

REVIEW OF REACTIVE POWER COMPENSATION IN WIND TURBINE

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Abstract:—Different aspects of reactive power regulation problem in wind farms are presented in this paper. In the first part some background of the reactive power control in Wind Park is presented, including motivations for its use and methods that can be used. In general, there are active (wind generator, compensator) and passive methods (L, C) of reactive power compensation. The wind park model (the model of doubly fed induction generator (DFIG) based wind turbines, crowbar circuit, battery storage system, transformers, cable lines between wind farm and PCC, control system) has been shown in the proposed methods.

In wind farm the crowbar protection, changes from reactive power source to reactive power load with the rise of low voltage and then burden of fault power system is aggravated. In order to solve the problem a new strategy is formed where a new real time coordinate control system (RTCCS) is built. Based on reactive power compensator the STATCOM synchronizes with wind power system and the grid STATCOM exchanges the perceptual reactive and capacitive reactive which restrain system voltage fluctuation and maintain the stability of the system voltage at fault times. Wind power system and STATCOM control and reactive power control strategy are discussed with the help of basic working principle and relevant models and the simulation of actual system had been done with the help of PSCAD. The simulation result shows that STATCOM maintaining the system improves the wind power system voltage.

Keywords:- DFIG; Crowbar; Fault operation; Reactive power Coordinated control; RTCCS.

I. INTRODUCTION

Wind energy is a source of renewable power which comes from air current flowing across the earth's surface. Wind turbines harvest this kinetic energy and convert it into usable power which can provide electricity for home, farm, school or business applications on small (residential) - or large (utility) - scales. Wind energy is one of the fastest growing sources of electricity and one of the fastest growing markets in the world today. These growth trends can be linked to the multi-dimensional benefits associated with wind energy, such as green power, sustainable, affordable and economic development .Power factor is defined as the ratio of real power to apparent power. This definition is often mathematically represented as kW/kVA, where the numerator is the active (real) power and the denominator is the (active+ reactive) or apparent power. reactive power

says that in an alternating current system, when the voltage and current go up and down at the same time, only real power is transmitted and when there is a time shift between voltage and current both active and reactive power are transmitted. But, when the average in time is calculated, the average active power exists causing a net flow of energy from one point to another, whereas average reactive power is zero, irrespective of the network or state of the system.

In the case of reactive power, the amount of energy flowing in one direction is equal to the amount of energy flowing in the opposite direction (or different parts - capacitors, inductors, exchange the reactive power) shown fig.1. That means reactive power is neither produced nor consumed. Reactive power (vars) is required to maintain the voltage to deliver active power (watts) through transmission lines. Motor loads and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. Transformers, transmission lines, and motors require reactive power Survey graph shows the reactive power demand for a constant PF of 0.85 for the two months.

$$\text{Complex Power} = \sqrt{(\text{Real Power})^2 + (\text{Reactive Power})^2}$$

$$\text{Real Power} = \text{Complex Power} \times \cos(\Phi)$$

$$\text{Power Factor} = \cos(\Phi) = \frac{\text{Real Power}}{\text{Complex Power}}$$

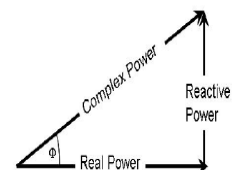


Fig:-1 Real, Reactive and complex power

When wind power system fault happens, wind turbine should maintain grid-connected operation within certain range of voltage and time, otherwise we have to turn-off large capacity wind farm. If not it will badly affect the running of the fault system and can even make it collapse. Double Fed Induction Generator (DFIG) is widely used in China, most of which is assembled with Crowbar, a kind of low voltage ride-through protection device. At present, the studies of Crowbar device and low voltage ride-through technologies mainly focus on two aspects [1].

On one hand, attentions are paid to Crowbar. Paper [3] point out the key point for DFIG wind turbine to maintain continuous grid-connected operation at fault time is the

maximum limit of normal rotor current and the setting of bypass resistance connected to the rotor winding. To improve traditional passive Crowbar, adopting active Crowbar circuit as control method, which control the status of Crowbar according to stator current, so that active power and reactive power can be provided to the power system in time.

On the other hand, besides using Crowbar protection, other measures are taken to improve the stability of low voltage ride through. One measure is to limit alternating component of rotor current caused by stator current by improving excitation current control strategy at system fault time. Or combining grid fault excitation control and normal wind power track control to ensure generators rerun quickly, so that the post-fault stability of the whole power system can be improved [5].

