Research of STATCOM Impact on Wind Farm LVRT and Protection

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Abstract

Because of the wind turbine which possesses low voltage ride through (LVRT) capability can keep on working during the system fault, greatly reduce the adverse effects of power grid and ensure the relay protection reliability. However, the asynchronous wind turbine which widely used in home and abroad doesn’t have enough LVRT capability. So this paper proposes a method to enhance the LVRT capability of fixed speed induction generator (FSIG) based on wind farm using static synchronous compensator (STATCOM). And this paper establishes the simulation model of asynchronous wind generator wind farm and STATCOM in Matlab/Simulink software; the research results show that the STATCOM device can improve asynchronous wind farm LVRT capability. Then analysis the asynchronous wind generator which possess LVRT ability characteristics and the time of the action protection relations. According to the current wind farm system protection configuration, studying the asynchronous wind farm which with STATCOM device effect on protection configuration of system and the existing problems. At last, putting forward some reasonable measures of improving LVRT cooperate with relay protection characteristics and minimizing probability of wind power units take off the grid.

Keywords: Matlab/Simulink; Asynchronous wind turbine; STATCOM; LVRT; Relay protection

1. Introduction

In recent years, our country vigorously development clean energy especially wind power in order to carry out and practicable the sustainable development measure and implement the economy and environment coordinated development, and with the wind power generation techniques increasingly mature, large scale capacity wind power growingly dive into the network. Wind power solves the energy crisis problem in a certain extent, but the large scale wind power dive into power system has brought a series of technical problems[1-4], one of the problems is that the impaction on the relay protection configuration can’t neglect[5].

In order to ensure the power grid safe and stable operation, the safety of the electricity system guidelines of all over the world have adjusted the wind generator dive into network operation, when power system fault cause power voltage drop, the incorporated wind generators must have ability not to take off from power grid and persistently work for a long time, and can help power system recover stable after cut off fault as soon as possible, It means that wind generators must have certain low voltage ride-through(LVRT) capability[6-8]. At present, there are three types of wind generator: Fixed speed asynchronous generator(FSIG), Permanent magnet synchronous generator (PMSG) and Doubly-fed induction generator(DFIG)[9]. Document [6, 10,11] put forward different wind generator reform and realize LVRT methods. In order to improve the asynchronous wind generator LVRT ability, it can through the installation of Static Var Compensator(SVC) or Static Synchronous Compensator (STATCOM) to adjust voltage, After installation of STATCOM, wind farm has certain LVRT capability[11], but it will produce certain affections to relay protection setting of power grid and there are no indications to illustrate the influence of wind farm LVRT and protection. Literatures[12-14] only put forward the wind farm impact on power grid protection and improvement methods, but not present wind farms which possess LVRT capability impact on power grid protection. If the wind farm which possesses LVRT capability to meet the requirements, it not only requires wind turbine transient characteristics be improved and having enough LVRT capability; but also has the cooperate with the grid relay protection control measures ability, only by the mean can make the LVRT ability get a full play.
This paper establishes a 49.5MW FSIG wind farm and STATCOM models in Matlab/Simulink software. Through real-time control and compensate wind farm reactive power STATCOM can improve the stability of the wind farm grid quickly. The simulation results show that during the power grid fault, the wind farm which install STATCOM has more powerful LVRT capability. Then discusses the wind turbine short-circuit current characteristics, and its LVRT capability influence on the relay protection.

2. Wind Farm LVRT Characteristics and Modeling Structure

2.1. Wind Farm LVRT Characteristics

LVRT refers to when power grid fault or be disturbed cause wind farm point of common coupling(PCC) voltage dip, wind generator can uninterrupt work in certain of the voltage drop within a scope. The LVRT capability of wind generator plays an important role in balance the network active power. If wind power install proportion is low, it can reduce the influence on the power grid when power grid fault or disturbed; If wind power install proportion is high, it can reduce the probability of system power tide change or even trigger widespread blackouts caused by power lines fault make a lot of wind farms cut off during the high speed [15].

