10 kW Optimization of grid-connected wind power system and its application in Xiamen

Guangze Zhu1, *, Jiacheng Li2, Zihao He3, Chengxiang Chen4 and Qiangqiang Zhu4

1School of Information Science and Engineering, Huaqiao University, Xiamen, Fujian, China
2School of Mechanical and Power Engineering, Henan Polytechnic University, Jiaozuo, Henan, China
3School of Electrical Engineering and Automation, Henan Polytechnic University, Jiaozuo, Henan, China
4Training Center, State Grid Zhejiang Electric Power Co., Ltd., Hangzhou, Zhejiang, China

*Corresponding author: 1715311049@stu.hqu.edu.cn

Abstract. Coastal areas not only have large annual average wind speed, but also have more days of strong winds in a year. Xiamen ≥8 gale days, 22.4 days a year, so it is very suitable for wind power generation. This design is 10 kW wind grid-connected power generation system, each branch is composed of permanent magnet synchronous motor, rectifier, boost module, inverter and filter, 20 groups are used in parallel to form 10 kW system. Choose a single permanent magnet synchronous wind turbine power of 500 W, need 20. System DC voltage: 12 V, when the power is fixed, the proper lifting of DC voltage is helpful to reduce the current, thus preventing the IGBT from causing device damage due to overcurrent. A two-dimensional fuzzy controller is used to select the outer loop error and error differential signal as input variables. In order to verify the correctness of fuzzy adaptive PI control strategy, a system simulation model is built.

Keywords: Wind power generation, closed-loop control.

1. Installation and wind speed of wind power generation system
   1) Project location: Jimei District, Xiamen City, Fujian Province
   2) Latitude and longitude: East 118°04’04”, latitude 24°26′46”
   3) Weather conditions
      (l) Monthly changes in sunshine hours
      The annual average wind speed in Xiamen is 3.4 m/s, the maximum annual average wind speed is 3.6 m/s, and the minimum annual average wind speed is 3.4 m/s. from Table 1 and figure 1.

| Year | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|------|------|------|------|------|------|------|------|------|------|------|
| Wind speed | 3.5 | 3.4 | 3.5 | 3.5 | 3.4 | 3.6 | 3.4 | 3.5 | 3.5 | 3.4 |
As can be seen from tables 2 and 2, Average wind speed in Xiamen is 3.4 m/s, per month From October to December, 4.2 m/s, respectively m/s 4.0 and 3.6 m/s. May and June, 2.9 m/s. wind speed

| Table 2. Average monthly wind speed (m/s) |
|------------------------------------------|
| January | February | March | April | May | June | July |
| 3.5     | 3.5      | 3.3   | 3.1   | 2.9 | 2.9  | 3.1  |
| August  | September| October| November| December| Average |
| 3.0     | 3.5      | 4.2   | 4.0   | 3.6 | 3.4  |      |

(2) Windy weather
Coastal areas not only have large annual average wind speed, but also have more days of strong winds in a year. Xiamen ≥8 gale days ,22.4 days a year, as shown in Table 3.

| Table 3. Days of Windy Weather in Xiamen |
|-----------------------------------------|
| January | February | March | April | May | June | July |
| 1.3     | 1.3      | 2.3   | 1.8   | 1.3 | 1.2  | 2.0  |
| August  | September| October| November| December| Year |
| 2.1     | 2.2      | 2.9   | 2.6   | 1.4 | 22.4 |      |

Strong winds in Xiamen, the maximum was on 23 August 1959, The Pu wind level is above 12(38 meters per second). Then came the gale of July 3,1973, Wind speed 28.7 meters per second, The Pu wind grade reaches 11. The smallest of the winds is level 7, More than 13.3 meters per second.
(3) Wind speed resources in Xiamen

The seasonal change of Xiamen monsoon circulation is obvious, the northeast monsoon lasted roughly from September to February, the most typical is November. Strong northeast monsoon, the average wind speed is 3.7 m/s, the pressure rises, the temperature drops, the sky is high, less precipitation, Weather's stable, the monsoon is stable, the frequency is the highest throughout the year. The southeast monsoon season lasted from April to August, among them, July is typical. In general, the southeast monsoon is weak, the average wind speed is 3.4 m/s.

