Study on Control Strategy for Wind Driven Generator Considering Power System Stability

Qifu Lu1,*, Zhengfu Liu1, Xiangyu Kong2, Hongxing Wang1, Chao Sheng1, Chang Zhao2

1Electric Power Research Institute of Guangdong Power Grid Co., Ltd., Guangzhou, China
2Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, Tianjin, China

*Corresponding author e-mail: 1024725808@qq.com

Abstract. Wind power has random fluctuations and intermittent as a way of renewable energy generation. This paper uses a model of multi-state unit to equivalent the transmission grid system include wind power generation considering the influence of increasing capacity of wind farm connection on the reliability of distribution system. A hybrid system dispatching model of double-fed wind turbine is proposed based on the analysis of the structure of double-fed wind turbine and the outage model of fan and conventional unit. In order to maximize the use of wind based on the constraints of the power system, the base load of conventional units such as thermal power units are used first, and then the wind power is used as a priority to minimize the entire power generation cost. At the same time, the output of the wind power unit is constrained by the penetration power limit that the influence of wind power randomness on the safe and stable operation of the system is considered. The simulation results show that this control strategy can keep frequency by change the velocity, track the maximum wind energy, adjust the power factor and stabilize the voltage of the power grid.

1. Introduction

Wind driven generator uses wind as motive force. The random fluctuation and intermittency of wind determine that the output characteristics of Wind driven generator is also fluctuating and intermittent. In addition, the Wind driven generators are mostly asynchronous generators, the reactive power is absorbed from the system while the active power is emitted. The reactive power demand changes with the change of the active power output. When the capacity of wind farm is small, the influence of these characteristics on the power system is week, but with the increase of the proportion of wind farm capacity in the system, the impact of wind farm on the system will become more and more significant.

Paper [1] proposed an adaptive virtual synchronous generator control of DFIG based on operation state evaluation. Simulation results showed that the adaptive virtual synchronous generator control of DFIG could provide frequency support to power grid at all operating conditions, frequency stability of power system was improved, and operation stability of DFIG was guaranteed in process of frequency regulation. In [2], small signal models of the fault unit and weak grid are presented according to dynamic characteristic of the rotating mass, and correctness of the theoretical analysis is verified with Simulation. Paper [3] presents an optimal control strategy with torque following the variation of generator speed optimally, and in [4], the control strategy which was decided by the output power changes of wind turbine generation about the operation mode of pitch actuator was proposed and
according this control strategy, the variable-speed pitch control which was based on the fuzzy control strategy was also proposed. The results of the simulation indicate that the output power could be stable based on the proposed control strategy. Paper [5] improved a control strategy for expanding the transition zone is proposed to eliminate the negative effects of power fluctuation and mutation load caused by switching near the rated power operating point. Paper [6] proposes a wind power maximum tracking control technology, which can improve the wind power efficiency and reduce the power generation by controlling the optimal wind speed curve of double-fed wind turbine. Paper [7] using MATLAB / SIMUUNK to establish a comprehensive system simulation on the no-load operation, the problems of the instant industrial conditions are solved in the traditional simulation ways in which the stator voltage output direction is different to discuss before and after the connection with grid.

The connection problem of wind power to grid is mainly the voltage problem of the weak system, followed by the flash problem. The problem of starting has been basically solved by soft starting technology. In China, most of the wind resources are located along the coast and in some remote areas where have not main power grid and the short circuit capacity of the regional power network is relatively lower. These factors seriously affect the power quality and restrict the development of wind power scale. In this paper, a control strategy for wind turbine is proposed which takes the stability of power system into account. After the short circuit failure of the system, the smaller X/R ratio of the tie line can improve the dynamic stability of the wind power.

2. Normal output and failure model of wind driven generator

2.1. Wind driven generator model

Wind farms are composed of dozens or even hundreds of large-scale wind power generators installed in parallel on the same site. The output of Wind driven generators change frequently with the wind speed, but the relationship between wind power and wind speed is not linear. Because of the randomness of its output after the Wind driven generator connected with the traditional transmission network, overload may be caused when the wind resources are relatively abundant and insufficient output may be caused when the wind resources are insufficient [8]. Therefore, the output of the Wind driven generator $P_t$ can be regarded as a random function, varying between $0 \sim P_{\text{max}}$.

