The Influences and Countermeasures of Contact Line Differential Protection and Auto-reclosing As Wind Integration

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Abstract: In this paper, doubly-fed wind turbine generator and direct-drive wind turbine generator dynamic model were built in the State Grid Simulation Center and a grid model include wind power was built in laboratory, various types of grid fault tests were carried out and in-depth studied. Through research on the contact line differential protection and three-phase auto-reclosing according the protection configuration combined with wind power, the influences of wind power to protection and auto-reclosing were revealed and corresponding adaptation measures to ensure the correct operation of the relay protection and reclosing were put forward.

Introduction

Renewable energy has become an important developing direction of the world energy policy support [1], especially the wind power developed rapidly, and China has become the largest nation of wind power connected to grid. According to renewable energy development plan, China will build multiple "don kilowatt wind power base", to the wind power installed capacity in 2015 reached 1 gigawatts (gw), to the wind power installed capacity in 2020 reached 2000 gw, meet 5% of its electricity demand, the overall rendering the characteristics of large-scale, long distance, high voltage and centralized access., after The line protection and reclosing will be affected after the big capacity of wind power access to system because of the difference between wind power and regular power characteristics in the failure.[2-10].This paper studies the problems and put forward to the corresponding countermeasures.

Modeling and Experiment

Laboratory Modeling. Set up the dynamic simulation system of doubly-fed and direct drive wind turbine in the laboratory [11], and it mainly includes the simulation of dc motor, doubly-fed wind turbine generator, the bidirectional converter and controller, etc. The dc motor is used as a prime mover model simulating wind turbine characteristics, and the simulating wind turbine operation characteristics realized through the simulation mathematical model of the fan control motor. The low voltage across in the wind turbine is realized through a increase in Crowbar circuit and to join in the rotor of the generator circuit current limiting resistor. Dynamic simulation experiment can intuitively, really to reflect the characteristics of the simulation system and provide important technical basis for system analysis and research. A system test in the lab to build model, is shown in figure 1.

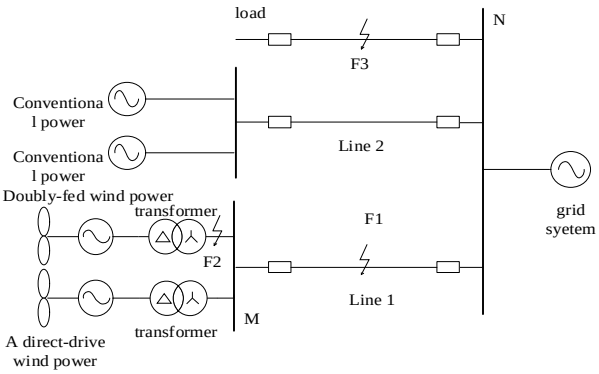
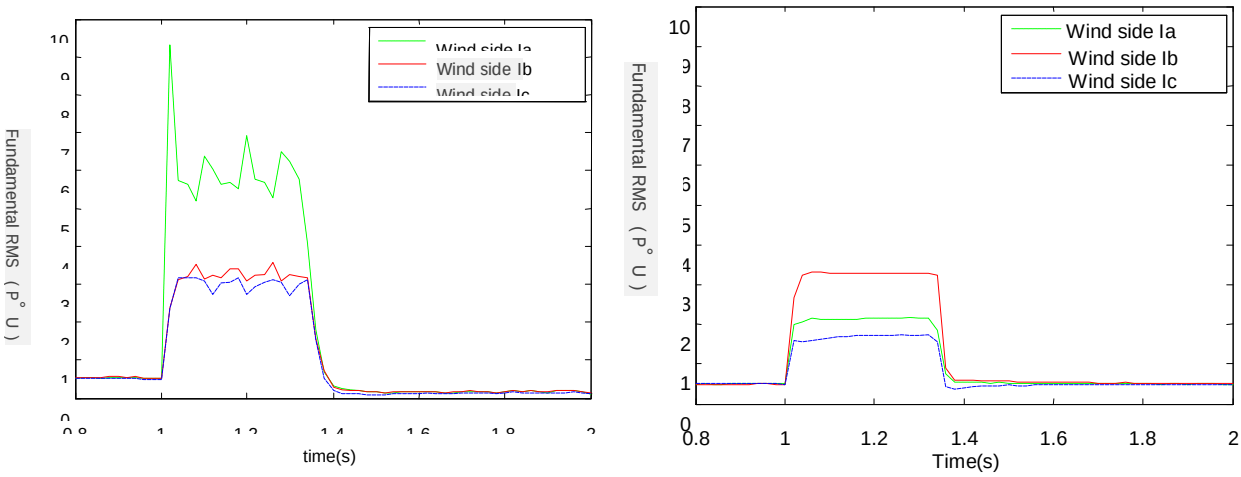


