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The Maximum Power Tracking Method and Reactive Compensation Simulation Research Based on DIgSILENT*

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ABSTRACT

This paper studies about the mechanical part of wind turbine and wind generator operation stability.1) It makes a comparative study of two control methods for maximum power tracking: curve fitting method and hill climbing algorithm, sets up improved control modules in DIgSLIENT and makes comparison research, thus gets the conclusion that the improved control modules of hill climbing algorithm has good effect on MPPT, and it is more desirable in the condition of steady wind. 2) This paper sets up SVC and STATCOM models and improved control modules in DIgSLIENT, which are connected to wind power system, verifying the validity of SVC and STATCOM models, and verifying its influence on wind power plant and system. The results of the study show that STATCOM is more helpful in voltage recovery when large disturbance of three-phase short-circuit happened in wind power grid, reactive compensation is more effective.

Keywords: Maximum Power Tracking; Hill Climbing Algorithm; SVC; STATCOM; DIgSLIENT

1. Introduction

With the rapid development of large wind power generation research, it is more focused that variable speed constant-frequency doubly-fed wind power generation technology has the feature of variable speed within comparably wide range in maximum power tracking. [7] Discusses a new and simple control method for maximum power tracking in a variable speed wind turbine by using a step-up dc-dc converter [8]. Analyze the wind machine characteristics and maximum wind power captured principle, proposes a control strategy without measuring wind speed. [5] Reviews the existing maximum wind energy extraction algorithm and develops an intelligent maximum power extraction algorithm.

In China, the area that is suitable for large-scale development of wind power is in a network terminal. The power grid structure in this area is comparably weak, so once connected to grid, large-scale wind power may appear a series of problems, such as voltage decline, increasing system short circuit capacity, system transient stability change, etc. Therefore, reactive compensation for power factor improvement is of great practical significance to voltage stability and improving transmission efficiency. The principle structures and controller models and dynamic compensation effects of SVC and STATCOM have been discussed in [9-11].

2. Mathematical Model

2.1. Wind Turbine Model

Wind turbine is the component that converting winds energy into mechanical energy. With a certain speed and angle, the effect of wind makes the paddle rotating, and thereby the wind energy turns into mechanical energy, which drives the generator. The process that wind turbine turn wind energy into mechanical energy is a complex aerodynamics process, which is quiet difficult to accurately describe. According to Betz' Law, the mechanical power of wind turbine capture is:

$$P = 0.5 C_p \pi \rho v^3 R^2 \tag{1}$$

In (1), P is the power of wind turbine capture, ρ is air density, R is radius of the turbine blade, and v is wind speed. C_P is the wind power utilization coefficient of wind turbine, and its physical meaning is: the percentage of energy absorbed from natural wind by wind rotor and the wind energy contained in undisturbed air within rotor swept area. C_P is the function of tip speed ratio λ and pitch angle β. It could be simulated in the following nonlinear function [1].

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$$\begin{cases} C_P(\beta,\lambda) = 0.22\cdot(\dfrac{116}{\lambda_i} - 0.4\beta - 5.0)e^{-12.5/\lambda_i} \\ \lambda_i = [\dfrac{1}{\lambda + 0.08\beta} - \dfrac{0.035}{\beta^3+1}]^{-1} \\ \lambda = \dfrac{\omega R}{v} \end{cases} \tag{2}$$

2.2. Shaft Model

Shaft drive system mainly includes a wind turbine, overdrive gearbox and drive shaft, but generally, overdrive gearbox and wind turbine are equivalent to one mass, doubly-fed generator is one mass, thus shafting drive model with two masses is built. As shown in **Figure 1**:

Two masses model [2]

$$\begin{cases} \dfrac{d\theta_G}{dt} = w_G \\ \dfrac{dw_G}{dt} = \dfrac{T_G - \delta_G w_G - k(\theta_w - \theta_G)}{J_G} \\ \dfrac{d\theta_w}{d} = w_w \\ \dfrac{dw_w}{d} = \dfrac{T_w - \delta_w w_w - k(\theta_w - \theta_G)}{J_w} \end{cases} \tag{3}$$

