Improvement of Transient Voltage Stability of the Wind Farm using SVC and TCSC

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***Abstract*-Static var compensator (SVC) and thyristor controlled series compensator (TCSC) are used to improve Transient Voltage Stability of the asynchronous wind farm in this paper. The related structure model of the wind farm power system is built in Matlab / Simulink. The contributions of SVC and TCSC to Transient Voltage Stability of the asynchronous wind farm and power grid are verified by the simulation. The result shows that: when the wind speed is in random fluctuation, SVC can offer reactive power to maintain the transient stability, in addition, when three-phase short circuit happens in the wind farm integrated place of power grid, TCSC can promote the terminal voltage, and improve the low voltage ride-through capability effectively.**

Keywords-SVC; TCSC; wind farm; low voltage ride-through; transient voltage stability

I. INTRODUCTION

With the increase of energy prices in recent years, smart grid becomes one of the develop objectives of power system in the future. A series of problems caused by the popularity of smart grid become the focus of the investigations [1-2].

Wind power is important distributed renewable energy resources. However, voltage stability issues with wind farms may require such systems to be augmented with reactive power compensation devices [3]. Improving the voltage stability using the SMES technology is proposed by reference [4]; Solving the problem of wind farm integration by installing the SVC or STATCOM proposed by reference [5-6]. The development of wind power technology could face the risk of being stopped if measures are not taken to ensure the stability and reliability of the power system[7]. Low Voltage Ride Through (LVRT) has emerged as a new requirement that system operators demand to wind turbines.

Reference [8] verified the effects of TCSC and SVC to improve transient stability of a typical high-voltage and long-distance AC transmission system. Reference [9] analyzed the influences of SVC and TCSC on preventing voltage collapse. However, there is no relevant literatures proposed improving the transient voltage stability of wind power with the combination of SVC and TCSC. The influences of SVC and TCSC on improving the low voltage ride through (LVRT) capability are verified in this paper.

II. THE TRANSIENT VOLTAGE STABILITY OF ASYNCHRONOUS WIND FARM

Asynchronous generator is different with syschronous generator. The asyschronous generator need to energized only through external power source for it has not energizing circuit.The electromagnetic torque (*Te*) of induction generator is proportion to the square of terminal voltage at the fixed speed[10].

$$T_e = KsU^2 \tag{1}$$

Where *K*— constant;

s— generator slip.

The equation of rotor motion of asynchronous generator is shown in (2).

$$J\frac{d\omega}{dt} = T_m - T_e \tag{2}$$

Where *J*— moment of inertia;

Tm — mechanical torque;

ω — generator angular speed.

The electromagnetic torque (*Te*) of generator decreases with the terminal voltage drop during the grid fault, and the decreasing of electromagnetic torque leads rotor to sped. The generator need to absorb reactive power in order to restore the electromagnetic field when the fault is cleared, and this will bring out the voltage reduces further.

Therefore, improving the terminal voltage by compensating dynamically the reactive power using SVC and restraining the fault current by changing the line reactance using TCSC are proposed in this paper.

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III. The Fundament of Improving Transient Voltage Stability with SVC and TCSC

A. Configuration and Characteristics of SVC

The SVC is composed of thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC). TSC are switched in groups, TCR is controled smoothly by thyristor. By dynamically changing the reactive power that is exported by SVC, the bus voltage which is connected to SVC is controlled[11]. The structure of the SVC is shown in Fig.1.

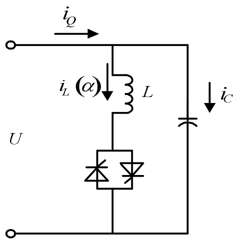


Figure 1. Diagram of SVC

The equivalent susceptance can be described as (3).

$$B(\alpha)=B_L(\alpha)-B_C=\frac{2\pi-2\alpha-\sin 2\alpha}{\pi\omega L}-B_C \qquad (3)$$

Where α — thyristor trigger angle;

L— inductance;

ω — fundamental angular frequency.

In (3), the equivalent susceptance is the continuous function of the thyristor trigger angle(α). By controlling the trigger angle, the total equivalent susceptance will be changed continuously. The controller of SVC is shown as Fig.2[12].