![Figure 1. Power characteristic curve of wind driven generator](image)

Under the standard air density condition, the relation curve between the output power and wind speed of a Wind driven generator is called the standard power characteristic curve of a Wind driven generator [9-10]. Under different installation conditions, the relation curve between wind power output and wind speed is called the actual output power characteristic curve of wind power set, as shown in figure 1. The piecewise function can be said by the following formula:

$$P_t = \begin{cases} 0 & 0 \leq V_r \leq V_{ci} \\ (A + B \times V_r + C \times V_r^2)P_r & V_{ci} < V_r \leq V_c \\ P_r & V < V_r \leq V_{co} \\ 0 & V > V_c \end{cases}$$

(1)
Where, \( P_t \) is the output of the Wind driven generator at time \( t \), \( V_t \) is the wind speed at time \( t \), \( V_{ci} \), \( V_r \), \( V_{co} \) represents the cut wind speed, rated wind speed and excised wind speed of the Wind driven generator; \( P_r \) is the rated power of the Wind driven generator; \( A, B \) and \( C \) are parameters which can be expressed by the following formula:

\[
A = \frac{1}{(V_{ci} - V_r)^2} \left[ V_{ci} \left( V_{ci} + V_r \right) - 4 \left( V_{ci} \times V_r \right) \left( \frac{V_{ci} + V_r}{2V_r} \right)^3 \right]
\]

\[
B = \frac{1}{(V_{ci} - V_r)^2} \left[ 4 \left( V_{ci} + V_r \right) \left( \frac{V_{ci} + V_r}{2V_r} \right)^3 - (3V_{ci} + V_r) \right]
\]

\[
C = \frac{1}{(V_{ci} - V_r)^2} \left[ 2 - 4 \left( \frac{V_{ci} + V_r}{2V_r} \right)^3 \right]
\]

2.2. Outage models of Wind driven generators and conventional units

In general, it is considered that normal operation time and repair time are constant from exponential distribution, failure rate \( \lambda \) and repair \( \mu \) rate is constant.

\[
\tau_1 = -\frac{1}{\lambda} \ln \gamma_1 = -T_{MTTF} \ln \gamma_1
\]

\[
\tau_2 = -\frac{1}{\mu} \ln \gamma_2 = -T_{MTTR} \ln \gamma_2
\]

Where, \( T_{MTTF} \) is the average time of no-fault work. \( \gamma_1 \) is uniformly distributed random number; \( \gamma_2 \) is uniformly distributed random number; \( T_{MTTR} \) is average repair time.

In a power system containing wind driven generator, the total output of wind farms and conventional units should be balanced with the active power of the loads, as follow:

\[
\sum P_{WTG} + \sum P_{CG} + P_{LD} \leq P_{PD}
\]

Where, \( P_{WTG} \), \( P_{CG} \), \( P_{LD} \), respectively represent the output power of the \( i \)th wind driven generator unit, the \( i \)th conventional unit and the active power of the load.

3. Wind power control strategy considering power system stability

3.1. Equivalent model of multi-state unit in transmission and generating combination system

As the increasing capacity of wind farms, wind farms are no longer directly connected to the power distribution system, but by the grid power supply to the power distribution system. To account the effect of wind power grid connection on the reliability of distribution system, the equivalent model of multi-state units can be adopted to make the transmission. Each state corresponds to a system state \( i \). the probability of occurrence of this state is \( P_i \), the frequency is \( F_i \), and the equivalent capacity provided by the transmission combination system to the distribution system is \( EG_i \). The formula for solving these reliability parameters is as follows:

\[
EG_i = G_i - L_i
\]

\[
P_i = \prod_{j=1}^{N} A_j \times \prod_{k=1}^{M} U_k
\]

\[
F_i = P_i \times \lambda_i
\]

Where, \( G_i \) is the capacity of all generator in the state of \( i \); \( L_i \) is the total load of distribution system at moment \( i \); \( A_j \) is the availability of element \( j \); \( U_k \) is the unavailability of element \( k \); \( \lambda_i \) is state transfer
rate of $i$; $M$ and $N$ are the amounts of available elements and unavailable elements in the system, respectively.

Due to the relatively simple structure of the Wind driven generator, scheduled maintenance time is short, and scheduled maintenance can be arranged at low wind speed or no wind, which can be ignored in reliability analysis. Therefore, the wind generator set adopts two state models, namely normal operation state and fault shutdown state. Given fault rate $\lambda$ and repair rate $\mu$, the state mode transformation diagram of wind turbines is shown in the figure 2.

![State mode transformation diagram of wind turbines](image)

The conventional unit also adopts the two-state model, that is the normal working state and the shutdown state. The sequential Mont Carlo simulation method is used to sample the duration of each element staying in the current state over a time span. It is assumed that the elements are in operation at the beginning, and the failure efficiency of the elements is assumed to follow the exponential distribution. The following formula gives the sampling value of the state duration of exponential distribution:

$$D_i = -\frac{1}{\lambda_i} \ln r_i$$  \hspace{1cm} (11)

Where, $r_i$ is the random number uniformly distributed in the interval [0, 1] corresponding to the tenth $i$ element; $\lambda_i$ is the failure rate of the $i$-th element if the current state is running.