At present, there are different regulations on LVTR capability in different countries and regions, as shown in Figure 1.

![Figure 1. Countries of the wind turbine LVRT rules](image1)

![Figure 2. China wind farm LVRT requirement](image2)

Figure 2 shows China’s regulation of wind farm LVRT ability, the solid line signifies the wind farm PCC voltage. During power grid normal operation, the PCC voltage is nominal voltage; When the system occurs short-circuit fault at 0s and causes voltage dip, if the voltage is not drop less than 20% of nominal voltage, wind generators mustn’t disconnect with the network during the 625ms of fault. The PCC voltage value must higher than the Figure 2 voltage contour line throughout 2s after the fault, and can recover to above 90% nominal voltage in 2s, the wind generator must connect to the grid in this process. That is: 1) the wind generator has LVRT capability when PCC voltage drops 20% of nominal voltage and continuous work for 625ms; 2) PCC voltage can return to 90% of the nominal voltage after voltage falls 2s and wind generator must connect with the grid during the process [15].

2.2. FSIG Modeling

The paper adopts wind generator type is Fixed Speed Induction Generator (FSIG), which mainly contains the wind turbine, gear box and asynchronous generator, its basic topological structure as shown in Figure 3.

According to the Bates theory, it can know that wind turbine can get mechanical power from wind in (1) [16].

\[ P_m = \frac{1}{2} \rho \pi R^2 v^3 C_f \]  

(1)

Where: \( \rho \) is the air density; \( v \) is the wind speed; \( R \) is the wind turbine radius; \( C_f \) is the wind energy utilization coefficient, it is the function of angle \( \theta \) and tip speed ratio \( \lambda \). \( \lambda \) is defined as the equation as in (2).
\[ l = \frac{w_{\text{wind}}}{R} \]  \hspace{1cm} (2)

Where: \( w_{\text{wind}} \) is the wind turbine rotation velocity. The relation of power coefficient and tip ratio function as shown in Figure 4.

As for general IG, its electromagnetic torque can be calculated from (3).

\[ T_e = \frac{U^2 R_{eq}}{w} (R_{eq}^2 + X_{eq}^2) \]  \hspace{1cm} (3)

Where: \( U \) is the wind generator terminal voltage; \( R_{eq} \) and \( X_{eq} \) respectively stand for IG equivalent resistance and reactance which look from turbine terminal; \( \omega \) is turbine speed [17].

From (3) we can know that FSIG electromagnetic torque will drop and generator speed will rapidly rise and its internal protection will quickly trip during the power grid voltage fall, these make FSIG do not have LVRT capability. In order to improve the FSIG’s LVRT capability, it can change pitch quickly to reduce wind turbine mechanical torque or takes other measures to raise the wind turbine terminal voltage, all these measures can avoid the wind generator protection device tripping and improve the wind farm LVRT ability to a certain degree [17]. This article raises improve wind generator LVRT capability by taking the measure of install STATCOM to rise wind generator terminal voltage realization.

2.3. STATCOM Modeling

STATCOM is a kind of dynamic reactive compensation equipment based on the principle of voltage source converter, which has fast and smooth adjustment characteristics and can regulate the alternating current power grid reactive power rapidly. In order to facility analysis and more effective to control power, this paper changes static coordinate time-varying coefficients differential equation for synchronization rotate coordinates constant coefficient differential equation by using the PI-dq current control method, the equations are (4) and (5), the STATCOM control system as shown in Figure 5 [18].

