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Frequency Monitoring of Power Systems with Off-Shore Wind Generation Using VSC-HVDC

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ABSTRACT: With the increasing wind penetration, large-scale offshore wind farms exert significant impact on power system security and operation, and thus are required to contribute to system frequency regulation. This paper develops a coordinated control strategy for offshore wind farms with voltage source converter-based HVDC (VSC-HVDC) transmission system to participate in power system frequency regulation. The strategy explores the frequency support capability of offshore wind farms and VSC-HVDC. By implementing the proposed coordinated control, the VSCHVDC link is able to provide quick virtual inertial response to onshore grid frequency drops. Shortly afterwards, the offshore wind farm detects the frequency changes and start to participate in inertial response and primary frequency control. By means of this approach, the dc capacitors of VSC-HVdc are controlled to absorb or release energy so as to provide frequency support. To further enhance the system frequency response, the frequency support from VSC-HVdc is also finely coordinated with that from offshore wind farm according to the latency of offshore wind farm responding to onshore grid frequency excursion. The control scheme is evaluated for both under frequency and over frequency events, and results are presented to demonstrate its effectiveness.

KEYWORDS: Frequency regulation, inertial response, offshore wind farm, primary frequency control, VSC -HVDC.

I. INTRODUCTION

Power system frequency stability refers to the ability of a power system to maintain stable frequency following a severe system upset resulting in a significant imbalance between generation and load. In the event of a sudden loss of a large power supply or a sudden increase in power demand, synchronous generators are able to extract kinetic energy (inertia response) and provide primary control reserve to stabilize the system frequency. As offshore wind farms are displacing conventional power plants, it is also necessary for wind turbines to contribute to frequency regulation like synchronous generators. Offshore wind farms, in general, consist of variable-speed wind turbines with power electronic converters. These turbines are naturally inertia-less due to the decoupling of converters and have no primary control reserve as the wind is not controllable, efforts have been made to allow the converter -interfaced wind turbines to inject their rotational kinetic energy into the grid during frequency deviation by converter controls. Energy reserve margin has also been achieved by operating the turbines away from their optimal points at the expense of less generation. To integrate large-scale offshore wind farms into the onshore power grid, VSC-HVDC transmission is more attractive and applicable compared to HVAC transmission system. For transferring the same amount of power, DC cables have lower losses and have no limitations in length owing to the immunity from charging current. VSC-HVDC also has other advantages such as fully controlled power flow and independent and rapid control of active and reactive power. However, offshore wind farms would not be directly affected by onshore system disturbances due to the decoupling of VSC-HVDC. The decoupling would prevent offshore wind farms from immediate responding to the frequency excursion of onshore AC network. As for offshore wind applications, the contribution of VSC-HVDC to power system frequency regulation was investigated. However, all these studies focused on developing artificial coupling methods between offshore and onshore networks using VSC-HVDC, but the VSC-HVDC itself did not participate in the actual frequency regulation. This study addresses the frequency regulation contribution of both VSC-HVDC transmission system and offshore wind farms. A new coordinated control strategy is developed which enables VSC -HVDC to participate in power system frequency regulation. In addition, under the proposed control, all offshore wind turbines would respond to the onshore frequency excursion timely. However, the electromechanical behavior of variable-speed wind turbines (VSWTs), which comprise modern OWFs, differs fundamentally from that of conventional synchronous generators (SGs). In the event of a sudden loss of a large power supply or a sudden increase in power demand, SGs are able to extract kinetic energy from their rotating masses (inertial response) to slow down the rate of change of frequency (ROCOF) at the very instant of the event. Soon after the disturbance, SGs will provide an additional power (primary control reserve) to stabilize the deviated frequency at a new steady-state level due to the droop setting of governors. In contrast, VSWTs that are interfaced with ac power grid via voltage source converters (VSCs) are naturally considered inertia-less to ac power systems and may have no primary control reserve as the wind is not controllable. Thus, the integration of large OWFs along with the decommissioning of conventional power plants is bound to reduce the system inertia and primary control reserve. Without countermeasures, this would put power system security at high risk. To solve this problem, ancillary frequency support schemes have been equipped to VSWTs for active power control. Control methods for converters were proposed to provide short-term frequency support by utilizing the rotational kinetic energy of VSWT’s generator. Large OWFs are probably far away from onshore connection point. To integrate a long-distance large-scale OWF into the onshore power grid, voltage-source converter-based–high voltage direct current (VSC-HVdc) transmission is more attractive and applicable compared to HVAC transmission system. For transferring the same amount of power, dc cables are smaller with lower losses and have no limitations in length owing to the immunity from charging current. VSC-HVdc transmission also has other advantages, such as fully controlled power flow, independent reactive power control at each ac end, and independently controlled active and reactive power. However, on one hand, OWFs would not be directly affected by onshore system disturbances due to the decoupling of VSC-HVdc. On the other hand, this decoupling would prevent OWFs from immediate responding to system disturbances of the onshore ac network. For a system frequency deviation, it is apparent that OWFs cannot provide immediate frequency support following the frequency transient due to communication delay. VSC-HVdc, which performs well on voltage support, does not generally respond to the frequency deviation. The participation of VSC-HVdc-connected OWFs in the system frequency regulation was investigated. However, all these studies focused only on developing artificial coupling methods between offshore and onshore networks using the VSC-HVdc link, but did not probe into the potential frequency support capability of VSC-HVdc itself.