3.2. Scheduling model of hybrid systems

To realize the full absorption of wind power system, it is necessary to carry out scheduling based on the constraints of power system and the principle of making full use of wind power. First, the thermal power unit and other conventional units is used to undertake the load, and then the wind power is used first to minimize the total generation cost. At the same time, the influence of wind power randomness on the safe and stable operation of the system should be considered. Because of its intermittency and non-controllability, it should reduce the wind power if the system contains wind power or occupies a large proportion of wind power. When the voltage of some terminal nodes is reduced due to the system failure, the double-fed induction motor needs to absorb reactive power from the grid. To ensure the grid safely, some or even all wind power must be abandoned.

According to the above principles, the mathematical model with the minimum sum of power cut and power generation cost as the objective function is:

The objective function:

$$\min \sum b_{jD}P_{DF_i} + \sum b_{jI}P_{CG_i} + \sum b_{mP}P_{WTG_i}$$  \hspace{1cm} (12)

The constraint condition is:

$$\sum_{j \in i} P_j + \sum_{k \in d} P_{CG_k} + \sum_{k \in e} P_{WTG_k} = P_{DN} - P_{DF_i}$$  \hspace{1cm} (13)

$$|P_j| \leq P_{j \max}$$  \hspace{1cm} (14)

$$P_{CG_{\min}} \leq P_{CG_i} \leq P_{CG_{\max}}$$  \hspace{1cm} (15)

$$\sum P_{WTG_i} \leq \lambda \sum P_{DN}$$  \hspace{1cm} (16)
Where, $P_{\text{cut}}$ is the cutting load in case of failure; $P_{\text{load}}$ is the load power; $P_{\text{WF}}$ is the power of wind farm; $P_{\text{c}}$ is the conventional power supply power; $P_{\text{L}}$ is the power of the transmission line; $\lambda$ is wind power penetration power limit.

4. The example analysis

Some double-fed wind generator sets are composed of a wind source, a wind turbine, a variable-pitch module, a double-fed induction motor, and a rotor side excitation module. The stator side output voltage is boosted by a transformer and then integrated into the infinite power grid via a double loop.

To simulate the transient stability of wind power system, a wind farm model as is constructed by using MATLAB, which model is used to simulate the situation that three-phase grounding short circuit fault occurs at the junction of wind power plant when gust and wind speed are constant. The constant wind speed is 10 m/s and the mechanical torque output by the Wind driven generator changes with the wind speed. The variable pitch system starts and changes the pitch Angle when the mechanical power exceeds the rated power. However, response lag often occurs due to the large inertia coefficient. The fault was set as: three-phase short circuit fault occurred at $t=0.2s$ at the outlet of the wind farm (node 10), and it went through 7 resected contact lines (node 9-10).

![Figure 3. Comparison of load angle changes with different wind power permeability](image)

![Figure 4. Comparison of different types of wind farms on system frequency changes](image)

For study the load angle characteristic of different wind power permeability, load and system reserve remain unchanged in the process of changing permeability. Increase of capacity of wind power is achieved by removing thermal power units. For maintain power flower does not shift significant, increases in capacity of wind power on wind farm, fan using the constant power factor control. A three-phase short circuit fault is set on the connection line of the wind farm. The simulation results are shown in Figure 3. It can be seen from the Figure that the amplitude of the system's load angle swing gradually reduced and the load angle characteristic stability is improved as the permeability increases from 5% to 35%. the load angle characteristic is improved with the increase of permeability in an initial range. Continues to increase the permeability on the original basis, the load angle stability is no longer improved with the increase of permeability as the permeability reaches a certain level such as 35%. The work Angle swing amplitude of the system at 40% permeability is significantly greater than that at 35% by comparing the load Angle curve after the failure of multiple nodes in the system at 35% and 40% permeability. The load Angle stability of the system deteriorates as the permeability increases.

The wind speed change does not have much influence on the frequency dynamic process of the system in wind farms with small grid-connected capacity. However, the wind power fluctuation caused by wind speed change cannot be ignored when the wind power permeability is high. In the
simulation process, the wind farms were set to generate gust disturbance within 0 to 10 seconds. The influence of the two wind farms frequencies under the permeability of 15% of wind power is shown in figure 4. The constant speed asynchronous fan is directly connected with the power grid, so the power generated is directly sent to the power grid, which has a great impact on the system frequency.

5. Conclusion
The paper carries on the modeling through analyzing the characteristics of the wind farm principle of each part and analyzes an actual wind power system in the simulation based on the MATLAB/Simulink software to achieve the doubly-fed wind power system dynamic simulation. The results show with the doubly-fed generator stator flux-oriented vector control when the wind speed changed, it can keep frequency constant by changing speed and track the biggest wind power. In addition, the power factor can be adjusted and the power grid voltage can be stabilized. The speed stability of the double-fed wind generator set is stable and the system voltage recovery time after fault is short in the case of large disturbance such as three-phase grounding short circuit. Moreover, the small connection line x/r ratio can improve the dynamic stability of the wind power system after short circuit fault. It lays a foundation for the comprehensive utilization of wind farm.

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