Although some works about wind turbine low voltage ride through have been done as summarized above, here are still two problems existing. First, the above researches all emphasize on how to maintain the wind turbine operate under low voltage, but the support ability of wind power to the power system hasn't yet been considered. As important system generation resources, wind farms are under an obligation to provide voltage support to the system at fault time. Meanwhile, the DFIG turbine with Crowbar protection is also able to provide the support. Second, DFIG has the ability of reactive power output indeed, but the system voltage level is very low in fault situation. So, if Crowbar protection acts, DFIG will turn to ordinary induction generator, then DFIG not only can not generate reactive power, but also need to absorb reactive power to maintain grid-connected operation, this means more heavy burden to the fault system [2],[3].

The above problems are very important to the DFIG based wind farm. The former is mainly about the function and possibility of wind farm operating as reactive power sources. In order to keep wind farm in grid-connected operation continuously, provide reactive power support to power system and maintain voltage level of grid-connected point in power system fault situation, further researches must be done on reasonable control of wind farm reactive power output.

A real time coordinated control system (RTCCS) is also introduced in this paper, which can control reactive power of wind power system in real time according to voltage level and the action of wind turbine protection device at fault time. Through coordinate control of the RTCCS, not only fault ride-through ability of wind power system can be improved, but also the reactive power and voltage level of the grid-connected point can be supported.

II. DFIG CHARACTERISTICS

In normal operating condition, Double Fed Induction Generator (DFIG) is capable of outputting reactive power, so wind farm can run as reactive power source to provide the power system reactive power. So that, DFIG is operated in a kind of power control mode, that is, reactive power is produced depending on system schedule [6].

When fault occurs in the power system, the mentioned power control mode will encounter difficulty, because the

voltage of the grid-connected point drops rapidly and Crowbar protection of DFIG will take action. Then the rotor side of DFIG will be shortening by the protection circuit, and turn to be a winding induction generator, which can provide reactive power to the system. Principle of DFIG Protection is shown as Fig.2.

In fault conditions, the voltage drops rapidly. When the rotor current or DC bus voltage rise over the critical value, DFIGs low voltage ride-through will start. In order to protect the converter, the crowbar will conduct, all the IGBT (insulated gate bipolar transistor) of the rotor converter side will shut off, and the rotor current shifts to the crowbar. Then DFIG turns to a winding induction generator, not only cannot provide reactive power to the system, but also needs to absorb reactive power from the system to maintain normal operation. The wind farm also turns from reactive power source to reactive power load, and the fault system must face greater stress if there is no effective compensation control strategy.

STATCOM compensation unit combined in the RTCCS in the paper has such functions. When power system fault happens, if the protection is in effect, the RTCCS will control the compensation unit to provide reactive power for wind farm and the fault system rapidly and continuously, raise voltage level of the grid-connected point, and help DFIG recover to normal operation state quickly. If the protection isn't in effect, the RTCCS will control the compensation unit to provide reactive power support for the fault system and the wind farm together, prevent the action of protection, and keep the wind farm in normal grid-connected operation, so as to provide more powerful voltage support for the fault system.

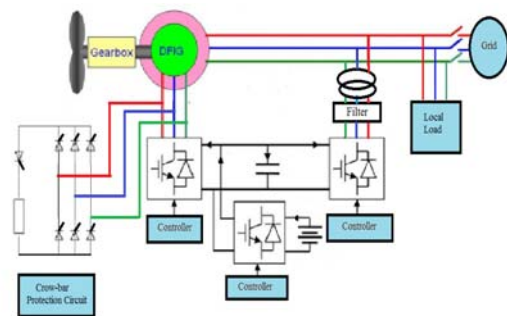
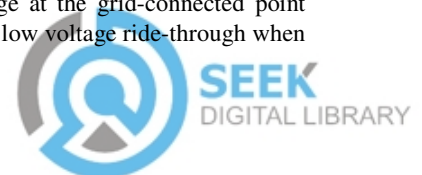


Figure 2:-Proposed Model

III. STATCOM MODEL

The STATCOM is a shunt connected FACTS device, as an advanced SVC. It generates balanced three-phase sinusoidal voltages in normal operation, with rapidly controllable amplitude and phase angle. A typical application is for voltage support. In this paper, the STATCOM is modelled as a PWM converter with a dc-link capacitor. Its objective is to rapidly regulate the voltage at the grid-connected point and enhance the capability of low voltage ride-through when fault occurs [7].