The SVC can give a compensation of reactive power by induction generator. It monitors the bus voltage and changes the equivalence susceptance of TCR by controlling the thyristor trigger angle.

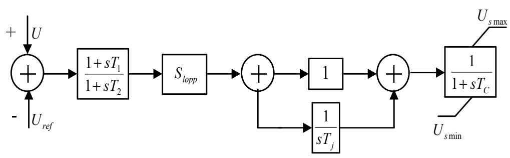


Figure 2. Controller diagram of SVC

B. Configuration and Characteristics of TCSC

The basic configuration of the TCSC is shown in Fig.3. It is mainly constituted by four parts: series compensating capacitor (C), bypass inductor (L), bi-direction thyristor SCR and zinc oxide voltage limiter MOV. The degree of TCSC basic compensation is controlled by the capacity size of capacitor[13].

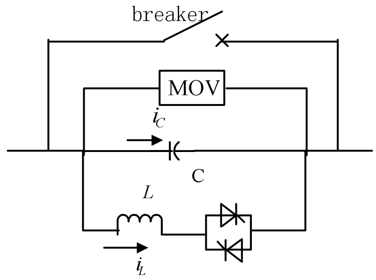


Figure 3. Diagram of TCSC

The fundamental equivalent impedance can be described as (4).

$$\begin{aligned}X_{TCSC}(\alpha)=&\frac{1}{\omega C}-\frac{A}{\pi\omega C}\\&[2(\pi-\alpha)+\sin(2(\pi-\alpha))]\\&+\frac{4A\cos^2(\pi-\alpha)}{\pi\omega C(k^2-1)}\\&[(k\times\tan(k\pi-k\alpha)-\tan(\pi-\alpha))]\end{aligned} \qquad (4)$$

Where

$$A=\frac{{\omega_0}^2}{{\omega_0}^2-\omega^2},\quad {\omega_0}^2=\frac{1}{LC},\quad k=\frac{\omega_0}{\omega}$$

In (4), the equivalent impedance (X_{TCSC})is the continuous function of the thyristor trigger angle(α). By controlling the trigger angle, the total equivalent impedance will be changed continuously.

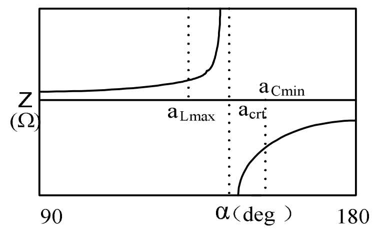


Figure 4. Operating characteristic curve of TCSC

Fig.4 shows the operating characteristic curve of TCSC. When $\alpha_{crt}\le\alpha\le 180^0$, the equivalent impedence of TCSC is appeared as capacitance; When $90^0\le\alpha\le\alpha_{crt}$, the equivalent impedence of TCSC is appeared as inductance[14].

In normal operating conditions, there are three modes of operation: blocking mode, bypass mode, continuous boost mode.When the thyristor valve is not triggered and the thyristors are kept in non-conducting state, the TCSC is operating in blocking mode, the TCSC performs like a fixed series capacitor. In bypass mode the thyristor valve is triggered continuously and the valve stays conducting all the time; So the TCSC behaves like a parallel connection of the capacitor with the inductor, in the thyristor valve branch. In the continuous boost mode, the TCSC can operate in capacitive or inductive mode, the latter is rarely used in practice.

In this paper, the control strategy is as follows: the TCSC is operating in bypass mode during grid fault, it behaves like a small inductive reactance at this time, for it can suppressor circuit current; After grid fault, TCSC can improves the bus voltage and the transient voltage stability of power system.

IV. SIMULATION AND ANALYSIS

A. *Modeling of Simulation*

The simulation is based on the system that is shown in Fig.5. The gross installed capacity of wind power is 9MW. The wind farm contains three wind turbines, the output active power of each wind turbine is 3MW, and each wind turbine is equipped with capacitor bank in order to reactive power compensation. The transformer of the unit alter the voltage to 25KV after 1km transmission line, and 25km transmission line to substation, and the voltage is changed to 120KV before entering the grid.