In (3), “w” “G” respectively stand for turbine and generator: θ is the torsion angle of shaft, K is stiffness coefficient, J_w and J_G are the inertia time constant of wind turbine and generator, δ_w and δ_G are the damping coefficient of wind turbine and generator rotor, T_w is the mechanical torque of wind rotor and T_G is the mechanical torque effected on rotor shaft of generator. It is known that two masses model of differential variables have four, this will increase the workload, so that influence the simulation speed, therefore we need to simplify the shaft model, a simplified model is that the two inertia time constant are equal to one:

$$J_{eq} = J_G + \frac{J_W}{N} \tag{4}$$

where: N stand for Gear box of variable ratio. So that one mass model equation:

$$J_{eq}\frac{dw_G}{dt} = T_w - T_G - \delta w_G \tag{5}$$

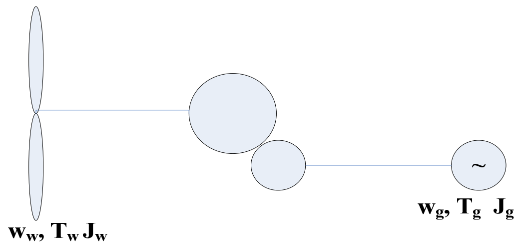

Figure 1. Shaft model diagram..

2.3. Wind Turbine Model

Considering DFIG stator transient process and transient state of system, the increasing of system order is time-consuming, it is necessary to lower the order of generator. As electromagnetic transient state of stator is much rapid than that of rotor, and have less effect on transient stability of generator, so transient process of stator is ignored, that is, the change of the stator magnetic chain is zero. The voltage equation of DFIG in the two phase synchronous speed rotating coordinate system is converted as[3,4]:

$$\begin{cases} u_{sd} = -\omega_s\Psi_{sq} + R_s i_{sd} \\ u_{sq} = \omega_s\Psi_{sd} + R_s i_{sq} \\ u_{rd} = p\Psi_{rd} - s\omega_s\Psi_{rq} + R_r i_{rq} \\ u_{rq} = p\Psi_{rq} + s\omega_s\Psi_{rd} + R_r i_{rq} \end{cases} \tag{6}$$

Equation (5) and (6) are combined, a third order equation of wind generator is set. As a third Order model could fully reflect the characteristics of wind power generation in system transient state, precision is acceptable, and calculation speed is fast, and In the DIgSLIENT, wind generator mechanical and electrical transient model is to use the third order model.

3. Wind Energy Capture

3.1. Method Introduced

The common control method of MPT could be classified into three types [5]: Tip Speed Ratio, Power Signal Feedback, and Hill-climbing Search. This paper tries to compare wind MPPT control by listing two different realization methods in DIgSLIENT.

Method 1[6]: curve fitting method, the optimal power curve of the wind turbine is fitted to the wind turbine speed ω as the independent variable, Power P is the polynomial expression of the speed ω, the generator rotational speed ω and the power P is a one-to-one relationship. Back stepping the actual active output of the wind generation, we can get the corresponding optimal speed as the speed reference value, input the value to speed controller to get the optimal power reference value, and then input to the active control system of doubly-fed generation as the reference active power value. Speed controller role: the difference of the speed reference value and the measured values of the generator speed is the error value, the value input PI controller to obtain active power reference value. If the actual speed is equal to reference speed value, speed controller input signal is 0 which means it doesn't work; if not, speed controller will conduct continuous control until the wind generator output the corresponding optimal power. So the realization of the function the maximum wind power capture is in turn depend on the maximum power tracking module, speed controller and doubly-fed motor power control. As shown in **Figure 2**:

Method 2[7, 8]: constant step hill climbing algorithm is local optimization algorithm, The specific algorithm is as follows: First of all, the initial reference motor speed ω and active power P are given. Secondly, by observing the changes in P and ω, compare with previous P and ω to get the trend of the P and ω to decide positive and negative of the step: If the trends of the two variables are the same, then the calculated out step is positive. At last, the current step plus the previous cycle of reference value will get a new reference value.

