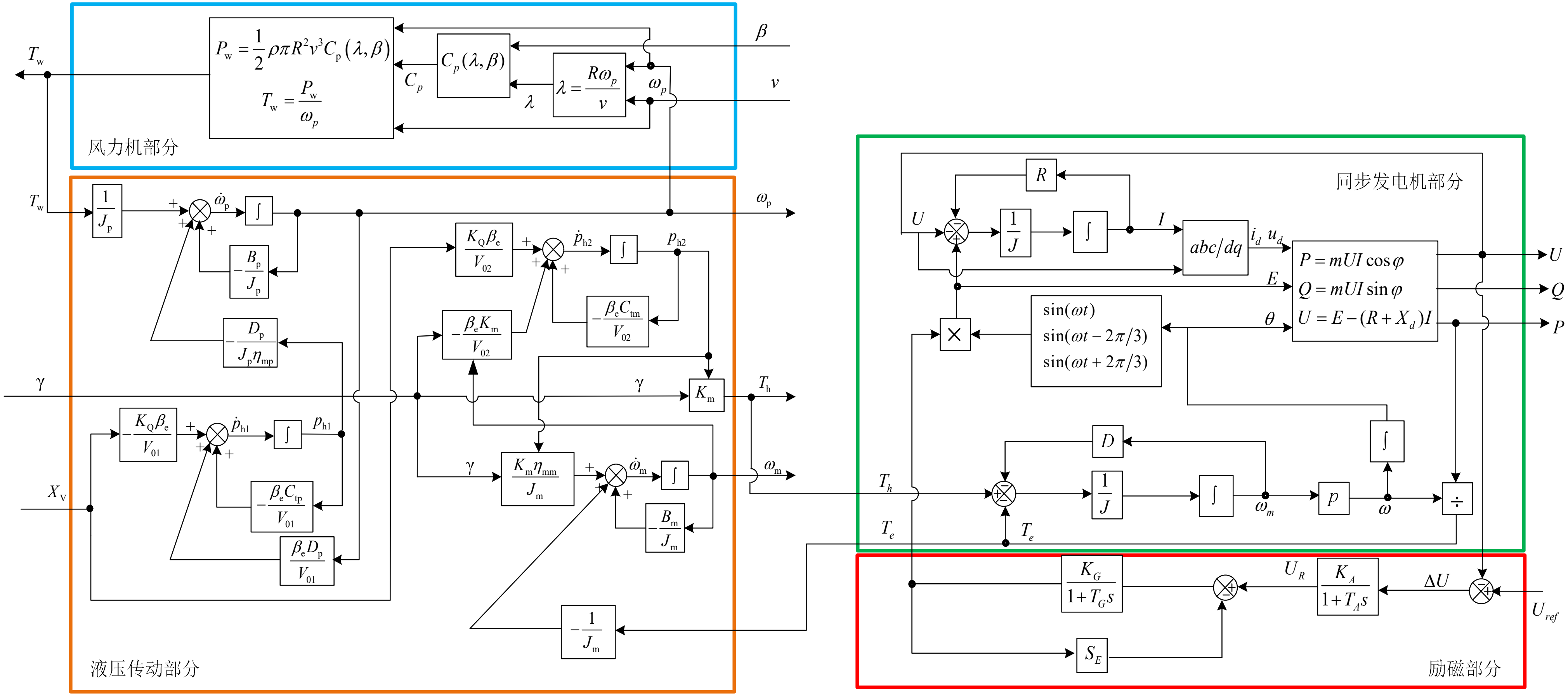
(4) Hydraulic pipeline

$$\dot{p}_{\mathrm{h1}} = \frac{\beta_{\mathrm{e}}}{V_{01}}(D_{\mathrm{p}}\omega_{\mathrm{p}} - C_{\mathrm{tp}}p_{\mathrm{h1}} - K_{\mathrm{q}}X_{\mathrm{V}})$$

$$\dot{p}_{\mathrm{h2}} = \frac{\beta_{\mathrm{e}}}{V_{02}}(K_{\mathrm{q}}X_{\mathrm{V}} - K_{\mathrm{m}}\gamma\omega_{\mathrm{m}} - C_{\mathrm{tm}}p_{\mathrm{h2}})$$

6 Low voltage ride through

6.2 Coupling analysis of hydraulic system

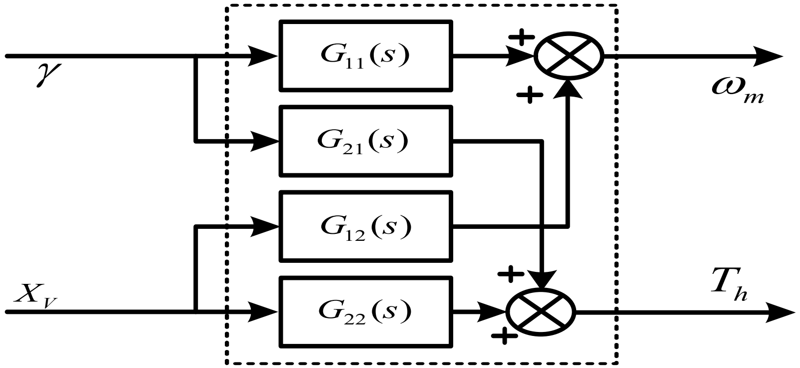


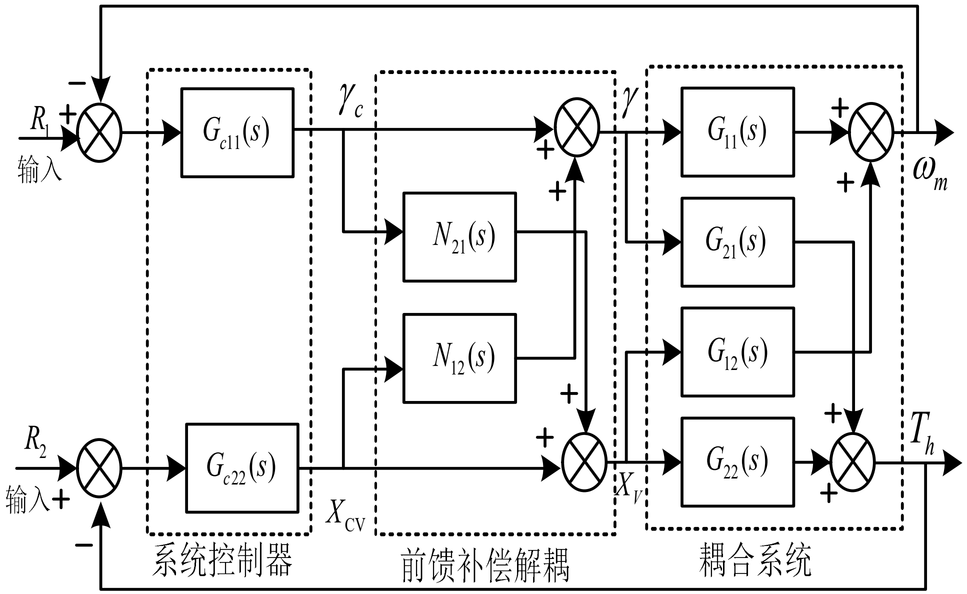
➢ Considering generator's load characteristic and the input of wind turbine's energy capture, the coupling mathematical model is proposed.