IV. REACTIVE POWER CONTROL STRATEGY

Reactive power compensation through capacitor banks or inductors is ineffective and inaccurate, but still widely used today. Often only inductors located at PCC are used. As a result wind park power factor is always inductive, but charges are smaller. Therefore to enable more accurate way of controlling reactive power, active compensation has been investigated. The main goal of the compensation method is to allow the wind farm to operate with a power factor (at PCC) which is variable within the specified range. Wind farm equipped with such a control system could take part in power system regulation.

RTCCS realizes reactive power balance among wind farm, compensation unit and grid-connected system by real time coordinated control. A complete RTCCS includes normal operation control strategy and fault operation control strategy. The former is already mature. The paper only study control strategies of fault conditions.

STATCOM is connected to low voltage side of the wind farm transformer. RTCCS control wind farm and compensation unit according to information collected from the wind farm, STATCOM, grid connected point and power system. The control system structure of RTCCS is shown as Fig.3.

Without fault, the RTCCS runs in power control mode according to reactive power instruction of the system. When fault occurs, the RTCCS will adjust control strategy based on the action situation of Crowbar. Wind farm still have ability to provide reactive power when Crowbar protection does not act. Then the RTCCS will stay in power control mode, the compensation unit and wind farm provide reactive power support to the fault system together, so as to guarantee the voltage level of the grid-connected point and keep wind farm in normal grid-connected operation. After Crowbar protection acts, the wind turbine cannot go on to provide reactive power. Then the primary control aim is to maintain grid-connected operation of wind farm. The RTCCS comes into voltage control mode, the compensation unit is controlled to promote the voltage level of grid-connected point to the best of its ability, so as to maintain wind turbine grid-connected operation and help to resume normal operation [8].

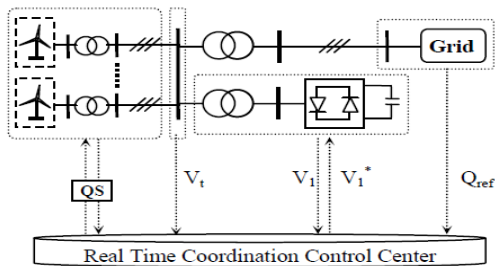


Figure 3:- Control system structure of RTCCS

The RTCCS aims at different control targets according to crowbar protection action status, and adopts corresponding control strategy. The control flow chart is shown as Fig.4.

In Fig.4, when fault occurs, RTCCS will use different operation mode according to the action of Crowbar. There are two advantages of this kind of double operation mode as follows: first, adopting real-time tracking control can response to system fault quickly.

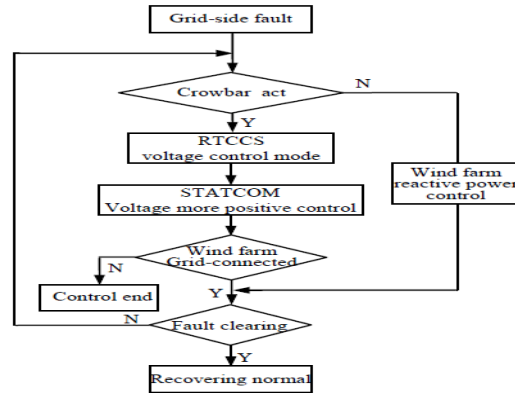


Figure 4:- Flow chart at fault time

Second, the wind farm reactive power output ability can be used furthest, then to provide reactive power for the fault system and to improve the possibility of wind farm fault ride-through.

V. CONTROL MODE

The RTCCS will operate under power control mode or voltage control mode according to different protection condition. When crowbar protection does not act, the RTCCS will operate in power control mode.

Distinguished from normal operating, the power control mode will not track grid side reactive power instruction Q_{ref} at fault time; instead, it controls reactive power output based on the real time output margin of reactive power source and the real time voltage level, and therefore provides voltage support to the fault system. Control system diagram is shown as Fig.5.