II. RELATED WORK

WIND TURBINE MODEL

The general configuration and control scheme of the FCWT adopted in this paper is shown in Fig. 1. The generator-side converter controls the generator active power and maintains the generator stator voltage to its rated value. At the same time, the grid-side converter controls the DC-link voltage and the reactive power flow to the offshore AC grid. In the traditional control strategy, the active power reference Pref is only provided by a maximum power point tracking (MPPT) approach and the wind turbine generator will not respond to grid frequency deviation. However, to implement frequency support, an ancillary frequency control loop is applied to wind turbines as illustrated in Fig. 2

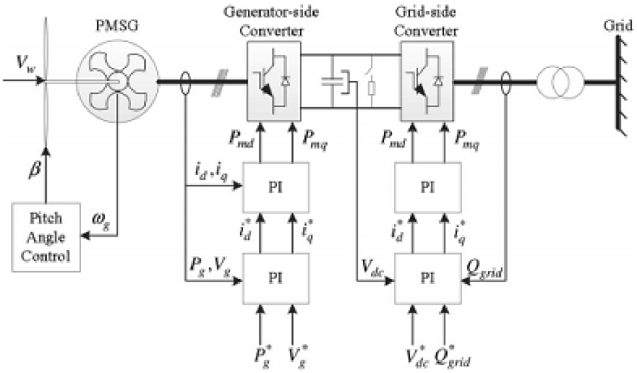


Fig. 1. Scheme of FCWT.

Ancillary control for frequency regulation

The ancillary frequency regulation control of the FCWT shown in Fig. 2 consists of two components. The component Piner is proportional to the derivative of the grid frequency, emulating the inertial response of a synchronous generator. The component Pprim is proportional to the absolute deviation of the grid frequency, emulating the primary frequency control of the governor of a conventional synchronous generator.

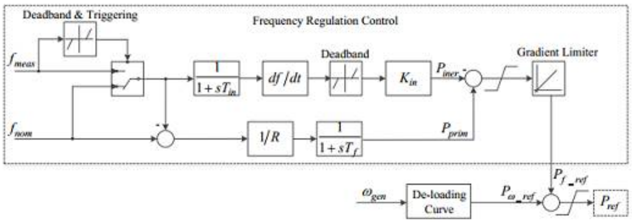


Fig. 2. Ancillary frequency control loop for FCWTs.