6 Low voltage ride through

6.2 Hydraulic system output decoupling algorithm

The transfer function matrix of the diagonal elements of the said output is affected by other input, so there are certain coupling control system.





$$\begin{bmatrix} \omega_m \\ T_h \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \begin{bmatrix} \gamma \\ X_v \end{bmatrix}$$

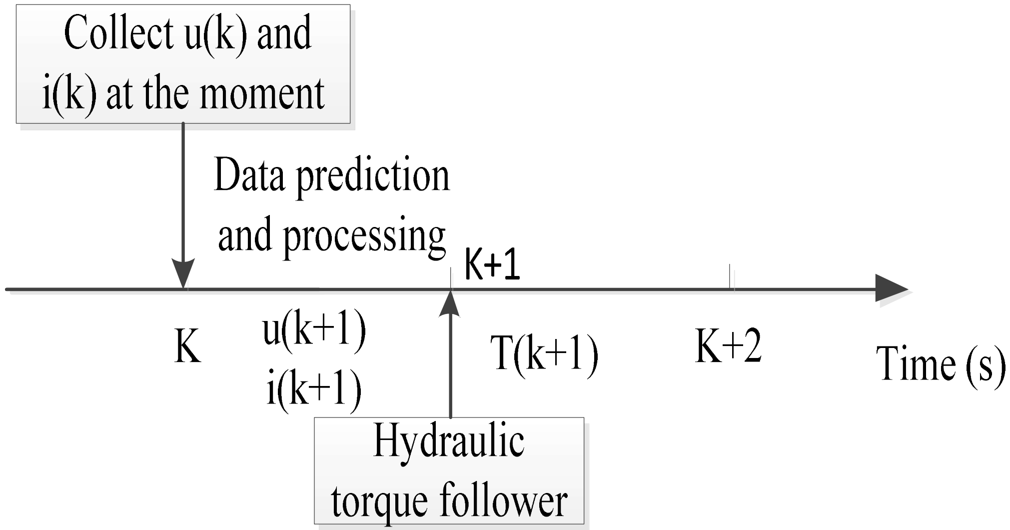
- The feed-forward compensation decoupling control method is used to remove the coupling between the control circuits.

6 Low voltage ride through

6.3 LVRT control – Torque control

$$\begin{cases} \begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{pmatrix} = K \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \lambda_1 & \lambda_2 & -\lambda_3 & \lambda_4 \\ -\lambda_4 & \lambda_3 & -\lambda_2 & \lambda_1 \\ -\lambda_3 & -\lambda_4 & \lambda_1 & \lambda_2 \end{pmatrix} \cdot \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \end{pmatrix} \\ \begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} \end{cases}$$

The electromagnetic torque state observer



The hydraulic torque following diagram based on time delay compensation in the actual system

- A prediction state observer and a dynamic compensation method are designed.

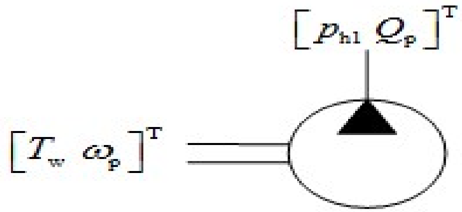
6 Low voltage ride through

6.4 LVRT control - Energy hierarchical control method

The energy transmission model

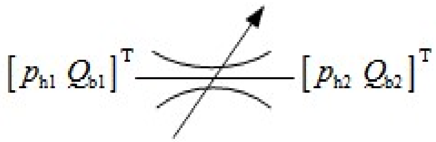
Fixed-displacement pump

$$\begin{bmatrix} p_{h1} \\ Q_p \end{bmatrix} = \begin{bmatrix} \dfrac{1}{D_p} & -\dfrac{Js + B_p}{D_p} \\ -\dfrac{C_{tp}}{D_p} & \dfrac{D_p^2 + C_{tp}(Js + B_p)}{D_p} \end{bmatrix} \begin{bmatrix} T_w \\ \omega_p \end{bmatrix}$$



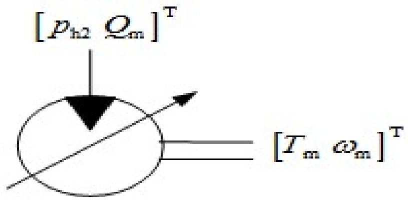
proportional throttle valve

$$\begin{bmatrix} p_{h2} \\ Q_{b2} \end{bmatrix} = \begin{bmatrix} 1 & -\dfrac{\rho Q_{b1}}{2 C_d^2 X_v^2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} p_{h1} \\ Q_{b1} \end{bmatrix}$$