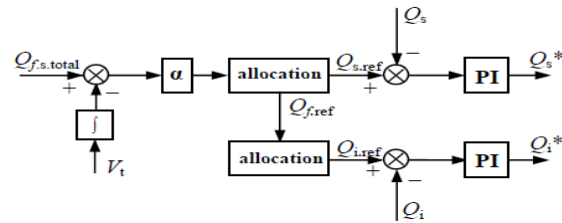


Figure 5:- Scheme of Power control mode

After turbine protection acts, The RTCCS will make the wind power system enter voltage control mode. Then STATCOM will track the voltage of the grid connected point, and adjust reactive power output according to the voltage error.

$$\Delta V_{k+1} = \Delta V_{k+1} - V_k \text{----- (1)}$$

$$\Delta Q_{k+1} = \Delta V_{k+1} \frac{dQ}{dU} \text{----- (2)}$$



Where ΔV_{k+1} is voltage difference between time k and time $k+1$, ΔQ_{k+1} is reactive power output adjustment of the compensation device at time $k+1$.

The wind turbine power factor depends on total value of inductance L and capacitance C . The value of reactive power Q_L absorbed by inductance L is equal to $Q_L = \omega LI^2$ and the Q_C value is $Q_C = -\omega CV^2$

Where: V denotes voltage, I current, ω grid pulsation.

From these formulae it follows that Q_C power is (for constant voltage) almost constant, but Q_L power depends on current or WT (wind turbine) active power or wind speed. Total reactive power is $Q_T = Q_C + Q_L$

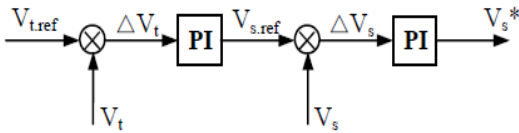


Figure 6:- Scheme of voltage control mode

Control Scheme of voltage control mode is shown as Fig.6. In voltage control mode, the voltage at the grid-connected point is correctively controlled by the control system directly, and then the output voltage of compensation unit is determined finally. Meanwhile, in such mode, the RTCCS will not deal with reactive power instruction of the grid and wind farm. Wind farm works in constant power factor mode on the other hand the grid receives abnormal information fed back from the control centre. When communication channel returns to normal, the control system will switch to power control mode.

VI. SYSTEM DESIGN & SIMULATION ANALYSIS

The system which shown in this paper is composed of 2.5MW DFIG. The system has been simulated in PSCAD. This circuit consist of the model diagram of wind farm ,wound DFIG, load, STATCOM and crowbar circuit which are connected to the load and the excess current directly goes to the Grid. Furthers researches has been done on reasonable control shown fig.7.

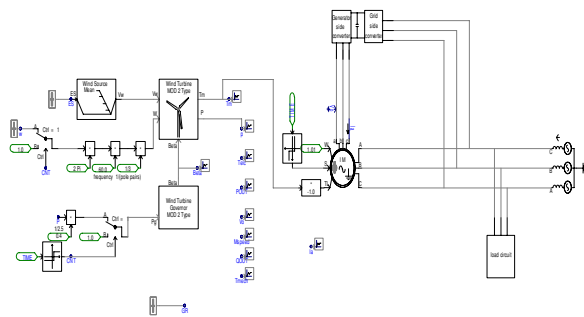


Figure.7:- Circuit diagram of wind modelling

In fig.8 the circuit consist of crow bar circuit (with Thyristor) and STATCOM model Connected with the transformer. A crowbar circuit is an electrical circuit used to prevent an overvoltage condition of a power supply unit from damaging the circuits attached to the power supply. It

operates by putting a short circuit or low resistance path across the voltage source, much as if one dropped a tool of the same name across the output terminals of the power supply.

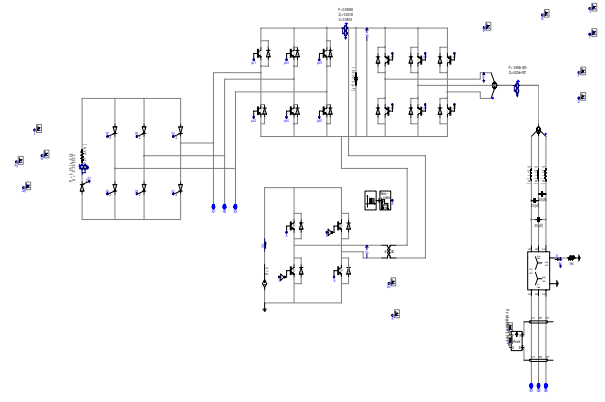


Figure.8:- Crowbar circuit, filters, battery with STATCOM Model.