Implementation: in the control cycle interval n and n-1 time in the control cycle, Sampling the P and ω and Observation of the current P and ω. If P increases, maintaining step ω_{step} direction, or else makes the step length ω_{step} inverting. Finally, the current ω_{step} plus the previous cycle of reference speed command will obtain a new reference value, the reference speed value input to speed controller and reference active power value is obtained by the PI controller, and then input to the active power controller of the DFIG. As shown in **Figure 3**:

Calculation $\triangle P$,$\triangle \omega$ and the next moment of reference speed:

$$\frac{dP}{dw} = \frac{P(n) - P(n-1)}{w(n) - w(n-1)} \tag{7}$$

$$w_{ref}(n) = w_{ref}(n-1) + sign(\Delta P) sign(\Delta w) w_{step}$$

where: if $x \geqslant 0$,$sign(x) = 1$; if $x < 0$,$sign(x) = -1$. Repeating the appeal process: change generator speed, until the unit output power is no longer sensitive to system parameter.

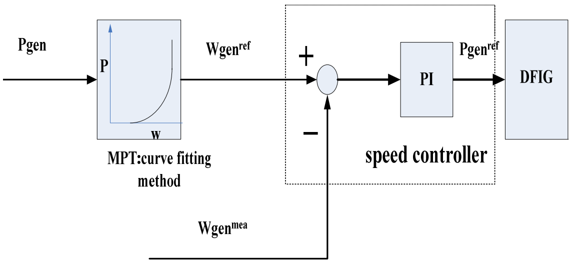

Figure 2. MPT and Speed controller model structure.

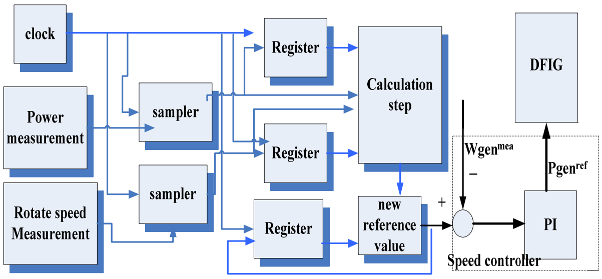

Figure 3. hill climbing algorithm structure diagram.

If power change is zero, the system has achieved the current wind speed of the maximum power point.

3.2. Example Comparison

1) The MPPT condition in constant wind speed 13 m/s, the comparison of two MPPT results:

Conclusion: The coordinate system in the above two graphs ranges from 0.8984 to 0.8992. Results can be seen that the precision of the two methods has met the requirements, because the interval range retains 3 digits after the decimal point. In the curve fitting method, output power reference still presents approximate linear increase in a very small range; while in the hill climbing algorithm, the reference presents slight fluctuations. It is obvious that the wave output in the hill climbing algorithm is more stable, making the active output of wind turbine followed active power reference more stable, which solve the problem that power is output fast and smoothly in the stable wind speed condition.

2) The MPPT condition: 0 s -17 s wind speed keeps 10 m/s, 17 s wind speed jump to 15 m/s, the comparison of two MPPT results:

Conclusion: Large changes in wind speed, hill climbing algorithms fluctuations are much larger than the curve fitting method from the **Figure 6** and **Figure 7**. At

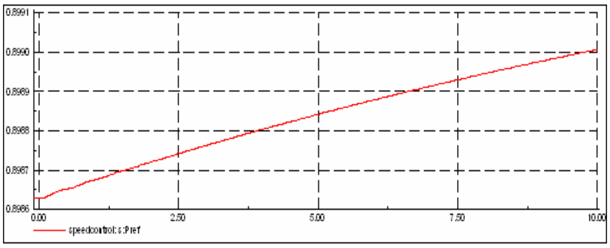

Figure 4. Pref value output by curve fitting method.