Various motor

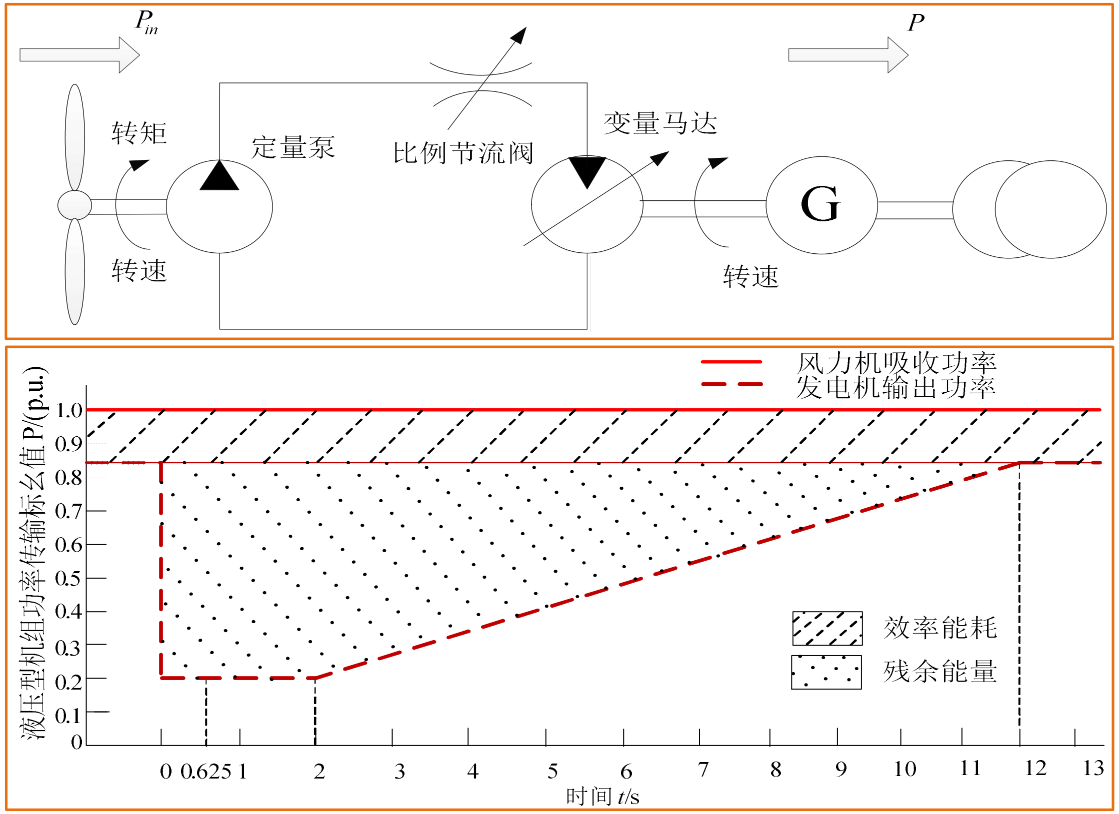
$$\begin{bmatrix} T_h \\ \omega_m \end{bmatrix} = \begin{bmatrix} -\dfrac{C_{tm}(Js+B_m)}{K_m\gamma} & \dfrac{(Js+B_m)}{K_m\gamma} \\ -\dfrac{C_{tm}}{K_m\gamma} & \dfrac{1}{K_m\gamma} \end{bmatrix} \begin{bmatrix} p_{h2} \\ Q_m \end{bmatrix} + \begin{bmatrix} T_e \\ 0 \end{bmatrix}$$



- The energy eigenstate from input and output side is analyzed respectively, which can obtain the energy transfer model of HWT.

6 Low voltage ride through

6.4 LVRT control - Energy hierarchical control method



Low voltage through the energy flow diagram

（1）Through the adjustable blade abandon the wind, the wind turbine inertial energy storage, proportional throttle coordination control to control unit to transmit power.

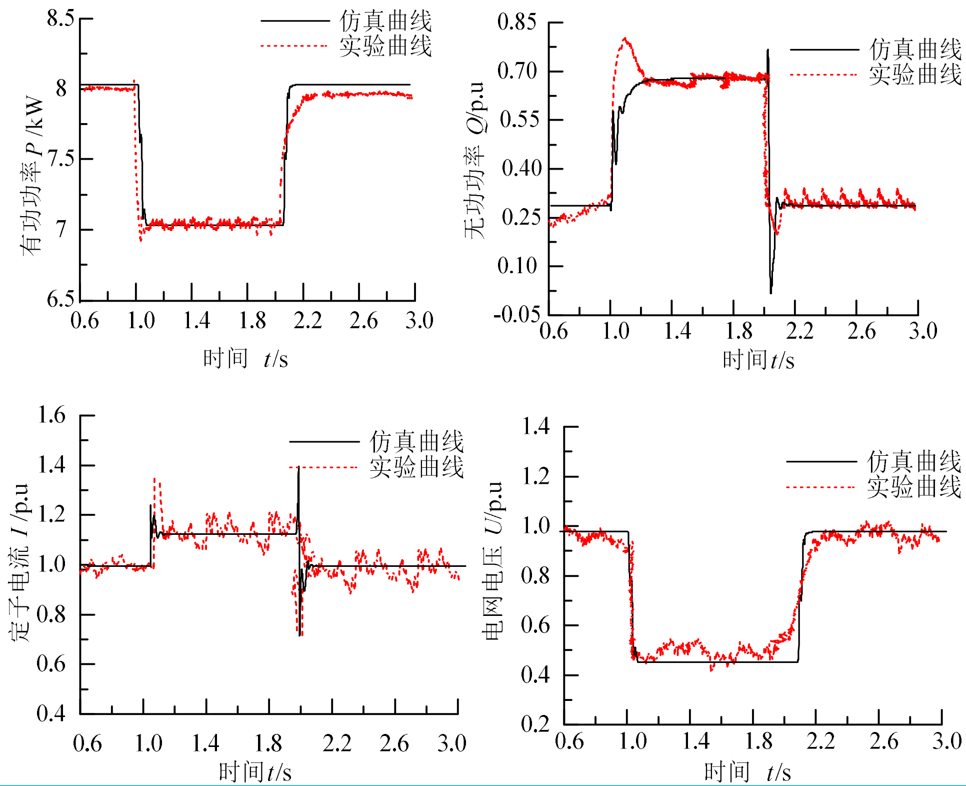
（2）Eventually in the process of the low voltage across, residual energy storage, dissipation and release.

- The control method for saving, storing and dissipating the redundant energy is achieved in the process of LVRT.