III. IMPLEMENTION

A. UNDER FREQUENCY EVENT

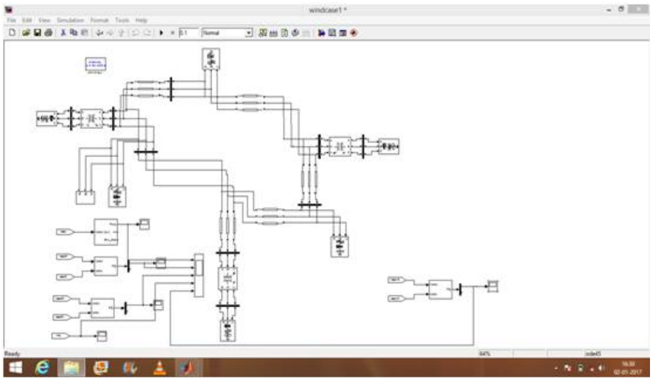
The frequency response of the ac power system is shown in Fig. 3(a). It is observed that the frequency support from the offshore wind farm makes up active power for the load increase and reduces the frequency drop significantly. The frequency is also stabilized much faster at a higher steady-state value compared to the case without offshore wind farm frequency support. Moreover, the participation of frequency support from VSC-HVdc improves the nadir frequency further. However, due to the latency of measurement and the VSC-HVdc communication, the initial ROCOF of the frequency decline is not ameliorated evidently though both offshore wind farm and VSC-HVdc provide frequency support. The offshore wind farm generation is shown in Fig. 3(b). It can be seen that if the ancillary frequency controller is not activated, the operation of FCWTs is not affected due to the decoupling of converters. In the cases that the frequency controller of FCWTs is activated, it can be observed that at the instant that the frequency drop is detected by the FCWTs, there is a sudden increase of the active power generation of the offshore wind farm as a result of the decrease of both turbine generator speed and pitch angle. The participation of VSC-HVdc in the frequency regulation does not exert evident influence on the generation of the OWF. Fig. 3(c) and (d) presents the response of VSC-HVdc for the load increase. It can be seen from curves of Case 2 that the onshore VSC increases its active power output[see Fig. 3(d)] as offshore wind farm starts to generate more power to support the frequency[see Fig 3(b)], while only offshore wind farm responds to the frequency decline. Accordingly, the dc voltage in Fig. 3(c) fluctuates a bit at the time that the active power output of the onshore VSC increases sharply and then maintains at the rated level again. When the ancillary frequency controller of VSC-HVdc is activated, the dc voltage is controlled to drop down to 0.9 p.u. quickly as shown in Fig. 3(c) to release part of the power stored in dc capacitance. In consequence, the onshore VSC is able to in feed more active power into the onshore grid to support the frequency as illustrated in Fig. 3(d). This coordinated frequency regulation of offshore wind farm and VSC-HVdc obtains better frequency response as mentioned above.

B. OVER FREQUENCY EVENT

A sudden decrease of Load C results in the frequency to be over the upper acceptable limit (50.2 Hz). The simulation results for the sudden load decrease scenario are shown in Fig. 4, while the communication delay of VSC-HVdc is also 300ms. The system frequency response is shown in Fig. 4(a). It can be seen that the frequency support provided only by the offshore wind farm does not improve the initial frequency dynamics but reduces the peak frequency and achieves significant enhancement on the frequency restoration. Comparably, the joint frequency support provided by both offshore wind farm and VSC-HVdc further lowers down the peak frequency more obviously. Fig. 4(b) presents the offshore wind farm generation regarding the given over frequency event. According to the reduction in the offshore wind farm generation is proportional to the over frequency deviation. As above mentioned, the VSC-HVdc support reduces the peak frequency. However, it, in turn covers the actual severity of the frequency variation to FCWTs and, thus, weakens the FCWTs' frequency support as the red curves illustrate in Fig. 4(a) and (b).

Fig. 4(c) and (d) presents the response of VSC-HVdc for the sudden load reduction. It can be observed from Fig. 4 that in the frequency-rising period, the dc voltage is controlled to increase to let the dc capacitors charge and absorb energy that slows down the ROCOF and reduces the absolute frequency deviation. After the offshore wind farm reduces its generation as a response to the over frequency as shown in Fig. 4(b), the dc voltage begins to drop[see Fig. 4(c)], and the dc capacitors then begin to discharge and release energy that impairs the frequency restoring. The charging and discharging of dc capacitance are reflected in the active power output of onshore VSC as shown in Fig. 4(d). The influence of the introduction of Kover on dc voltage and onshore VSC active power output are also clearly presented in Fig. 4(c) and (d), respectively.

