A Novel on Coordinated Voltage Control Scheme for SEIG-Based Wind Park Utilizing Substation Statcom and ULTC Transformer

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Received: 7 February 2012 Accepted: 29 February 2012 Published: 15 March 2012

Abstract

This paper presents a coordinated voltage control scheme for improving the network voltage profile and for minimizing the steady-state loading of the STATCOM to effectively support the system during contingencies. The paper addresses implementation issues associated with primary voltage control and optimal tracking secondary voltage control for wind parks based on self-excited induction generators which comprise STATCOM and under-load tap changer (ULTC) substation transformers. The voltage controllers for the STATCOM and ULTC transformer are coordinated and ensure the voltage support.

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Index Terms : Communication time delay, optimal tracking secondary voltage control (OTSVC), primary voltage control (PVC), short circuit ratios (SCRs), STATCOM, transient stability margin, under-load tap changer (ULTC).

1 SEIG self-excited induction generator ULTC under-load tap changer LDC line drop compensation PVC primary voltage control MCCT maximum critical clearing time FRT

fault ride through WAMS wide-area measurement system OTSVC optimal tracking secondary voltage Control oltage control is important for the integration of wind parks and their interconnections to achieve a required voltage response and fault ride through (FRT) capability according to the grid codes. The voltage control is divided into three hierarchical levels: primary, secondary, and tertiary control [1]- [4]. The large penetration of wind parks based on self-excited induction generator (SEIG) is often comprised of a central compensator, a STATCOM that controls the voltage by means of reactive power, and also underload tap changing (ULTC) transformers are used to control the voltage. This makes the application of secondary voltage control schemes to wind parks an interesting approach to improve the operation of the transmission system. Hence, a strategy to perform secondary voltage control by a coordinated use of the ULTC and STATCOM for providing a better voltage support and a larger dynamic margin during system contingencies are needed. Coordinated control methods for ULTCs and compensator devices are proposed in [5].

The ULTC provides a slow voltage control and the tap changing causes transient responses in the power system. Thus, the objective of the coordinated control of the ULTCs and a compensating device is to minimize the number of unnecessary tap operations and to provide a better voltage profile. In [5] and [6], an artificial neural network is used in the coordinated control of the ULTC and STATCOM to minimize the number of tap changes and for increasing the reactive power capability margin of the STATCOM in system contingency situations. Among voltage regulating devices, the ULTC has a larger impact on the voltage profile since it controls the sending voltage. One of the major measures of the ULTC operation is the line drop compensation (LDC) method, which estimates and allows compensation for the line drop at varying load currents [7], [8]. The LDC method has been widely applied to the ULTC operation. This paper presents a new approach to a coordinated voltage control for the STATCOM and the ULTC transformer. Using this control the STATCOM will be unloaded and ready to react with a higher reactive power margin in case of system contingencies. The performance of primary voltage control (PVC) and optimal tracking secondary voltage control (OTSVC) with and without the new coordinated method used by the STATCOM and the ULTC are compared considering steady-state and dynamic measures such as voltage response, voltage recovery, The wind park model analyzed in this paper is shown in Fig. 1 and consists of 12*1.5-MW SEIG wind turbines compensated with a STATCOM. The wind turbines are connected to the medium voltage bus via a 0.575/25-kV transformer, and then connected to the 120-kV system at bus B120 through a25-MVA 25/120-kV ULTC transformer. The reactive power absorbed by the SEIG is partly compensated by capacitor banks connected to each wind turbine, the rest of the compensation Fig. 1 : Layout of the wind park model. to maintain the bus voltage close to 1 p.u. is provided by the centralized STATCOM rated at 12 MVAr with a 3% droop setting. The control consists of a local wind park control that communicates with the transmission system through a communication link, which is used to transmit data signals obtained from a wide-area measurement system (WAMS). a) Self Excited Induction Generator Model For the SEIG in Fig. 1, a dynamic model in the stationary -reference frame as described in [9] is used.

2 b) Under Load Tap Changer Model

The control scheme for the ULTC transformer is based on the tap-changing device and a motor drive to move the taps in a controlled sequence of steps with a constant time delay shorter than 10 s. The system performs secondary voltage control when the voltage exceeds the specified dead band within the specified time delay [1]. The discrete equations of the ULTC control system are as follows: n(t+1)=n(t)-d*f(e(t);T(t))

(1) T(T+1)=g(e(t);T(t))

(2)

F(e,T)={1 , IF e> (3) e=V-Vref (4) where is the tap position of the ULTC, is the step size of the tap position, is the voltage error, is the time delay, is the controlled voltage, is the threshold of dead band, is the counter, and is the reference voltage. Equations (??)-(??) state that each tap position varies with step size of the tap position at time , when the voltage deviates from the specified dead band during the specified time delay.