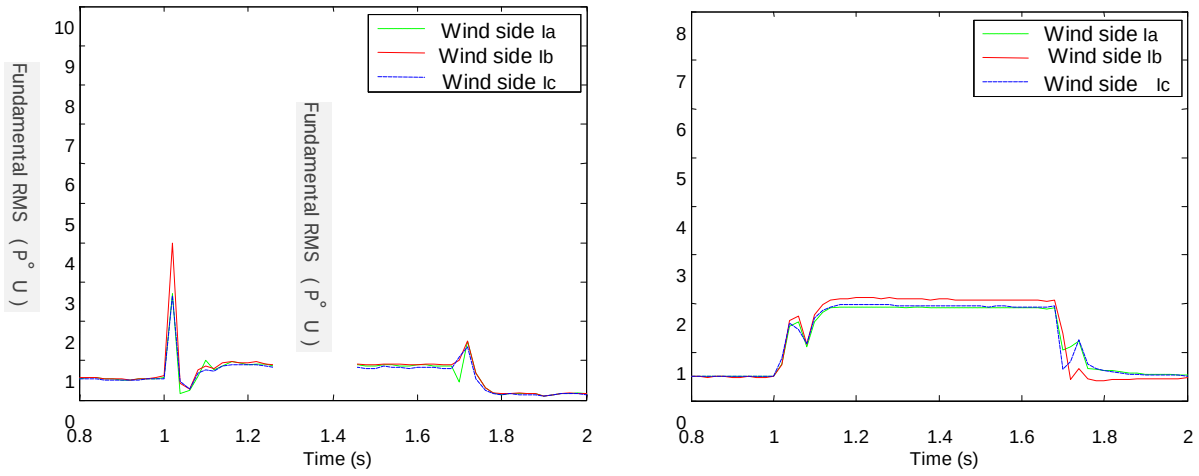
Figure 1 The wind power dynamic simulation system

In figure 1 doubly-fed wind power, direct drive wind power is connected to the grid system through the line 1 , conventional power through the line 2 access system, line 2 can enter or exit according to the test necessary.

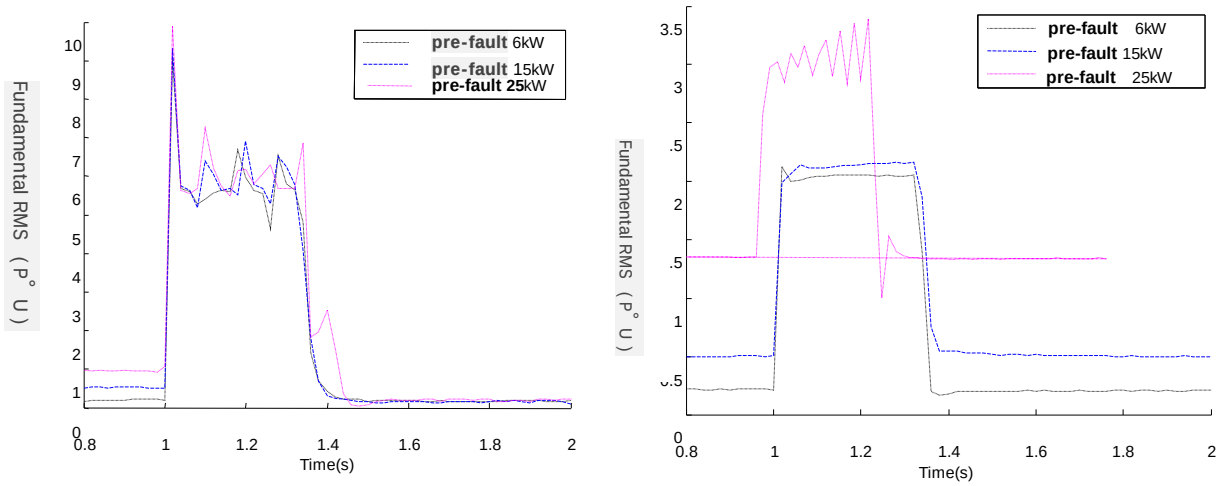
Fault Test Results. According to the operation of different load before failure wind farm, the doubly-fed and direct-drive wind electric mold system under different fault points and fault test, fault time is set to 330 ms (three-phase short-circuit fault time680 ms) . The wind farm cross through low voltage successfully. Detailed analysis was carried out on the fault wave record, only the current base associated with differential protection under the wave, as shown in figure 2 - 4.