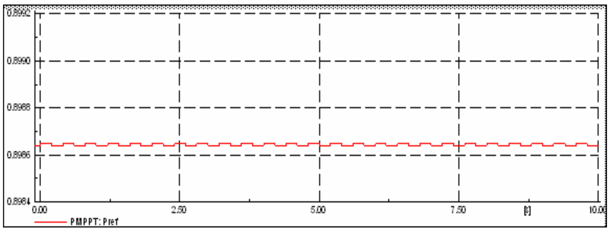

Figure 5. Pref value output by hill climbing algorithm.

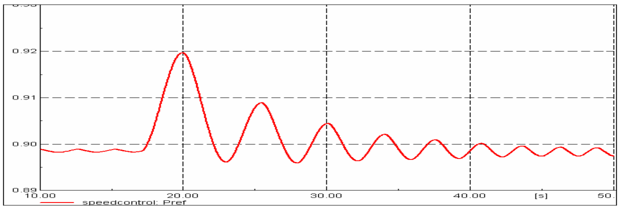

Figure 6. Pref value output by curve fitting method.

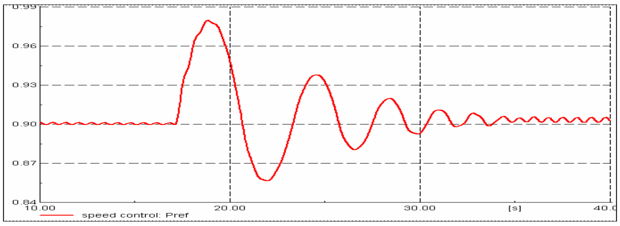

Figure 7. Pref value output by hill climbing algorithm.

17 s, the wind speed suddenly increases. In the hill climbing algorithm, the output power reference value fluctuations from 0.9p.u. to 0.975 p.u., however, in the curve fitting method, the output reference value just fluctuations from 0.899p.u. to 0.92 p.u.. But, in the hill climbing algorithm, over time is short, and it takes approximately 30 seconds to reaches a steady state, while in the curve fitting method it's about 40 seconds to reach a steady state. So it can be concluded that the constant step hill climbing algorithm applies winds less volatile condition, and the wind turbine of the inertia can not be too large, otherwise not timely tracking to the best power point.

4. Reactive Compensation

In the short circuit fault process, the wind generator will trigger rotor protection, which will make the wind generator asynchronous running in a short time. Thus, the continuous wind generator running need to absorb a large amount of reactive power, which can reduce the grid stability and the power factor of system, and in addition, the increase of line loss. Therefore, reactive compensation will have a great practical significance of improving the steady-state and dynamic performance of wind power generation system. This paper will make brief introduction and analog simulation of the control of two reactive compensation devices SVC and STATCOM which are widely applied.

4.1. STATCOM

The STATCOM's basic principle is the self-commutated bridge circuit that is connected with capacitor, through resistance and reactance or direct connects to the grid. According to the DC voltage of the capacitance and AC voltage of the access point, properly adjust the amplitude and phase of the AC output voltage of the bridge circuit to make absorption or generation reactive current of the circuit meet the system requirements, thus achieve the purpose of dynamic reactive power compensation.

As **Figure 8** shown, observing the amplitude and the phase of the AC voltage signal of the STATCOM connected bus. The amplitude difference with the set reference value, differences through the PI control become the signal which can control the PWM, but firstly the signal need connect to a limiter, then input to the PWM. At the same time, the phase angle of the phase-locked loop measurements that is use to make modulation wave synchronized with the system. Both of them control PWM, so that the phase of the PWM output modulated wave change to Trigger fully controlled devices (GTO/IGBT) which is in each leg of the three-phase inverter bridge off or on. So the AC side of STATCOM changes its reactive current to follow the command current I_{ref}.

4.2. SVC (Static Var Compensator)

The SVC system is a combination of a shunt capacitor bank and a thyristor controlled shunt reactance (TCR). The capacitors in the capacitor bank could be switched with thyristors (TSC) or could be permanently connected (MSC). Through TSC, reactive power compensation is into reasonable classification, get a hierarchical reactive power change. In addition, TCR can absorb continuous reactive power. If absorbing the whole reactive power is needed, disconnect all TSCs. For coordinated control TSC and TCR, the system can get continuous reactive power output.