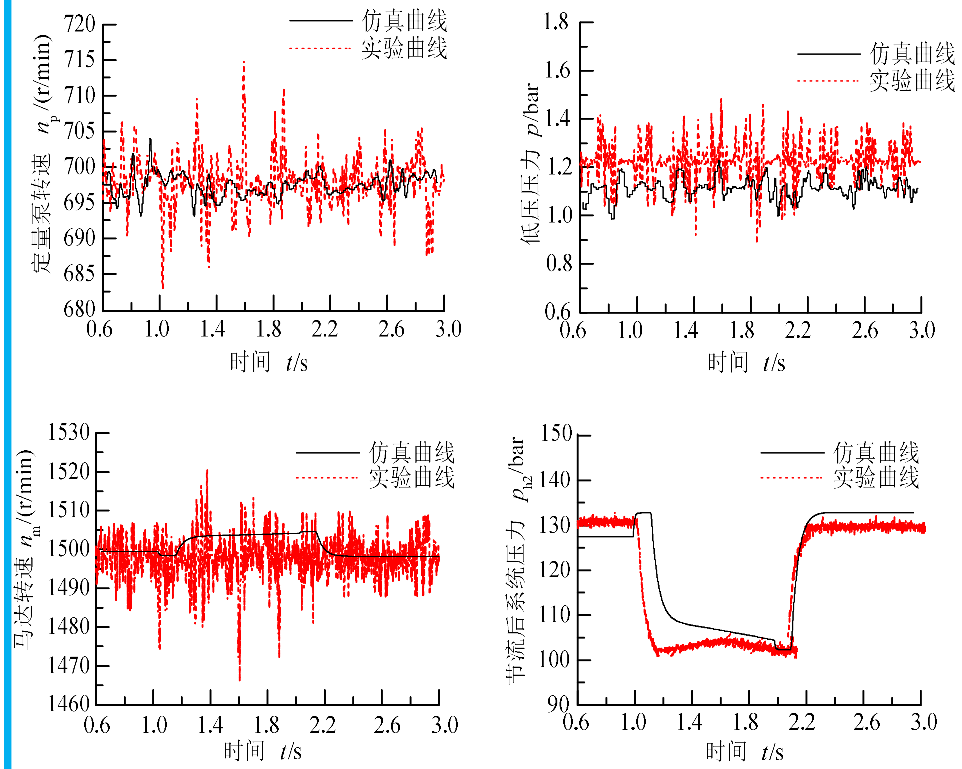
6 Low voltage ride through

6.5 Experiment

Power system



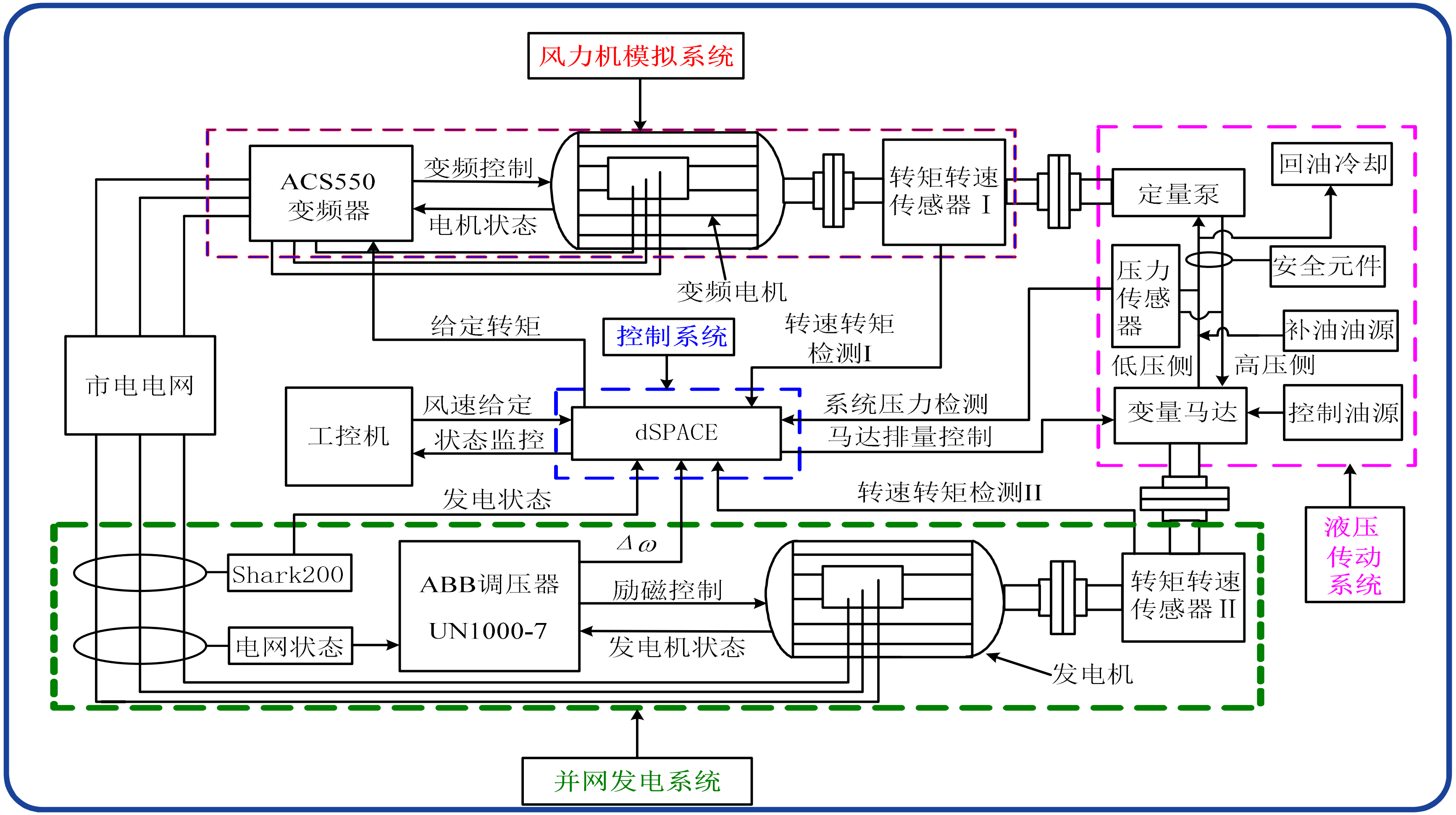
Hydraulic sysytem



- According to the experimental results, it can be seen that the proposed control method shows good control performance.

