Communication-free Inertia and Frequency Control for Wind Generators Connected by an HVDC-Link

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***Abstract*—This letter introduces a communication-free control scheme that allows wind generators connected by an HVDC-link providing inertia and primary frequency control services to the mainland system. The scheme consists of making the offshore and onshore frequency deviations proportional. It relies on frequency regulation at the offshore converter and dc voltage control with power and frequency droops at the onshore converter. The letter provides a mathematical formulation of the system and a discussion on application challenges related to the control scheme.**

***Index Terms*—Wind power generation, HVDC transmission, frequency control, inertia control.**

I. Introduction

Delivering offshore wind energy through HVDC connections raises numerous challenges. In particular, as the injection of a significant amount of offshore wind power tends to increase the rate of change of the mainland system's frequency [1], it is necessary to design control strategies that enable wind generators to contribute to the system inertia and provide frequency control reserves. This problem is addressed for onshore wind turbines through kinetic energy regulation [2] and wind turbine de-loading [3], but these schemes do not apply yet to offshore wind turbines, which are usually unaware of the mainland system's frequency. To this purpose, Ref [4] proposes a specific coordination scheme involving communication of remote information, namely the power setting of the wind farm. However, such an information exchange may challenge the effectiveness of the scheme, as it involves a delay that can be too long with respect to the time frame of inertia and primary frequency control. Indeed, inertia control must be performed within a few tens of milliseconds, whereas the measurement, processing, transmission, reprocessing, and treatment of remote information is subject to security and reliability issues and can occasionally take more than one second [5], [6].

This letter addresses this problem with an alternative coordination scheme that allows offshore wind generators to participate to mainland primary frequency control and inertia using conventional control schemes developed for onshore applications. The main principle of this control scheme is to make the frequency of the offshore ac grid connecting the wind generators reflect the balance of the mainland system without having to exchange information. It relies on local control actions of the HVDC-link converters, namely the onshore converters sets the dc voltage depending on the dc power flow and onshore frequency, and the offshore converter sets the offshore frequency depending on the dc voltage. The letter provides a mathematical formulation of the system and discusses the application challenges for the control scheme.

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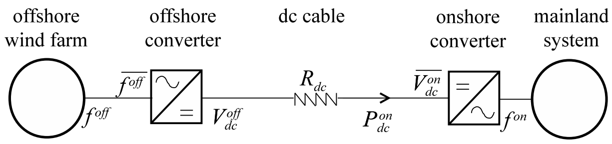

Fig. 1. Components and state variables for the system.

II. Power system components

This letter focuses on power systems as depicted in Figure 1. It is composed of a mainland system, an onshore converter, a dc cable, an offshore converter, and an offshore ac grid connecting wind generators. As the letter addresses mainly frequency-related problems, ac voltage magnitudes and reactive power injections are not considered hereafter.

The offshore wind generators are connected to the offshore ac grid. They receive an intermittent mechanical power, and they can apply conventional inertia and frequency control schemes such as in [2], [3] based on the local measurement of the offshore grid's frequency f^{off}.

The offshore converter controls the offshore frequency under setting $\overline{f^{off}}$, as in [7] for example. Its dc voltage V_{dc}^{off} depends on the power injected by wind generators and on the dc voltage of the onshore converter.

The HVDC transmission cable is modeled as a series resistance R_{dc} and its rated voltage is denoted V_{dc}^{R}.

The mainland system is connected to the HVDC-link by a converter that controls the dc voltage under setting $\overline{V_{dc}^{on}}$. The power P_{dc}^{on} received by the onshore converter on the dc side depends mainly on the intermittent wind generation. It is injected (except losses) into the mainland system, whose actual frequency is denoted f^{on} and its nominal value f_0^{on}.

The control scheme introduced hereafter applies to both line-commutated and voltage source converters. Nevertheless, voltage-source converters might be more appropriate for such application, as this technology is more effective to avoid ac voltage deviations induced by significant dc power flow variations.

III. Communication-free control scheme

The control scheme consists of specific actions at both HVDC-link converters. More specifically, the offshore converter is to set the offshore frequency depending on V_{dc}^{off}

$$\overline{f^{off}} = f_0^{off} + K_V(V_{dc}^{off} - V_{dc}^{R}) \,, \quad (1)$$

where f_0^{off} is the offshore nominal frequency and K_V is the offshore converter's gain.