As **Figure 9** shown, The SVC bus is installed voltage measurement, the measuring voltage is in turn sent to Lead lag correction link、Proportional lead lag correction link and inertial element, through the selector comparison with output results of a comparator, select one to input to the SVC interface and output the firing angle which can open or close the TCR and signal to control the number of TSC. In DIgSLIENT, we need to set out

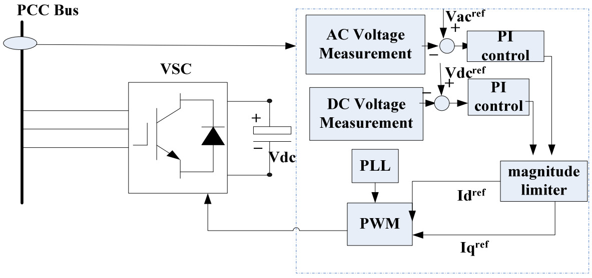

Figure 8. STATCOM control block diagram.

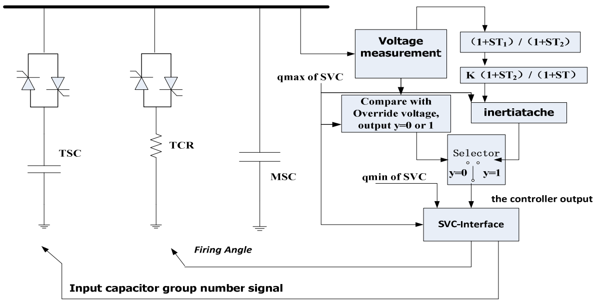

Figure 9. SVC control block diagram.

the minimum and maximum reactive power and control mode of the Static Var Components system separately.

4.3. Example

Using DIgSLIENT simulation, Wake effect between the various units of the wind farm is not considered in the simulation, and the assumption that wind conditions which is loaded into each wind turbine is same, so that 10 wind driven generations can be equivalent to 1. In wind farms, wind turbines whose rated voltage are 690 V, through the terminal transformer step up to 10 kV, and then connect to the Low voltage bus of wind farm, through the 1 km transmission lines to wind farms booster station and stepped up to 110 kV, finally using 20 km transmission cable connect to the external power grid, as shown below:

As shown in **Figure 10**, wind farms 10 kV low voltage bus respectively access the same capacity of the two kinds of reactive power compensation equipment, but separate simulation run. In a condition of given wind speed of 13 m/s, the short-circuit fault occurs in the middle of the transmission line which is on the second booster station 110 kV side, and set the fault type three-phase short-circuit fault: voltage drops to 0.39 p.u., fault starts at 5 s, continued 100ms till the fault is cleared, this paper mainly observes the bus voltage, reactive power compensation equipment issued and compares and analyzes the results.

1) STATCOM reactive power compensation (**Figures 11**,**12**)

2) SVC reactive power compensation (**Figures 13**,**14**)

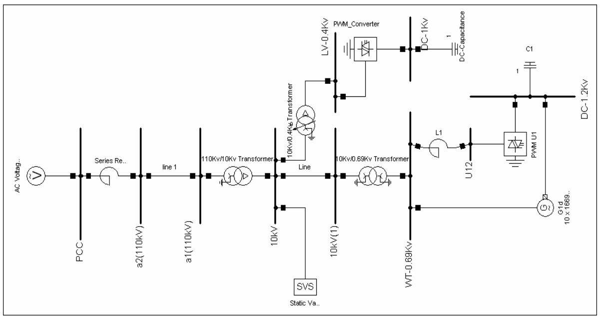

Figure 10. Single-line schematic diagram of the system.

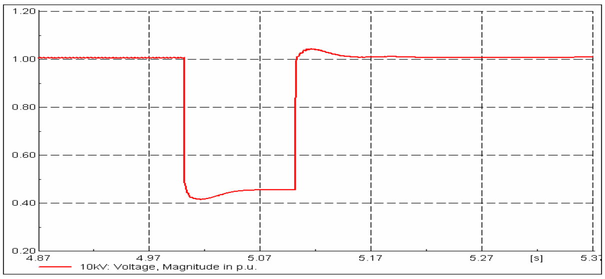

Figure 11. bus bar voltage waveform after compensation.