7 Test platform

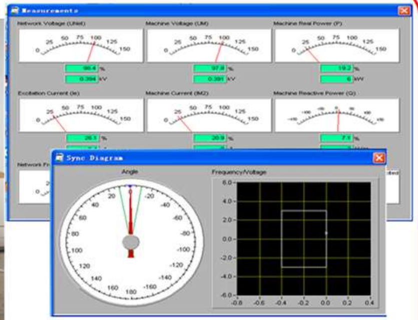
7.1 30kVA HWT test platform



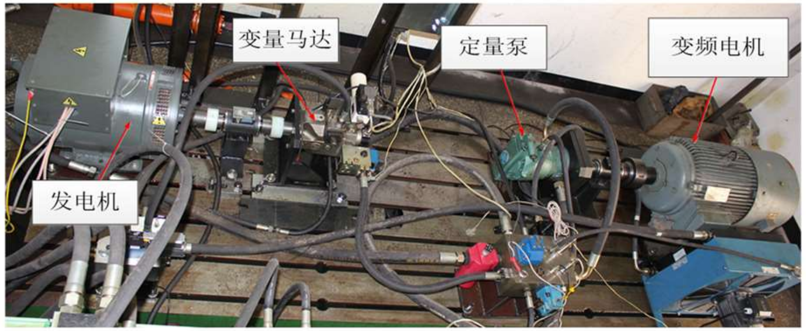
7 Test platform

7.2 The whole physical picture test platform

工控机与控制器



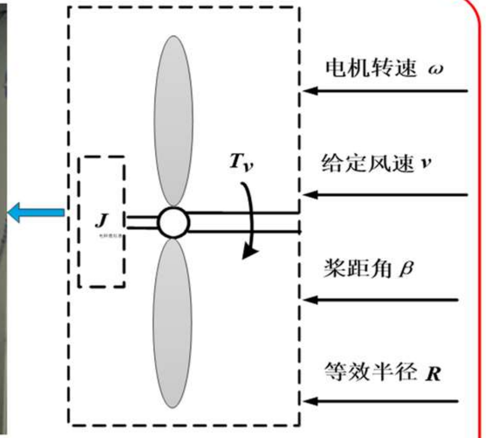
系统采集监控



液压传输系统

电网模拟器　主控制柜　并网控制柜　变频柜

变频器

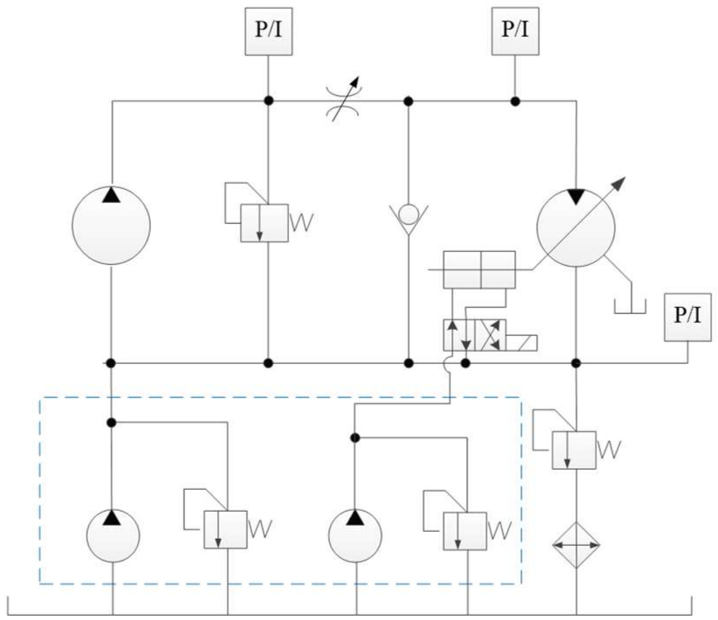


风力机模型模拟

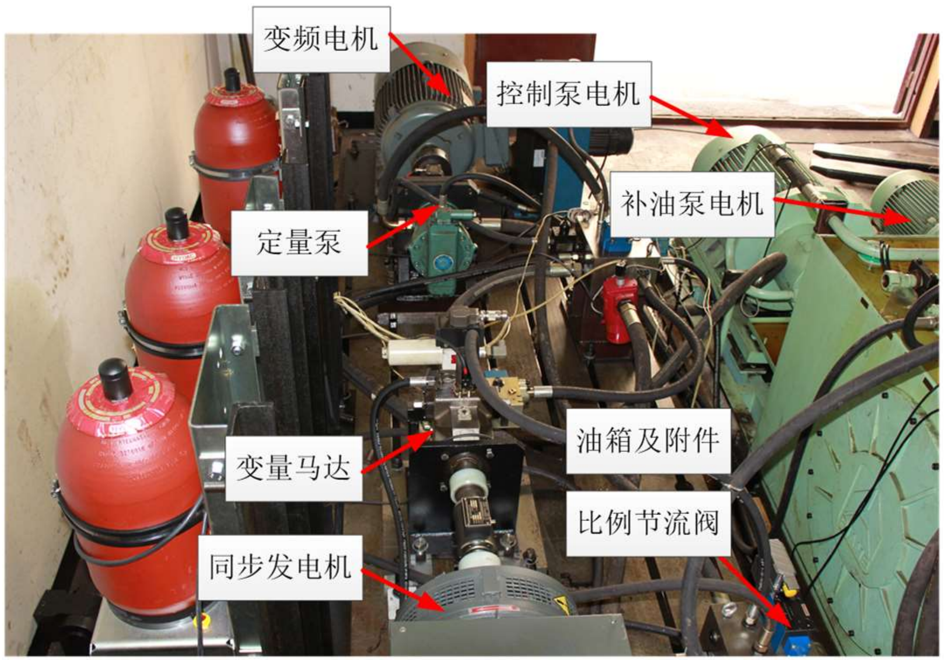
7 Test platform

7.3 Hydraulic main drive system

A fixed displacement pump - various motor is used in the transmission system. Composition principle and hydraulic transmission system is shown below.



a) The principle of the hydraulic drive system



b)) Hydraulic drive system physical figure

8 Accurate Vane Direction Control

8.1 Introduction

An active yaw system with valve-controlled hydraulic motor is designed.

Correspondingly, the accurate control method of vane direction based on pressure difference feedback is presented. The zero pressure difference means the vane direction is aligned at the wind direction.

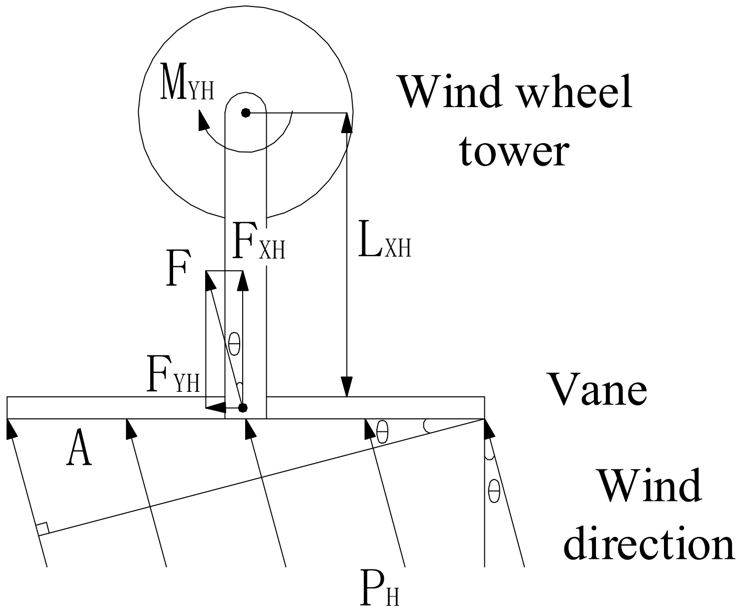
Then the simulation model is built to show that the control method presented in this paper is efficient.

Finally, an experimental platform is built to verify the feasibility of the control method presented

- In this chapter, we introduce the accurate method of vane direction.