\[
\begin{bmatrix}
    i_a \\
    i_b \\
    i_c
\end{bmatrix} =
\begin{bmatrix}
    1/2 & 0 & 0 \\
    0 & -\sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix}
\begin{bmatrix}
    i_a \\
    i_b \\
    i_c
\end{bmatrix}
\]

\[
\begin{bmatrix}
    i_a \\
    i_b \\
    i_c
\end{bmatrix} =
\begin{bmatrix}
    \cos(\alpha \omega t) & -\sin(\alpha \omega t) \\
    \sin(\alpha \omega t) & \cos(\alpha \omega t)
\end{bmatrix}
\begin{bmatrix}
    i_a \\
    i_b \\
    i_c
\end{bmatrix}
\]

(4)  

(5)

Figure 5 shows the STATCOM model structure and its controller diagram of this paper. Its controller principle is dual loops feedback control, the controller is divided into the inner and outer loop. The controller inner loop is a current regulator which control PWM converter output voltage amplitude and phase, and can make the STATCOM output current following the outer loop voltage regulator output without static errors. The controller outer loop includes the feedback STATCOM dive into the network point AC voltage regulator and the DC side of...
capacitor DC voltage regulator, through compare to the corresponding reference value, which processes static errors control [18].

2.4. Wind Farm Protection Configuration

Wind farm of our country mostly adopt concentrate access method, the voltage level is so high and impact on the system greatly. Concentrate access method is shown in Figure 6, wind turbine terminal low voltage rises to medium voltage through its boost transformer, and several wind generators are collected together and dived into converge bus through feeder, then are sent to transformer substation by transmission line and rised to 110kV or 220kV or higher voltage level and connected with the grid via out going line.

At present, the FSIG protection includes inverse time over-current, over voltage, over frequency, over-speed and temperature protection and so on. Generally breaker installs in wind turbine export.

Package transformer high voltage side configures fuse protection, lightning arrester protection and load switch and so on. The low voltage side protection is depended on wind turbine export breaker achieve.

Generally, feeder configures stage current protection or distance protection, which is a conventional feeder protection. Confluence bus usually adopts the high or low resistance bus differential protection, which is the special bus protection.
According to requirements of the stability system, in addition to configure the differential protection and non-electricity protection, the wind farm transformer high voltage side configures bus differential protection, and the back-up protection acts as transformer low voltage side line and its internal fault back-up protection, which only configures in transformer high voltage side. This is according to the protection configuration scheme of conventional step-down transformer.

The out-going line of wind farm side usually installs instantaneous break protection, or inverse time over current protection, or take line fiber optical current differential protection or pilot distance protection as the key protection, and without other long time limit protection. Back-up protection according to the single power configuration solutions. The out-going line of system side protection bases on normal configuration, such as three stages distance protection, but I stage protection should have direction to prevent misoperation of the wind farm provide through current for fault space when outside failure [19].

3. Simulation Results and Discussion
3.1. Containing STATCOM Modeling Simulation System
This paper using a 49.5MW wind farm electric diagrams, which has three 35kV feeders, and each line includes eleven 1.5MW FSG. The FSIG stator winding connects with frequency of 50Hz grid directly, ans the speed is 9m/s. Wind farm connects to step-up station through a length of 25km 35kV transmission line, and the voltage level rise up to 220kV, then dives into the power grid by a 100km out-going line [20]. The STATCOM is installed on the wind farm confluence bus. The system structure is shown in Figure 7.

The fault site mainly difference is internal and external of the wind farm for STATCOM. In order to research the wind farm LVRT capability, respectively set three-phase ground fault in wind farm 1# feeder and wind farm export line at 15s, the fault last for 0.1s.

3.2. Wind Farm Internal Fault
When the fault occurs in wind farm internal of 1# feeder, assuming the fault point is K_2 of Figure 6, the fault equivalent circuit is shown in the Figure 8.