Wind direction: Xiamen from September to January of the following year to the northeast wind, among them, 10.11 The frequency is highest in two months, 2~ March winds northeast, 4~ The southeast wind in August, about 14 times a month, In April and August, on average ,17 static winds in April, the average number was 15 in August.

To sum up, Xiamen area is suitable for the establishment of wind power generation system.

Design of Wind Power Capacity.

Total load :10 kW.

Annual power generation: according to the annual working time of 6000 hours, the power generation is 60,000 degrees.

Number of wind turbines required: select a single permanent magnet synchronous wind turbine power of 500 W, need 20.

The DC voltage of the system is 12 V (usually including 1200 V, 800V, 400V, 200V, 50V, 24V and 12 V according to the size of the fan voltage). When the power is fixed, the proper lifting of DC voltage is helpful to reduce the current, thus preventing the IGBT from causing device damage due to overcurrent.

Theoretical power generation calculations, Average annual wind speed of Xiamen m/s ,3.4 Wind power is not affected by day and night, so generating electricity 24 hours a day, at m/s 3.4, Fan output power 200 W, 20 Typhoon output 4000 W, based on calculations ,96 kWh, of electricity is generated per day Annual power generation kWh.35040.

2. Generating system overall configuration

10 kW the structure of the wind power grid system is shown in Figure 3. According to figure 3, it can be seen that each branch is composed of permanent magnet synchronous motor, rectifier, boost module, inverter and filter, and 20 groups are used in parallel to form 10 kW system.

Figure 3. Structure of the system
(1) Rectifier selection and design:
The rated maximum output power of the fan is 500 W. Considering the actual annual wind speed of Xiamen is 3.4 m/s, the output power of the fan will not reach the rated power. However, in order to ensure that the converter has the ability to transmit rated power, the rated capacity of rectifier is 500 VA, rectifier is Sansong bridge module MDS100A1600V, rated current is 100 A, rated voltage is 1600 V.

(2) Inverter selection:
Grid-connected converter: because permanent magnet synchronous wind turbine belongs to full power converter, the rated power of the system is 500 W, so the capacity of rectifier and inverter is 500 W, and the number of rectifier and inverter is 20 rectifiers and 20 inverters. The type of inverter is: Sol pure sine wave inverter, the selection parameter is 12 V DC input, AC 220 V output, rated power is 500 W.

(3) Boost module selection:
Booster module: because the output power of the fan is small and the voltage level is low, the voltage obtained by the fan through the rectifier deviates from 12 V, while the input voltage of the rear inverter is 12 V. When the input voltage level is not reached, the DC-DC boost converter module with rated power of 100 W is needed.

(4) Filter selection:
Filters: in order to improve the quality of grid-connected current, filters need to be selected. The filters of three-phase inverter are divided into three forms, including: L filter, LC filter and LCL filter. Since the power level is small, the L filter is used to filter the system, and the 3 mH filter designed by Wave Liang Electric Company is selected.

(5) Fuzzy adaptive PI control strategy:
The control strategy of wind power generation system is divided into two parts: rectifier control part and inverter control part. The main function of rectifier is to realize maximum power tracking. To overcome the defects of the traditional linear PI regulator, the fuzzy PID control strategy is used to realize the optimal speed control, which can improve the dynamic response and anti-interference ability of the system. The main function of inverter in the system is to control DC voltage and grid side current, in which the outer loop of DC voltage adopts fuzzy PID control strategy, and the DC voltage can be stabilized quickly by fuzzy PID control.

In this design, a two-dimensional fuzzy controller is used to select the outer loop error and error differential signal as the input variable. The system control structure is shown in figure 4.

Figure 4. Basic Principle of Fuzzy Control
In order to verify the correctness of fuzzy adaptive PI control strategy, a system simulation model is built.