8 Accurate Vane Direction Control

8.2 Load calculation of the active yaw system



Force diagram of wind wheel

$$M_{YH} = F_{YH} L_{XH} = P_H A \cos\theta \sin\theta L_{XH} = \frac{1}{2} P_H A L_{XH} \sin 2\theta$$

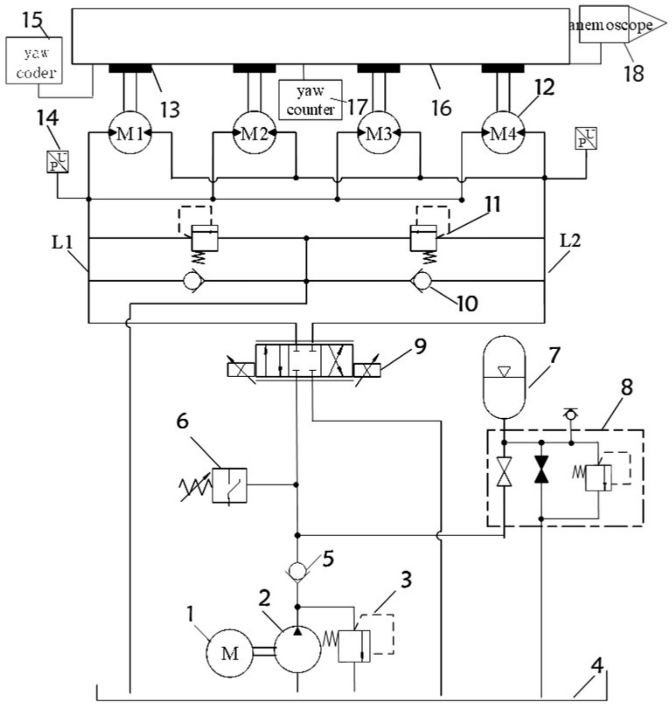
Parameter	Value	Unit
Rated generation power	850	kW
Rated wind speed	13	m/s
Best aerodynamic coefficient	0.4496	
Swept area of vanes and wind wheel hub	1559.9	m^2
Vertical distance between the center of Tower and wind wheel	3.177	m

Parameters of 850kW wind turbine

- The torque applied at the wind wheel is calculated and the parameters are confirmed.

8 Accurate Vane Direction Control

8.3 Principle of active yaw hydraulic system



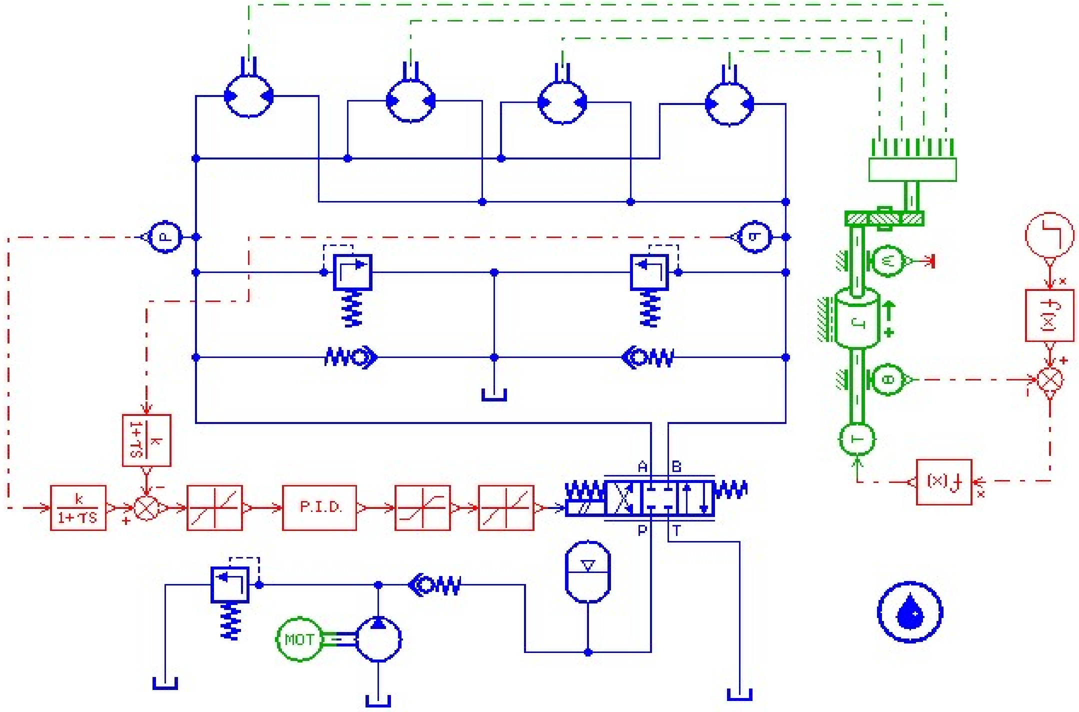
Principle of active yaw hydraulic system

1. motor 2. pump 3. relief valve 4. tank 5. check valve 6. pressure relay 7. energy accumulator 8. valve bank for energy accumulator 9. proportional direction valve 10. check valve 11. relief valve 12. hydraulic motor 13. yaw gears 14. pressure sensor 15. coder 16. cabin internal-geared ring 17. counter 18. anemoscope

- According to the load calculation result and the requirement of active yaw, the principle of active yaw hydraulic system is designed.