(a) doubly-fed wind farm (b) direct-drive wind farm
Figure 2 Current of single-phase ground fault (AN)



(a) doubly-fed wind farm (b) direct-drive wind farm
Figure 3 Current of three-phase fault (ABC)



(a) doubly-fed wind farm (b) direct-drive wind farm

Figure 4 Current of single-phase ground fault (AN) with different load pre-fault

Through analyzing the result of the test, we get fault feature of wind farm composed of different wind turbines in the laboratory as follows:

(1) The doubly-fed wind power increase to a larger value of current moment after single-phase fault of the system, and it can increase to 9p.u. then decrease quickly, but begin to increase again after damping for a moment. and because the control system, may repeatedly increases, the attenuation process, finally to maintain in a stable value, it up to 4 p. u around in the experiment; Direct-drive wind power fault after fault current increase to a steady value, experiments can be up to 2 p. u ~ 3 p. around u, but the non-fault phase current is greater than the fault phase current;

(2) When the system face three-phase fault , the experiment of doubly-fed wind power current can up to 4 p. u after the fault for a moment then damp quickly, eventually reached at about 1 p.u. The direct-drive wind farm fault current increase to 2 p. u around;

(3) The load before the fault doesn't impact hugely to the short circuit current of doubly-fed wind power, but huge to the direct-drive wind farms' short circuit current. The larger the load before the fault is, the larger the prior motor in allowed to work within the scope of its fault current is.

The Fault Feature Analysis. In the doubly-fed machine control system, the frequency of the rotor current is made up of the difference of phase angle of the stator flux linkage θs and rotor position angle theta theta θr. θs is calculated as follows

$$\begin{cases} \varphi_{s\alpha} = \int (u_{s\alpha} - R_s i_{s\alpha})dt \\ \varphi_{s\beta} = \int (u_{s\beta} - R_s i_{s\beta})dt \\ \theta_s = \tan^{-1}\dfrac{\varphi_{s\alpha}}{\varphi_{s\beta}} \end{cases} \quad (1)$$

The representation of a type of subscript s stator quantity, as the flux, u for voltage, R for resistance, I for the current, α、β three-phase motor respectively into two phase axis.

θ_r is calculated by : $\theta_r = \int \omega_r \, dt$ (2)

In the formula, ω_r is the rotor angular velocity.

In the normal, the frequency of the $\theta_s - \theta_r$ is sω1=5Hz so that the frequency of rotor loop

current is low. When the export of wind farm is short-circuit, the stator flux voltage phase angle θ_s is approximate to zero due to the fault phase voltage approximation is 0, and the frequency of the rotor position angle θ_r remains (1-s) ω1 , so the frequency of $\theta_s - \theta_r$ is (1 - s) 1 = 55 Hz, namely frequency of rotor current reference by approximation for the dc into approximation for the fundamental frequency before and after the fault .

There's no transient process for the change of the rotor current before and after fault as the power electronic equipment response quickly. The rotor current almost no, after the failure of rotor current dc component quickly decay into a limit value, corresponding to the fundamental frequency component of the stator current and decay quickly, to a stable value, its dc component and the second harmonic component has decay.

Wind outlet short circuit occurs, the line voltage instantaneous wind drop, because of a malfunction after wind load loss, the output power down, wind machine to adjust the pitch angular velocity slower, as the second level corresponding, engine power is constant, and falling output electromagnetic power, cause the power imbalance, will lead to excess power machine side. D axis component of the network side controller voltage drops rapidly, network side appeared three phase current of the converter, dc capacitor on the voltage drop, E feedback control system at this time, increase the network side f reference current and the reference voltage, attempt to maintain voltage constant, E further increase, resulting in current voltage E also increases further, forming tilting rotor current and dc bus over-voltage.

Fault with the loss of the voltage of the machine, after the electromagnetic torque of doubly-fed machine is reduced, the time of the doubly-fed machine transient voltage and stator current will be rapid attenuation of 0, but time transient electric potential in fault will not happen before and after mutation, so short circuit instantaneous will produce very big in the stator winding current, corresponding to produce a large transient electromagnetic torque, and then quickly decay. After the control system detects the dc bus over-voltage, through closed-loop control to adjust the output current, make the output power increases, in an attempt to reduce the dc bus voltage, current increase, therefore cause machine end and may appear repeatedly.

For direct-drive wind power system, it is completely isolated between wind turbine and power grid as the full power converter is adopted, and the grid voltage drop will not directly affect the wind turbine itself, so the power grid voltage drop full power converter control strategy is directly related to the output of the wind power system short circuit current.