1 Simulation results under average wind conditions:
Figure 6. Simulation results of traditional control and fuzzy adaptive PI control for average wind condition

Figure 6 shows the simulation waveforms of DC bus voltage and fan output power of traditional control strategy and fuzzy adaptive PI control strategy. From the simulation waveform, it can be seen that the fuzzy adaptive PI control strategy can improve the dynamic response speed of the system, shorten the time of the system reaching steady state, and at the same time, the transient variation caused by the change of wind speed is smaller. The feasibility and effectiveness are verified.

Figure 7. Simulation results of traditional control and fuzzy adaptive PI control for the combination of average wind and gust
According to figure 7, under the condition of combined wind speed, the addition of gust leads to a sharp change of wind speed. From figure 7(b), it can be seen that the DC voltage fluctuation controlled by fuzzy adaptive PI is very small and the power quality is better.

3 Simulation results under the combination of average wind and gradient wind:

![Simulation results](image)

**Figure 8.** Simulation results of traditional control and fuzzy adaptive PI control for combined wind speed with average wind and gradient wind

According to figure 8, during the combination of average wind and gradual wind, the main work is in the climbing stage, and the results obtained by fuzzy control and traditional control are similar, which indicates that both can be tracked well when the reference value changes slowly. When the wind speed changes to 8 m/s, at 4 s, the output power decreases suddenly. At this time, the output power and DC voltage of the system change little, which reflects better immunity.

4 Simulation results for combined wind speed of average wind, gust and gradient wind:
Figure 9. Simulation results of traditional control and fuzzy adaptive PI control for combined wind speed of mean wind, gradient wind and gust

The simulation waveform before 4 s is basically similar to the previous simulation results. At 4 s, the wind speed also changes step by step, but the output power and DC voltage of the system can reach steady state faster. The main reason is that the quantization factor is mainly designed according to rated condition, but fuzzy control still reflects good dynamic response ability.

(6) Grounding and lightning protection
In order to ensure the safe operation of the system in severe weather such as thunderstorm, lightning protection measures should be taken for the system. There are mainly the following:

Ground wire is the key to lightning protection and lightning protection. At the same time, the distribution room infrastructure and fan construction are carried out, a thick and wet soil layer is selected nearby, a 2-meter-deep ground wire pit is dug, 40 flat steel is used, resistance reducer is added and ground wire is drawn. 35 copper core cable is used in the lead line, and the grounding resistance should be less than 4 mm2. Ω

Build a lightning rod near the distribution room, 10~15 meters high, and make a separate ground wire, the same method.

The 3-lightning connector may use 12 mm round steel, if lightning protection belt is used, round steel or flat steel, round steel diameter greater than or equal to 48 mm, flat steel thickness should not be less than or equal to 4 mm2.

Round steel or flat steel should be used in the lead line, and the section of flat steel with round steel diameter greater than or equal to 8 mm, should not be less than 4 mm2. should be preferred.

The AC output line of the off-grid inverter adopts the primary protection of the lightning protection box (there is an AC output lightning protector in the off-grid inverter)

Grounding device: angle steel, steel pipe or round steel should be used for manual vertical earthing: flat steel or round steel should be used for horizontal earthing. The diameter of round steel should not be small 10 mm, flat steel section should not be less than 100 m, angle steel thickness should not be less than 4 mm, steel pipe thickness should not be less than 3-5 mm. Artificial earthing in soil should not be less than 0.5 mm, need hot plating Zheng anticorrosion treatment, in the welding place should also carry on anticorrosion and rust prevention treatment.
3. System efficiency analysis

Wind power system from input to output power, each link has a certain loss resulting in the overall efficiency reduction, the efficiency of each component can be obtained as shown in the table below.