8 Accurate Vane Direction Control

8.4 The simulation model of active yaw hydraulic system



AMESim® simulation model of the whole system

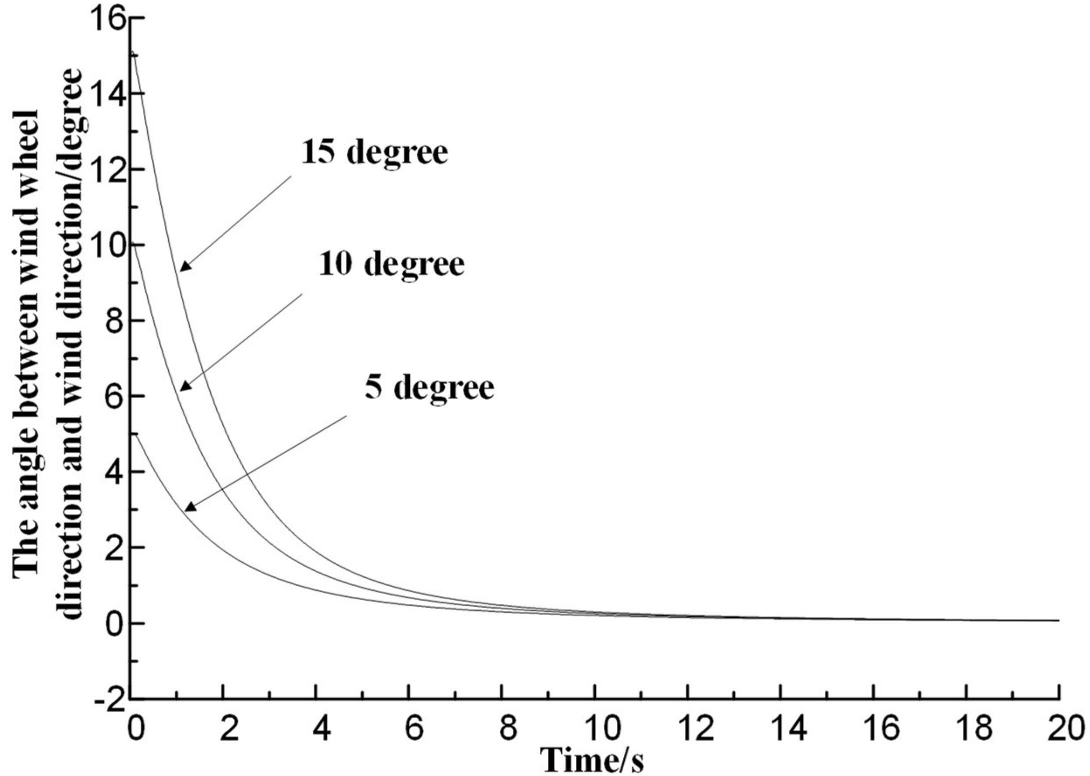
Parameter	Value
Transmission ratio (actual value)	16.7
Inertia torque of cabin and axis of wind wheel tower (calculated from the 3D model)	8.96×10^5 kgm^2
The mass of vane and wheel hub (calculated from the 3D model)	1.14×10^4 kg
Total mass of wind wheel and cabin (calculated from the 3D model)	4.5×10^4 kg
Motor speed	990 r/min
Pump displacement	4 ml/r
Rate volume of energy accumulator	30 L
Opening pressure of check valve	0.15 MPa
Rate flow of proportional direction valve	8 L/min
Displacement of hydraulic motor	940 ml/r
System pressure	25 MPa
Parameters of pipes	Estimated according to the actual situation
oil	Software default

Parameters of AMESim® Simulation model

- The overall simulation model is composed of hydraulic system model, load model and control system.

8 Accurate Vane Direction Control

8.4 The simulation analysis of active yaw hydraulic system

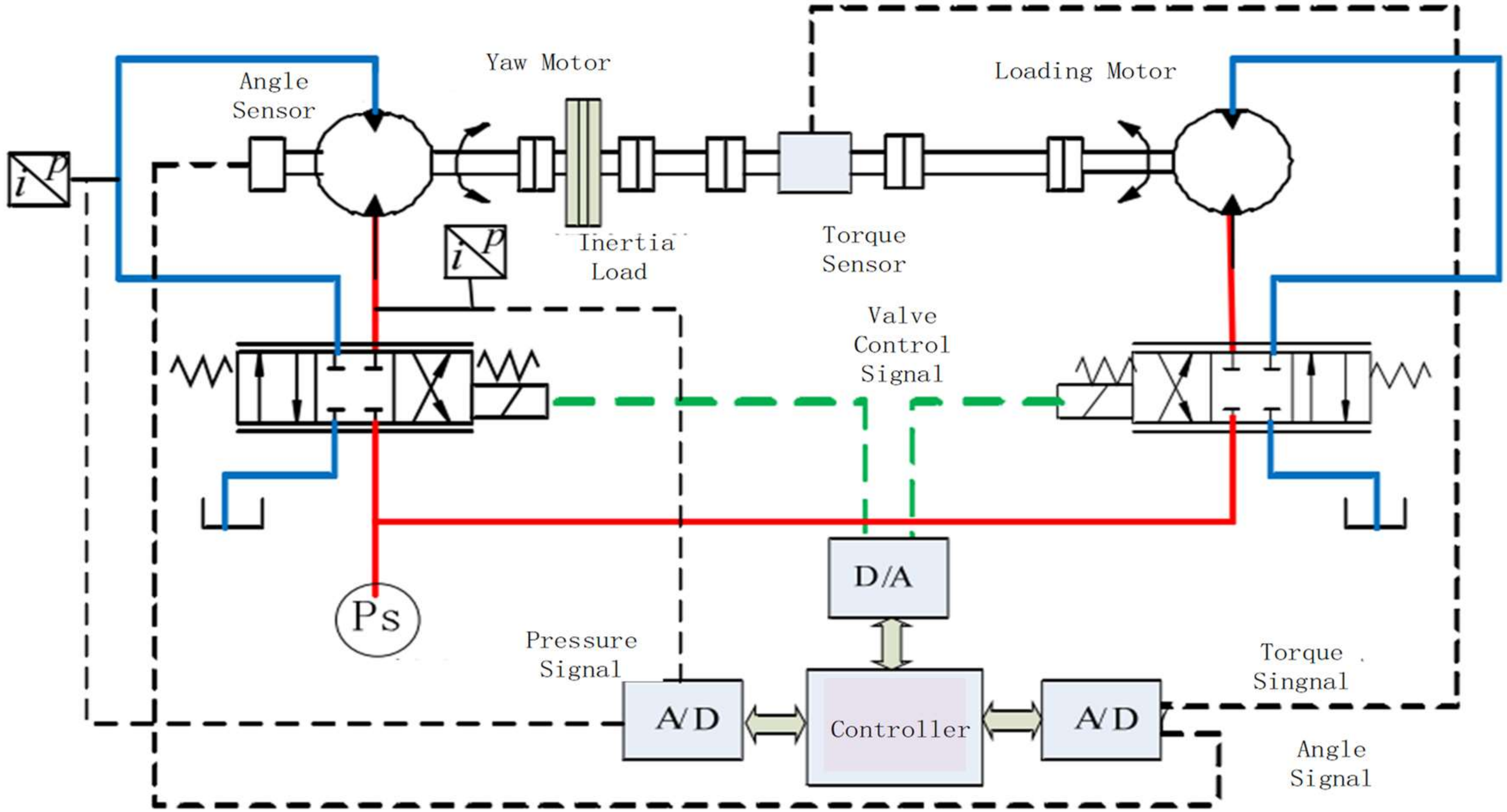


Vane direction curve under compensation control of friction torque

- The simulation results verifies the active control method of vane direction.