Simulation Model



Simulation Results

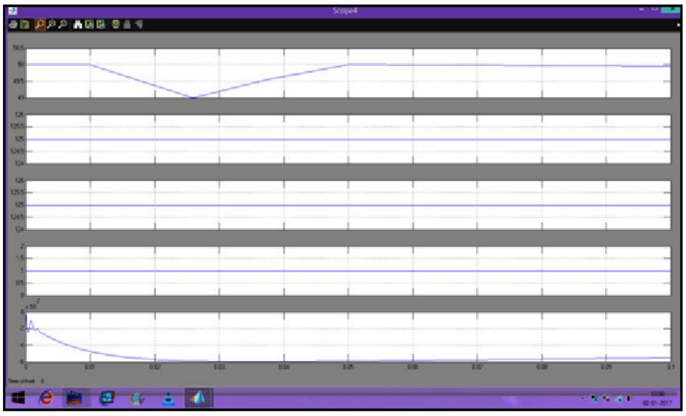


Fig. 3. System response for sudden load increase. (a) System frequency.(b) OWT active power. (c) HVdc dc-link voltage. (d) Onshore VSC active power. (e) Total spinning reserve of the grid.

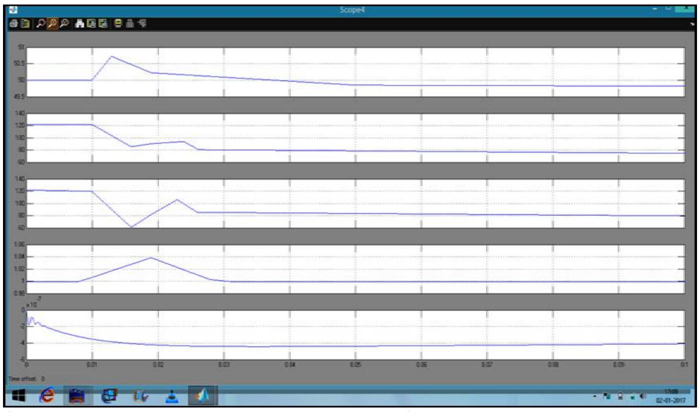


Fig. 4. System response for sudden load decrease. (a) System frequency. (b) OWT active power. (c) HVdc dc-link voltage. (d) Onshore VSC active power. (e) Total spinning reserve of the grid.

V. CONCLUSION

A new control strategy control technique is developed on this assignment to permit the VSC-HVdc transmission to make a contribution to the system frequency law without further funding. The ancillary frequency controller introduced to the offshore VSC simplifies frequency signal communicating and reduces the latency of offshore wind farm responding to the onshore grid frequency deviation. The ancillary frequency controller brought to the onshore VSC makes use of the dc capacitor banks to release/absorb energy through adjusting its voltage to fluctuate in a unique variety. As a end result, the VSC-HVdc is competent to respond to procedure frequency vacation virtually right away and vary its lively vigor output to support the procedure frequency.

The implementation of the proposed manage method is deliberately coupled with the frequency manipulate of the FCWTs of the offshore wind farm, which is integrated into the onshore vigor grid by means of the VSC-HVdc. By means of simulations and evaluation, it's shown that the proposed control approach permits the VSC-HVdc to furnish amazing inertial response with none further investment. The coordination of the frequency manipulate of the VSC-HVdc and wind turbines obtains a tremendously more desirable frequency response for the studied power process. The collective frequency help capability is related to that of conventional vigour vegetation.

The VSC-HVdc dc-hyperlink voltage and dc capacitor capacity constraints, the quantity of the vigor released/absorbed by means of the dc capacitors is restricted and, consequently, the frequency help from VSC-HVdc is most effective temporary. In view of this, the frequency-responding latency of the offshore wind farm instantly impacts the force of the inertial response from the VSC-HVdc.

Performances of the proposed VSC-HVDC procedure under constant state and under various transient conditions are studied. The efficiency of the controllers is adequate as the HVDC procedure takes very less time to arrive steady state after clearing of the fault. Proposed procedure is built-in with the wind farm to extract the wind vigor and to give the vigor to the grid and method response is checked with the aid of DC voltage and AC voltage. Distinct analysis of this integrated method has to accomplished.

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