3 c) Statcom Model

The STATCOM is used to generate or absorb reactive power by controlling the magnitude of the dc link and ac voltage while keeping the angle very small to allow active power flow to compensate solid state switching and coupling transformer losses. The active and reactive powers in the mathematical model of the STATCOM are described in [10]. The current is decoupled in two control loops, controlling the direct and the quadrature current, for controlling the active power and the reactive power exchange between the converter and the ac-system, respectively. The output of the current regulators are the voltage signals and , which are added to the feed forward signals of the Park Transformed three phase terminal voltages. To achieve higher performance, the voltage drops across the converter inductors are also added to the controlling voltage signals. PVC or OTSVC will be alternatively employed as the outer control loops of the STATCOM to determine the reference quadrature STATCOM current. The determined direct and quadrature-controlling voltages are finally transformed from the -reference frame to three phase voltages, which are used directly to control the controllable voltage sources. The local control PVC is not affected by the communication delays as it is normally less than 10 ms and often ignored in controller design and stability analysis of the power system [11]. The experimental research presented in [11] has characterized the time delays associated with different communication links. All communication delays are higher than 100ms, the satellite link showing the highest time delay. This delay can be higher than 700 ms when a large number of signals are to be routed and remote signals from different areas are waiting for synchronization [11], [12]. Much smaller delays have been reported for fiber-optics links, typically in the order of 38 ms for one way, while the time delay for using modems via microwave is over 80 ms.

4 Global Journal of Researches in Engineering

5 b) Voltage Control Schemes

PVC is the basic approach for the voltage regulation of the high voltage bus to which the wind farm is connected. Besides the normal voltage control based on voltage and current measurements for enhancing the wind park performance, the STATCOM controller here is extended with auxiliary damping control loops, based on rotor speed deviation and active power variation measurements. The two loops are structured based on an analytical approach for synchronizing power and damping power. A lead-lag control structure is chosen for the two loops. A more detailed description of the damping control loops are given in ??18]. Hence, in order to increase the system damping, it is necessary to add additional control blocks with adequate input signals.

6 i. Primary Voltage Control

There are two damping control loops specified based on the rotor speed deviation and the variation of active power in a specified time interval as shown in EL ??), but with parameters adaptable in accordance with the evolution of the system variables. Once the injected friction function is selected, the expression of the control law is designed using (7) based on the control mode. The STATCOM is controlling the bus terminal voltage , thus the control law is (7) The damping loops utilize the integral time absolute error of the rotor speed and the active power. They are set by the following objective functions: The rotor speed deviation. The active power deviation in a specified time interval. The target is to minimize the objective functions in order to improve the system response. Therefore, adopting the parameters of the control loops should be tuned to achieve an appreciated system response. The damping control loops consist of a gain block, a signal washout block, and a two-stage phase compensation blocks. It is preferable that the additional control signal is local to avoid the impact of communication time delay. The damping signal is fed through a washout control block to avoid affecting the steady-state operation, and an additional lead-lag control block is used to improve the dynamic system response. The washout block performs as a high-pass filter which allows signals associated with oscillations to pass unchanged. The STATCOM with the damping control loops is tested while the system shown in Fig. 1 is subjected to three phase faults at PCC at s and cleared after 200 ms. The damping control loops demonstrate superior performance for damping system oscillation .

7 ii. Optimal Tracking Secondary Voltage Control

In order to address some of the shortcomings of line drop compensation, OTSVC is proposed [13]- ??17]. By this method all the voltages at the major load buses are considered, and the control algorithm, shown in controls the voltages at all buses in an optimal way by minimizing the voltage deviation from nominal 1.0 p.u. considering a maximum operating voltage of the wind park to be 1. First some steady-state simulation results using the OTSVC control strategy are presented. The wind park comprises six WTGs which are simulated at different system strength of SCRs, and the voltage profiles are compared with alternatively employing PVC and OTSVC The performance of the OTSVC strategy demonstrates better performance than the PVC in improving the network voltage profile. One disadvantage of using the OTSVC is, however, that the line currents increase since the reactive power compensation increases, and this would also increase the line losses. Further, we can note that the reactive power consumed by the wind park is inversely proportional to the SCR, due to the larger system impedance. b) Steady-State Operation With Coordination of STATCOM and ULTC Then the coordination of the STATCOM and the ULTC transformer under steady-state is examined using either PVC or OTSVC. The simulations are performed using periodic load data, as shown in Fig. **??**. This simulation case assumes that the load level varies from 50% to 250%. The simulation is carried out with 12 WTG connected at SCR shows how the STATCOM reactive power changes with the load, and it is noted that the STATCOM reactive power is much higher when the transformer tap is fixed and PVC is applied compared to when employing coordinated PVC or OTSVC. The loading of the STATCOM is reduced to nearly 50% at and in 252 IEEE TRANSACTIONS. The voltage control without the coordination of the STATCOM and the ULTC is not sufficient for controlling the bus-voltages due to the time response of the systems. The STATCOM normally reacts to a voltage deviation in a few milliseconds whereas the ULTC take some seconds to react. Consequently, the STATCOM may go to its limit in the steady-state voltage deviation and there by loose its primary function, The coordination is done by using the following settings: 1) The STATCOM reference voltage is set to be equal to the calculated ULTC reference voltage based on either PVC or OTSVC voltage control. 2) The dead band of the ULTC has to be known and the ULTC should operate when the controller voltage exceeds the ULTC dead band. The STATCOM react continuously due to the ULTC time delay for doing the tap changes.