In general, the generator side converter adjust the rotation speed of motor according to different wind speed, to make the wind turbine run under the maximum power and take the generator power to the direct current capacity. The converter on grid is to complete the power factor control, then take power into grid timely. Among then, the converter on motor side and grid side's control and operation is relatively independent. In the case of loss ignoring, the output power of generator is equal to the motor input power to the dc side of the converter, and dc side to grid side converter output power is equal to dc side to grid side converter output power.

When there is a failure in the power grid voltage drop, the grid side converter output power is constant, in order to keep to the grid and try to ensure the three-phase power balance, to increase output current. When the current reaches the device current limiting value, the output power is restricted, the generator keep excess energy will be carried out on the dc side capacitor charging, need to take measures to prevent damage of converter.

If direct drive wind turbines carry small load before fault, the output power is low and the

power loss after fault is small, the output power of the wind turbine is lower, after overvoltage of the dc bus appeared, then the grid side converter make the output current increase to balance the loss of power, and the output fault current is small due to the relatively small power loss. When load is bigger before the failure, the bigger loss of power after failure, we must increase output current control in order to balance the loss power and reduce the dc bus voltage. It can be included that the output current values associated with fault before loading.

The Differential Protection of Wind Contact Line

The Problems. The typical starting element of the line protection includes: the current mutation quantity start, zero sequence current mutation quantity start. The current mutation quantity start components as follows:

$$\Delta I_{\varphi\varphi MAX} > 1.25\Delta I_T + \Delta I_{ZD} \quad (3)$$

or $$\Delta I_{\varphi\varphi} > I_{QD} \quad (4)$$

where $\Delta I_{\varphi\varphi MAX}$ is the maximum of the half wave integral of interphase current, ΔI_{ZD} is the fixed threshold which can be adjust ,ΔI_T is the floating threshold.

$\Delta I_{\varphi\varphi} = ||i_k - i_{k-T}| - |i_{k-T} - i_{k-2T}||$, $\varphi\varphi$ is interphase and phase identification, K is the sample values of the sampling point, T = 24 is the amount of the sampling point, (K-T) is sample value of the K point one week ago, (K-2T) is sample value of the K point two weeks ago.

The zero sequence current mutation quantity star components as follows:

$$\Delta 3I_0 > I_{QD} \quad (5)$$

Where $\Delta 3I_0$ is the break variable of zero sequence current, I_{QD} is the setting value of the mutation quantity starting current.

In the case that wind power is still week source compare to the whole system, when short out appear in the line, the wind power especially the start elements of wind farms which consist of direct drive wind won't start as the current variable can't reach constant value. If the wind farm side transformer neutral point grounding, line light before short circuit, short circuit after no zero sequence current, direct drive wind farm crew sent I current is small, current mutation quantity start element does not start, while wind power supply side differential protection is not, can only rely on backup protection action to remove the fault. System side protection movement situation related to the processing logic, if the action logic to the contralateral differential protection allows tripping signals, differential protection will refuse to move, the removal of backup protection fault; If action logic don't need the contralateral differential protection allows tripping signals, the differential protection can still be correct action.

We get to know from the fault features of wind power that for the wind turbine with low voltage across, its fault characteristics is different from the conventional synchronous unit as the function of the inverter control system. Its short-circuit current and fault phase is not necessarily completely, but as the wind farm is still a small power supply. The differential protection

differential current phase selection can generally be correct action when the line fault,.

Adaptation Measures.1) No device always start element protection

In order to ensure the protection for weak wind, if the line fails, the protection on both sides can fast tripping, any side of the differential protection will send the other side to jumping signal at the same time when it's taking action, the other side can also rapidly export tripping after receiving the united jumping signal.

2) Device always start element protection

There're two schemes as follows to ensure the weak feed line differential protection of wind turbine can start reliably:

A. Set up open differential current starting element through the low voltage. When the differential current reach the threshold value of the steady state quantity, and this side voltage differential relay action related to phase, alternate with of low voltage criterion met, operation;

Set to start low voltage auxiliary components, in the judgment does not appear the PT wire break signal, the phase selection element for auxiliary start up. The logic is as follows:

1) Without PT wire break;

2) Any phase voltage is less than 0.4 the Un, and the other two phase voltage is greater than 0.7 the Un, is sentenced to single-phase fault as the third phase, start;

3) The voltage is lower than 0.4 Un, convicted of interphase fault, start.

B . Using differential far jump tripping signal receiving system side. Wind side received system side of the differential protection tripping signals from a distance, and no other atresia criterion in this side is set, the wind side differential protection action.