In Fig. 9 the load circuit is our Sustainable power & research centre’s room of our university. we use load of 0.00006 MW, 0.0001 MW, 0.0004 MW, and 0.0035 MW and got the result and simulation graph which is shown in below.

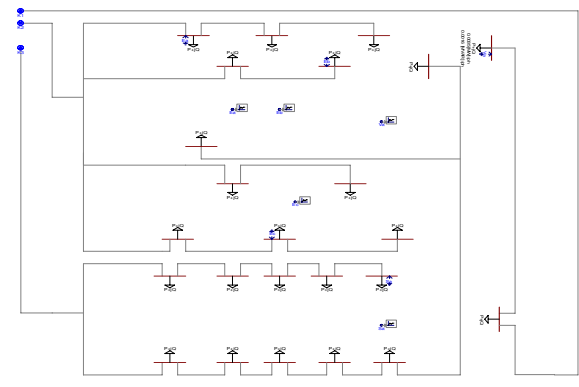
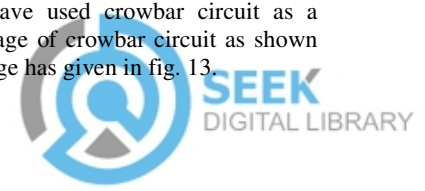


Figure.9:- Load circuit

Using the RTCCS proposed in the paper, real time coordinated control is practiced to the wind farm and STATCOM compensation unit, then reactive power is injected into the fault system quickly, the voltage level of the grid connected point rise its shown in fig.12. It can be seen from Fig.11 that the compensation unit input a large amount of reactive power into the system at the fault time. A much higher voltage level of the grid-connected point is maintained, and the crowbar protection is prevented from action consequently. To control the dynamic reactive power of the DFIG we have used crowbar circuit as a protection circuit. The voltage of crowbar circuit as shown in fig.10. And dc link voltage has given in fig. 13.



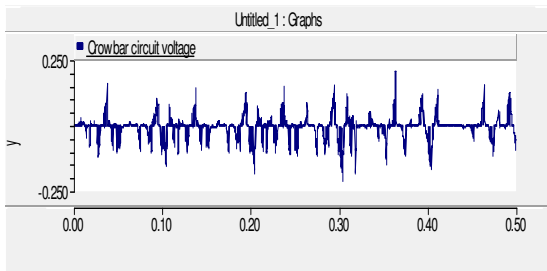


Figure.10:- Crow bar circuit voltage

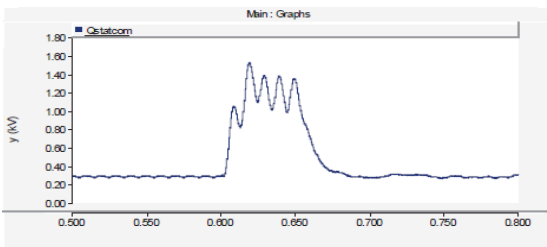


Figure.11:- STATCOM reactive power curve

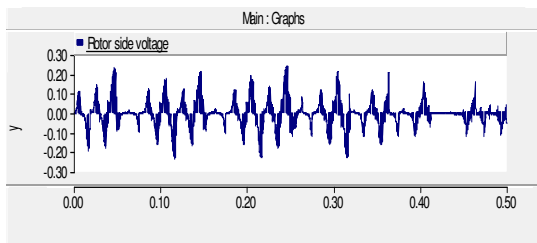


Figure12:- Rotor side voltage

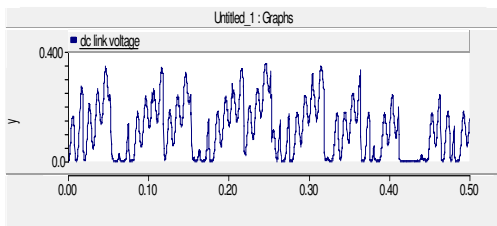


Fig.13:- Dc link voltage

It not only alleviates the pressure of the fault system, but also favours the normally operating wind farm to provide reactive power to the fault system.

VII. CONCLUSION

In this paper, STATCOM compensation module is combined with RTCCS, and new RTCCS is proposed. The new RTCCS will control STATCOM to compensate DFIG reactive power through crowbar circuit and filter has been used to compensate the reactive power in the grid side which raises the voltage level of the system. Therefore the wind farm can ride through low voltage more stable.

VIII. ACKNOWLEDGMENT

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