3) The measured voltage signal to the ULTC are filtered an LPF with a time constant equal to 10 s to allow the STATCOM to react instantaneously to support the system for voltage deviations exceeding the dead band of the ULTC. steady-state operation so it is able to react with a higher reactive power margin at contingency situations. shows the improvement of the voltage profile in the whole network grid when applying the coordinated OTSVC.

8 c) Variation of Wind Speeds

The system is then simulated changing the wind speed for four wind turbines from 7 to 11 m/s. The measurements of the active power generation of the wind park and the loading of the STATCOM are undertaken to examine the performance of the coordinating controllers with changes of wind park load 3 is increased by 100%. Again the system is controlled to ensure that the deviation of the voltages at all grid busses with reference to the voltage 1 p.u. is kept at a minimum. Again the OTSVC shows the best performance with regard to the voltage profile, but also to ensure that the loading of the STATCOM is less than for the other control methods (see Figs. 11 and 12). In this case, the maximum regulation margin was selected to bus B3_120, which was 0.06 p.u. in this case e) Performance Following Disturbances Then the performance of the OTSVC compared to the PVC following a disturbance in the form of a three phase to ground fault at bus B3_120 with duration of 150 ms is analyzed. The performance is analyzed both with and without the coordinated control between the STATCOM and the ULTC transformer. The assumed time delay associated with the OTSVC is set to 100 ms (corresponding to a fiber-optic solution) for the first simulations and the SCR of the system is set to 5 (simulations have shown that for a short circuit less than 4 the system never recovers). The SCR influence the system in two ways: The voltage drop along the lines is larger for weaker connections, and the recovery time is larger. The initial voltage drop is dependent of the impedances between the voltage source and the impedance to the point of measurement and the fault location. For smaller SCR, the initial voltage drop is lower, since the wind park is electrically further away from the faulted bus and the load bus. As the wind park is moved further away from the load bus, the ability to aid the voltage recovery is reduced, due to the higher reactive power requirements of the line. In the analysis important measures such as the voltage dip, the voltage response, the reactive power reserve from the STATCOM, and the maximum critical clearing time (MCCT) of the fault are examined, since these can be used as indicators for the transient stability margin. the voltage at PCC is shown for the four control cases, and it is seen that the PVC without coordinated control of the STATCOM and the ULTC fails to control the system to recover after the fault. The three other control methods control the system in a way so the systems recover. The reactive power flow at the PCC and the reactive power supplied from the STATCOM is shown in Fig. 14 **??**II at a constant time delay for the OTSVC at 0.1 s. The results show again the better performance when using the coordinated control, the coordinated OTSVC with the best performance. In Table **??**V, the influence of the time delay of the communication system is shown for the network grid with different SCR. It is seen that an increased time delay has a negative impact on the voltage recovery. At the 700-ms delay for the OTSVC, the PVC is initially dominant, and only after the voltage has nearly completely recovered the OTSVC signal causes some small deviations around the reference value as shown in . This suggests that a decoupling of the two modes would be favorable for mitigation of this impact as shown in . This is most easily accomplished by inserting a low pass filter on secondary control signal, and in this way decouple the PVC from the OTSVC. Alternatively, a reduced bandwidth of the secondary control could be used. The coordinated voltage control controls the ULTC transformer steps to maximize the capacity margin of the STATCOM and in this way the capacity dynamic margin is increased with up to 70% during system contingency situations and at the same time the number of tap-changes is minimized. The coordinated control for both PVC and OTSVC shows better performance for improving the voltage profile in steadystate conditions, for minimizing voltage dips, improving the voltage recovery after faults, and increasing the MCCT, with the coordinated OTSVC having the best performance of them all. Different SCRs and time delays of the OTSVC influence the performance of the controller and also the transient stability margin. However, only at a delay ofs more than 700 ms, the system response becomes unacceptable, and it should be possible to make the control system with a shorter delay or accomplished by inserting a low pass filter on the secondary control signal and in this way decouple the PVC from the OTSVC. Alternatively, a reduced bandwidth of the secondary control could be used. [1]

Figure 1:

1 I.

Figure 2: 1)

I

Figure 3: Volume

[illegible]TRODUCTION

Figure 4:

[illegible]

Figure 5:

II.

Figure 6:

S

Figure 7:

IG

Figure 8:

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