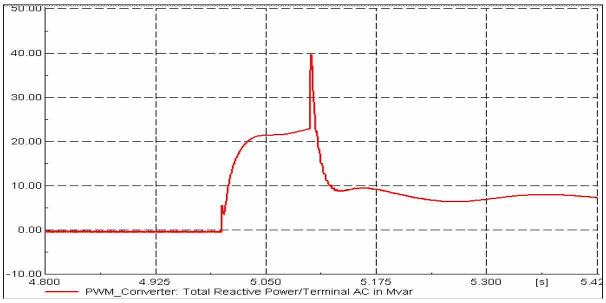

Figure 12. Reactive power of compensation.

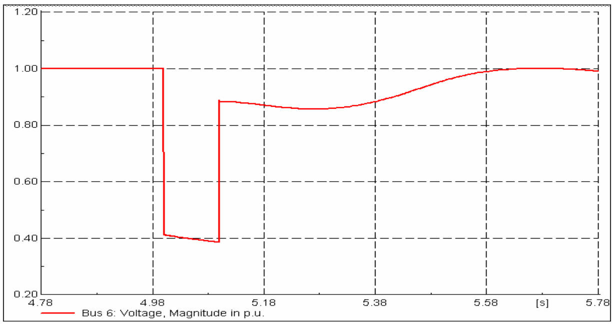

Figure 13. Bus bar voltage waveform after compensation.

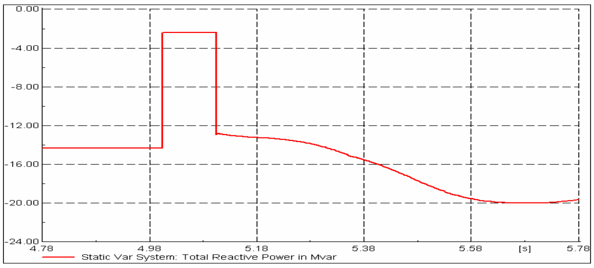

Figure 14. Reactive compensation(amount in absolute value).

The results of simulation analysis:

1) Compared with without compensation equipment situation, during the fault，STATCOM improves the voltage from 0.39 p.u. to 0.503 p.u., and generates a large amount of reactive power about 20 Mvar. In the fault clearing time 5.2 s, reactive power has a great impact, because the voltage recovery needs a lot of reactive power. STATCOM dynamic compensation prevent the wind driven generator which run as a asynchronous generator due to the low voltage protection action, absorption power grid more reactive power and make the voltage stability variation.

2) SVC output reactive power is proportional to the square of the connected bus voltage. Therefore, during the fault, bus bar voltage reduction makes SVC compensating reactive power reduction, Voltage is just raised from 0.39 p.u. to 0.403 p.u. Once the fault clearance, SVC will improve the compensation capacity from 14.35 Mvar rise to about 20 Mvar, so as to help the system recovery voltage.

3) From the chart, we know that SVC and STATCOM can control reactive power, effectively maintain system voltage stability, improve the system power factor, etc. In contrast, STATCOM has obvious advantages: STATCOM compensation effect is better, more amount of compensation and Since the SVC is group for cut, after fault clearance, longer time is need to compensating reactive power. But the control of STATCOM is more complicated, and the cost of the frequency converter is higher.

5. Conclusions

This paper finishes two parts on the DigSILENT:

1) It sets up two kinds of methods for the MPT modeling simulation: the curve fitting method and hill climbing algorithm, and improves the hill climbing algorithm control, the conclusion is: output in the hill climbing algorithm is more stable and converges faster so that the hill climbing algorithm is better than the curve fitting method.

2) It sets up the SVC and STATCOM modeling simulation, compare and analyze these two kinds of equipment in the power grid fault cases, and the dynamic response of STATCOM compensation capacity is bigger, the effect is more apparent.

This conclusion has certain reference and guidance for practical engineering application.

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