![Figure 7. Wind farm connects the grid simulation model](image)

![Figure 8. Wind power feeder line fault equivalent circuit](image)

In Figure 8, \( E_w \) is the wind turbine terminal voltage; \( E_x, I_x \) and \( R \) respectively stand for STATCOM export voltage, current and equivalent impedance; \( Z_{st} \) is the feeder impedance; \( Z_1 \) is the wind farm to step-up switchyard line impedance; \( Z_x \) is the sum of step-up switchyard , transmission line and the system impedance; \( E_x \) is the grid voltage; m is the fault location, \( I_f \) and \( R \) respectively stand for fault point short-circuit current and resistance [21].

From the fault equivalent circuit, we can come to the conclusion that the 1# feeder relay measure voltage and current are shown in (6) and (7) when wind farm internal fault.

\[
V_m = I_f R_f
\]

(6)
\[ I_m = 22I_0 + E_s / Z_i + E_s / (Z_f + Z_x) \] (7)

From (6) and (7), we know that STATCOM have an effect on the feeder current protection, which will lead to protect mal operation; During the grid fault, STATCOM and wind turbines of other feeders all will provide short-circuit current for fault place, the voltage and current values of wind farm export relay measured are opposite of normal, the protection will trip if these values are higher than relay set values.

Through simulation it can be concluded that with and without STATCOM of the wind farm, the 35kV confluence bus voltage and current and STATCOM reactive power curve are respectively shown in Figure 9(a), (b) and (c).

![Figure 9. Wind power internal fault simulation results](image)

3.3. Wind Farm Export Line Fault

When the fault occurred in wind farm export line, assuming the fault point is \( K_3 \) of Figure 7, the fault equivalent circuit is shown in Figure 10 [21].

In Figure 10, \( m \) is the percentage of the distance from fault site to wind farm export relay point occupies transmission line. According to the equivalent circuit, the export relay measures voltage and current are shown in (8) and (9).

It can know that STATCOM will provide short-circuit current to fault point by (8) and (9), which would lead to wind farm export relay mal-operation.

![Figure 10. Wind power export line fault equivalent circuit](image)
\[ V_m = (33I_G + E_s/Z_s) \cdot m Z_i + I_f R_f \]  
\[ I_m = 33I_G + E_s/Z_s \]  

According to the simulation results, the 35kV confluence bus voltage and current and STATCOM reactive power of the wind farm with and without STATCOM curves are shown in figure 11(a), (b) and (c) respectively.

![Figure 11](image-url)

Figure 11. Wind power external fault simulation results

3.4. STATCOM Relay Protection Impact on Wind Farm

According to the analysis and simulation results, we can get to some conclusion:

1) During the fault, STATCOM can provide wind farm with reactive support, which will help wind generator terminal voltage rise up rapidly and suppress the rotor speed up effectively and improve the wind power transient stability and wind farm LVRT capability.

2) During the fault, STATCOM can provide fault point with short-circuit current, which will have greatly influence on the line current fast-tripping protection and lead to relay trip.

3) The fault happen in different place make the influence of STATCOM on protection are also different. According to the Figure 10 and Figure 11, it can know that STATCOM has smaller influence on protection compare fault in wind farm internal with its export line.

4) The protection exists problems, for those possess poor LVRT capability wind farms, wind turbines will take off from grid at the time of grid or wind farm fault for their protections are very sensitive. So, it requires that wind turbine control system should lock these protections during wind turbine LVRT. In addition, the wind turbine current fast-tripping protection action time is generally 0~0.05s. It requires protection to keep watch on the fault site to avoid current protection misoperation when the wind turbine outside fault.

4. Conclusion

This paper summarizes the Fixed Speed Induction Generator (FSIG) and Static Synchronous Compensator (STATCOM) model. Discusses the requirements of wind farm has LVRT capability which connects with the grid and establishes FSIG and STATCOM simulation model in Matlab/Simulink software. The simulation results show that the STATCOM can...
improve the wind farm’s LVRT capability effectively and make the system back to stable state quickly, and can help wind farm continuous running during the fault. Because of STATCOM provides fault point with continuous short-circuit current during the fault, which make current fast-tripping protection trip quickly and can improve the power grid safety and stability.

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