Besides, the onshore converter should set the dc voltage depending on both the mainland grid frequency and the dc power flow

$$\overline{V_{dc}^{on}} = V_{dc}^{R} + K_f(f^{on} - f_0^{on}) - K_P P_{dc}^{on} \,, \quad (2)$$

where K_f and K_P are the frequency and power droops, respectively.

Note that these control loops involve only local measurements and actions. Under the assumption that the onshore HVDC converter performs an instantaneous application of its setting (i.e. the actual onshore dc voltage V_{dc}^{on} is equal to its setting $\overline{V_{dc}^{on}}$), Eqn (2) yields

$$V_{dc}^{off} = V_{dc}^{on} + R_{dc}\frac{P_{dc}^{on}}{V_{dc}^{on}} \quad (3)$$

$$= V_{dc}^{R} + K_f(f^{on} - f_0^{on}) + (\frac{R_{dc}}{V_{dc}^{on}} - K_P)P_{dc}^{on} \quad (4)$$

By choosing $K_P = \frac{R_{dc}}{V_{dc}^{on}}$, one obtains that the offshore dc voltage depends only on the mainland frequency. Hence,

$$\overline{f^{off}} = f_0^{off} + K_V K_f(f^{on} - f_0^{on}) \,, \quad (5)$$

which makes the offshore and the onshore frequency deviations tend to be proportional, and thus enables offshore wind turbines to participate in inertia and frequency control.

IV. Application Challenges

Even though it does not require real-time communication of frequency or power generation measurements, the proposed scheme raises the following application challenges.

A. Assessment of the controller droops

The value of K_P can be tuned based on real-time measurement of V_{dc}^{on} and offline estimation of R_{dc}. It will be nearly constant, as the values of R_{dc} and V_{dc}^{on} are unlikely to change dramatically.

The value of K_f results from a trade-off between i) easy detection of the dc voltage variations induced by frequency perturbations by the offshore converter (high value), and ii) maintaining the dc voltages in a reasonable range around nominal operation conditions (low value).

The offshore droop K_V should be chosen accordingly such that $K_V K_f \approx \frac{f_0^{off}}{f_0^{on}}$. When tuning K_V, it might be anticipated that the inertia and reserves to be provided by offshore wind farms will not be fully delivered to the mainland system, as part of the extra power shall generate extra losses.

B. Effective contribution to the mainland inertia and reserves

Inertia and reserves provided by offshore wind turbines might be less reliable than those provided by onshore resources, as they can not inject power during a failure on the offshore AC grid or on the HVDC-link. Specific reliability studies are thus necessary to evaluate the economic benefits of providing inertia and reserves with offshore wind farms.

C. Interactions with protection schemes

With the proposed control scheme, the information on the mainland frequency is transmitted by means of the dc voltage. The behavior of the offshore system during transient phenomena affecting the dc grid should thus be carefully considered to avoid unexpected behavior during dc faults. For example, a fault on the dc cable results in a dc voltage dip, generating in turn a dip of offshore frequency that wind generators may perceive as a need for more power injection. Appropriate rules should thus be defined so that inertia and frequency control apply only when the system is operated under normal conditions (i.e. dc voltage close to its rated value).

V. Conclusions

This letter introduces a communication-free control scheme for an HVDC-link connecting offshore wind generators with a mainland power system. The proposed approach enables the wind generators to provide inertia and frequency control services to the mainland system while avoiding reliability and security issues of control schemes based on remote measurements. More specifically, the letter shows that setting the offshore frequency and the onshore ac voltage with appropriate power and frequency droops makes the onshore and offshore frequency deviations tend to be proportional. It also discusses the main application challenges.

This finding opens thus new perspectives not only for offshore wind energy, but more generally for remote energy sources to provide ancillary services to mainland power systems. Further works are however needed to evaluate the real capabilities of a remote power source associated with a dc-link operated with such a control scheme. They shall encompass real-time dynamic simulations of the generators and HVDC-link, and also focus on the potential limitations related to the technical constraints of the dc cable and converters (e.g. current limiter, ramp rates).

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