Table 4. Efficiency of components of wind power generation systems

| Coefficient code | Coefficient name                        | Loss rate  | Remarks     |
|------------------|----------------------------------------|------------|-------------|
| $\eta_1$         | Loss of cleanliness on blade surfaces  | About 2 per cent |             |
| $\eta_2$         | Maximum power point deviation loss     | About 3 per cent |             |
| $\eta_3$         | Loss of pitch angle                    | About 3 per cent |             |
| $\eta_4$         | Rectifier efficiency                   | 95%        |             |
| $\eta_5$         | Efficiency of Boost Module             | 98%        |             |
| $\eta_6$         | Inverter efficiency                    | 95%        |             |
| $\eta_7$         | Line losses                            | About 2 per cent |             |
| Integrated $\eta$ | Efficiency of grid-connected systems   | 85%-90%    |             |

4. Power generation benefit analysis

The wind power system of 10 kW of the system generates 96 kWh per day on average. Taking into account the loss factor of wind power generation system, 0.93, the energy efficiency of the system is 89.28 per kWh, and the energy efficiency of the system is 32587 kWh in the first year of the system Design life of wind power system is 25 years, the calculation is shown in Table 5 below (unit kWh).

Table 5. Analysis of the Factors Affecting Wind Power Generation System

| Number of years | 1   | 2   | 3   | 4   | 5   |
|-----------------|-----|-----|-----|-----|-----|
| System attenuation rate | 1%  | 0.9%| 0.9%| 0.9%| 0.9%|
| Electricity generation  | 32587| 32261.13| 31970.78| 31683.04| 31397.89|
| Number of years   | 6   | 7   | 8   | 9   | 10  |
| System attenuation rate | 0.9%| 0.9%| 0.9%| 0.9%| 0.9%|
| Electricity generation  | 31115.31| 30835.27| 30557.76| 30282.74| 30010.19|
| Number of years   | 11  | 12  | 13  | 14  | 15  |
| System attenuation rate | 0.9%| 0.9%| 0.9%| 0.9%| 0.9%|
| Electricity generation  | 29740.10| 29472.44| 29207.18| 28944.32| 28683.82|
| Number of years   | 16  | 17  | 18  | 19  | 20  |
| System attenuation rate | 0.9%| 0.9%| 0.9%| 0.9%| 0.9%|
| Electricity generation  | 28425.67| 28169.34| 27916.31| 27665.06| 27416.07|
| Number of years   | 21  | 22  | 23  | 24  | 25  |
| System attenuation rate | 0.9%| 0.9%| 0.9%| 0.9%| 0.9%|
| Electricity generation  | 27169.33| 26924.81| 26682.48| 26442.35| 26204.36|
| Total electricity generation | 731760|             |             |             |             |
| Average 25 years of electricity generation | 29270|             |             |             |             |

5. Environmental benefit analysis

Wind energy is a clean and renewable energy, which will not produce any harmful gases to be discharged into the air. Therefore, the development and use of wind energy for power generation is the main trend in the future.

Annual system power generation over 25 years: kWh 29270.
Table 6. Fossil energy consumed by conventional generator sets

| Category                  | Annual fuel consumption (tons of standard coal) | Average annual electricity generation (kWh) |
|---------------------------|-----------------------------------------------|--------------------------------------------|
| Thermal power generation systems | 11.825                                         | 29270                                      |
| Photovoltaic systems      | 0                                             | 29270                                      |
| Annual energy saving      | 11.825                                         | 29270                                      |

After implementation, the emission reduction effect of major air pollutants:

Table 7. Comparison of energy saving and emission reduction

|                     | CO2     | SO2     | TSP     | NOX     | CO2       | SO2     | TSP     | NOX    |
|---------------------|---------|---------|---------|---------|-----------|---------|---------|--------|
| Annual emission reductions (t/a) | 29.18   | 0.8823  | 7.96    | 0.4412  | 729.592   | 22.085  | 199     | 11.029 |
| Lifetime emission reductions (25 years) | CO2     | SO2     | TSP     | NOX     | CO2       | SO2     | TSP     | NOX    |
|                      | 22.085  | 199     | 11.029  |         |           |         |         |        |

Note: For each saving of 1 (kWh) electricity, 0.404 kg of standard coal is saved accordingly, while reducing pollution emissions by 0.272 kg of carbon dust, 0.997 kg of carbon dioxide (CO2), 0.03 kg of sulfur dioxide (SO2), 0.015 kg of nitrogen oxides (NOX).

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