Reclosing Equipment on the Line of Wind Power

The Problems. When link failure occurs, the line on both sides of the protection action will remove the fault, if it is instantaneous fault, the big power supply side line is detected without pressure conditions meet after reclosing action, small power supply side during the same period inspection conditions meet the reclosing after movement, the link to restore power, this way can ensure reclosing successful action to prevent impact than the same period of the small power at the same time, so had been showed with wide application in the field.

But the scheme is adaptive to 110 kV wind farm and it has appeared problem repeatedly: when the wind farm grid tie line instantaneous fault occurs, the system focuses on closing the inspection line pressure less way can usually be successful action, and wind power switch on the conventional way of inspection in the same period is often difficult to success. Analysis of reasons are as follows:

1) If the wind farm don't have the ability of low voltage across, as the low voltage protection wind turbines typically set to 0.9Ue (which is rated voltage), unless some extreme high resistance earth fault makes wind power voltage of the machine is not dropped to below 0.9Ue, usually at the point of failure isolation wind turbines protection has action before cutting machine;

2)If wind farm has the capability of low voltage across, according to the national grid company wind farm access technology, when the voltage drops to 0.2Ue should have 0.625 s crossing ability, so after opening on both sides of the switch in the link protection action, wind farms can still run. At this time, in two cases:

A. Wind farm on the island operate with partial load. Wind turbines are working according to the maximum wind power tracking at the rated wind speed, when the rated wind speed output

power rating, if appear wind and load fluctuation is bigger, the output and load do not match, will lead to high frequency, low frequency protection action of wind turbines and cutting machine, appear fluctuation of cutting machine;

B. Wind farm on the island with no load operation. The wind turbines through adjusting the pitch Angle to reduce power control, input unloading circuits and crowbar protection measures, such as sustainable and stable operation, wind farm side charged normally.

Thus, only in the wind turbines have low voltage crossing ability and stable operation without load, wind power switch to on by investing in check over the same period, the link to restore power, other cases, the wind power plant side have cutting machine, losing electricity inspection conditions are not met, the same period reclosing is not action.

Adaptation Measures. Combined with the feature of different wind turbines control strategy and fault, when wind through a 110 kV access system, consider the following solution.

Wind Farm Operating Without Island . Using automatic reclosing of wind farm side "" strategy, logic is:

(1) Check line pressure;

(2) Wind farm bus bar voltage, if have a pressure test in the same period;

(3) wind farm bus bar voltage, if no pressure, direct investment.

in the wind and system instantaneity fault occurring on the tie line of F1, action to remove the fault lines on both sides of the protection. Then system focus on closing inspection after stressful conditions meet overlap, line charged, wind side if the fan has to take off the net, the detection circuit with pressure and wind pressure condition is met, reclosing action closed circuit switch; Fan have low voltage through the function, if not to take off the network operation, the inspection line pressure and wind pressure, reclosing inspection conditions meet the action during this period, the closed circuit breaker.

Wind Farm Operating With Island. Use wind farm side solution column reclosing, wind farm side contact circuit breaker tripping, protection action point switch, jump drive wind farm side wind at this time sends out the basic capacity and load balance, and the adjusting effectively and can keep the island on load operation.logic is:

(1) Check line pressure;

(2) The point of wind farm voltage detector, if a pressure test in the same period;

(3) Point of wind farm voltage detector, without pressure, direct investment.

In the wind and systems on the tie line of F1 permanent fault occurs, the system skips side circuit breaker reclosing after tripping and atresia, lateral wind jumped clean point after the switch, because there are pressure condition does not meet the inspection line, reclosing is not action. The wind farm island can take part load operation, reduced the scope of power, improve the power supply reliability.

Conclusion

With large-scale wind farm access system, various types of wind turbines of wind farms in the system failure sent out short circuit current characteristics are different, the effects on the system relay protection, especially the main protection should carry out in-depth study. Through research, this paper draws the conclusions as follows:1, the system fault, the doubly-fed generator of wind farms and rapid attenuation of current moment after failure, because of the control system, may repeatedly increases, the attenuation process, finally to maintain a stable value; Direct-drive wind power fault after fault current increase to a stable value;2, direct drive unit consisting of wind farm out fault current and fault zone before positively related to the load;3, contact line fault, the wind

side of the differential protection can begin to add a low voltage auxiliary device to prevent unable to start correctly; Contact 4, 110 kV power line according to the requirements, whether or not to bring a load island operation of wind farms may take different reclosing strategies, to solve the problem of line can't correct overlap.

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