9 Test Platform of Vane Direction

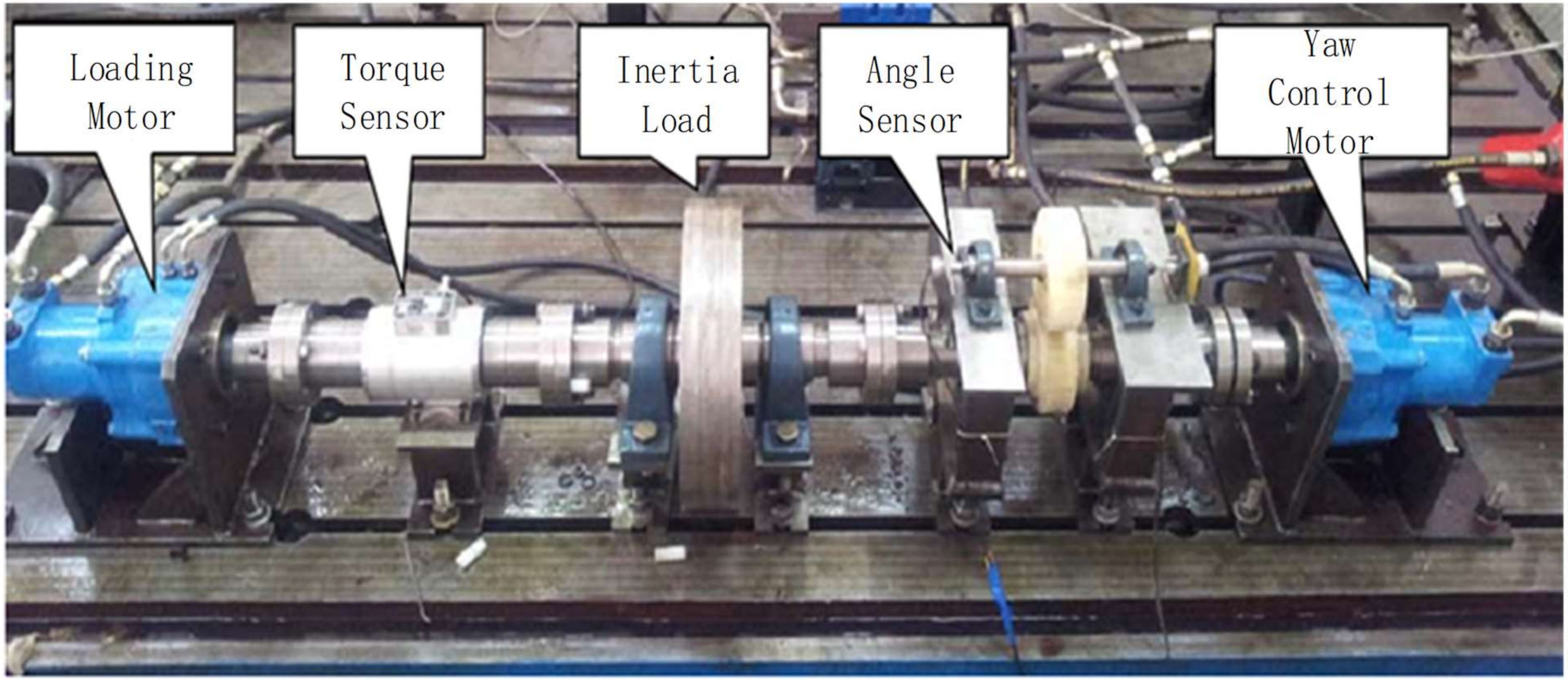
9.1 Hardware composition of simulation experimental platform



- The above figure shows the overall schematic of the simulation experimental platform

9 Test Platform of Vane Direction

9.2 Hydraulic system of experimental platform

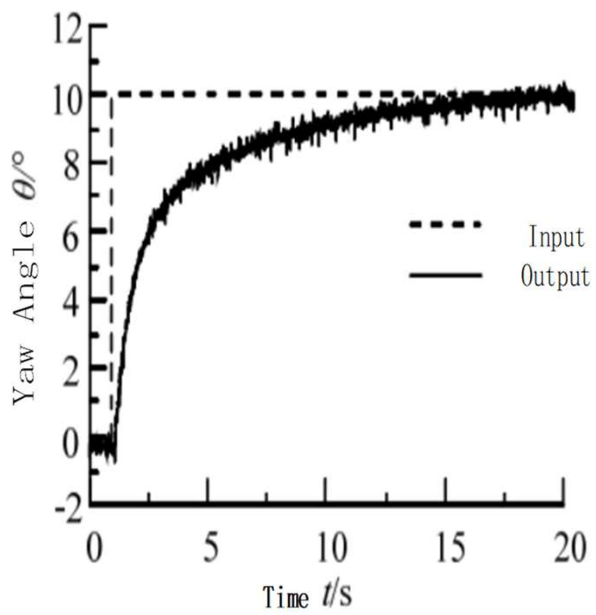


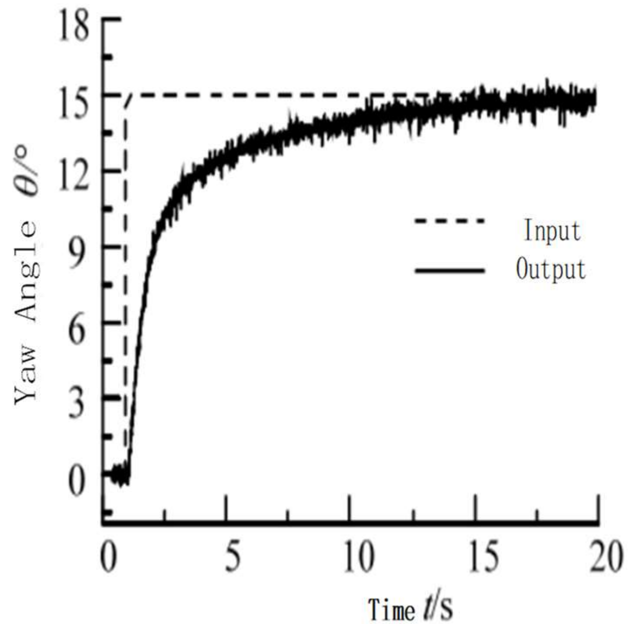
- The yaw simulation hydraulic system is composed of a variable pump, a constant delivery pump, hydraulic control valves, a control system, detection components, valve blocks and pipes.

9 Test Platform of Vane Direction

9.3 Experimental analysis

The system pressure is set to 10MPa. When the input angle signal is 10 degrees and 15 degrees, the yaw angle curves of the simulation yaw system are shown in the following figure.





- The steady-state angle error meets the accuracy requirement. The accurate control of vane direction is achieved.

THANK YOU !