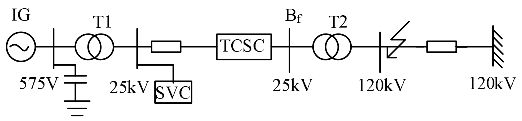


Figure 5. Diagram of the studied system

Fault settings: when t=2s, the three-phase short circuit fault happened at the 120kV line, and be cleared after 0.1s; The wind speed ranging from 8m/s to 11m/s in the 0~1.1s. The installation site of SVC and TCSC is shown in Fig.5.

B. *Analysis of Resulting*

In order to analysis the effect of improving transient voltage stability with SVC and TCSC, two different cases are analyzed, and the description of each case is provided in the following.

- SVC

The simulation result is shown in Fig.6. During 0~1.1s,the wind speed ranging form 8m/s to 11m/s, so the wind farm generated active power increasing smoothly, while the absorbed reactive power increases as the generated active power increase, the terminal voltage of wind turbine decreased; When the SVC is installed in the system, the voltage of the wind farm can remain the rating.

When t=2s, the grid side has a fault, the terminal voltage continued to decline and couldn't recover until the protection of the wind turbine tripped; When the SVC is installed in the system, the falling of the voltage can be suppressed effectively, but it can't recover.

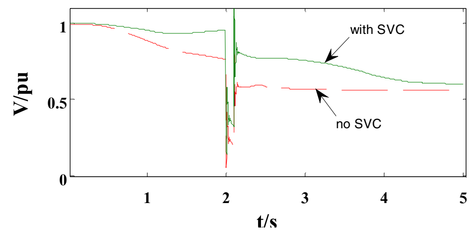
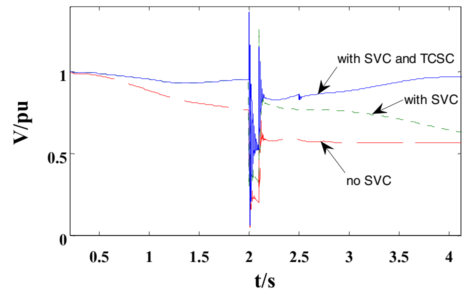


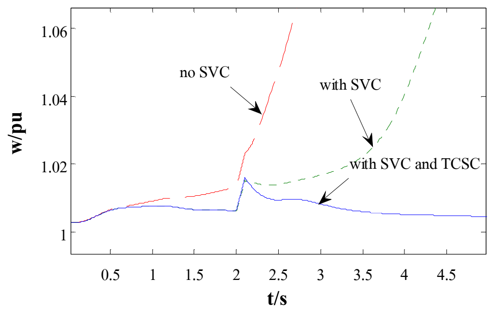
Figure 6. Terminal voltage with and without SVC compensate

- SVC and TCSC

The simulation result is shown in Fig.7. When the SVC is applied alone, the terminal voltage can't recover to 1pu, and the rotor speed increases continuously until the voltage of wind farm become unstability. When the SVC and TCSC are installed combinedly, the terminal voltage is promoted during the three-phase short circuit fault, and improves the capability of LVRT; After the fault, the terminal voltage can recover rapidly to the rating, and the rotor speed can recover to stability mode after about 1.5s.



(a) The genegrator terminal voltage



(b) The genegrator speed

Figure 7. Effect of SVC and TCSC compensate when three-phase fault happens at 120kV line

V. CONCLUSION

1) SVC has a significant contribution to the transient voltage stability of wind power system. When the wind speed changed dramatically, SVC can maintain the terminal voltage and ensure the system running continuously.

2) TCSC is effective in enhancing the transient stability of wind power system. With the TCSC, the fault current is limited effectively while the voltage stability is also improved, then the terminal voltage is raised to the rating after the fault is cleared.

3) Simulation analysis verified the effectiveness of improving the transient voltage stability of wind power system with the combination of the TCSC and the SVC. The control scheme can maintain the stability of system at the severe three-phase short circuit fault in the condition of maximum transmission power.

4) TCSC is used to increase the power transfer capability, improve the transient stability of system, and damp low-frequency oscillations. In this paper, other effects of TCSC are not considered, so the study should be improved in the future.

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