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Stabilising system frequency using HVDC between the Continental European, Nordic, and Great Britain systems

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ABSTRACT

For future efficiency improvement of the frequency containment process (primary control) within European power systems, cooperation between (multiple) synchronous areas using their controllable HVDC interconnections is optioned. However, the differences in system size, HVDC interconnection capacity, and the balancing performance per individual system will have its specific system frequency effect for each different balancing cooperation concept. Consequently, without alignment on cooperation, HVDC balancing might lead to disproportional support between systems, to frequency oscillations, reserve unreliability and non-compliancy, and to network constraints. Therefore, this work assesses frequency quality and associated DC power flows for several balancing arrangements, using a developed load-frequency control model with frequency interdependency for coupled power system. For a trilateral balancing cooperation case study, it is found that certain cooperation concepts result in undesired frequency oscillation and poor frequency quality. However, cooperation where especially fast-response services are shared, such as virtual inertia, show improved system frequency performance. For the case where power imbalances are proportionately distributed among the systems, it is concluded that power transfers over HVDC interconnections are limited and additional control optimisation can be performed. Those concepts with aligned central or coordinated control show best results for a future cooperation for balancing between synchronous areas.

1. Introduction

Current developments such as the integration of Renewable Energy Sources (RES) and coupling of multinational electricity markets deteriorate frequency quality (performance) of interconnected power systems [1,2]. Conventional generation is replaced, leading to a loss of system inertia and a loss of the supply of reserves. As a result, the ability of the system to counteract power imbalances decreases [2,3]. Meanwhile, reserve consumption by stochastic forecast errors is becoming significant [4,5], especially in larger sized balancing areas [6,7].

The lack of balancing performance is especially noticeable in the relative smaller power systems such as the synchronous areas of Great Britain (GB), former UKTSOA, and Nordic (NE), former NORDEL. Their risk of not being compliant to frequency quality targets is expected to increase, should however remain pursuant to regulations, as defined by the European Network of Transmission System Operators of Electricity (ENTSO-E) in the Network Code [8]. These contain mandatory restrictions on the occurrence and magnitude of frequency deviations (frequency quality).

A viable option to improve frequency quality is cooperation between synchronous areas (inter-synchronous area) using HVDC interconnections. Such (bilateral) cooperations for the frequency containment process (primary control) have been investigated [9–16] for the purpose of supporting system balance. However, the focus was mainly on one single cooperation concept, and mainly on a bilateral cooperation (only two synchronous areas). Besides studies, a pilot between two synchronous areas (GB and Continental

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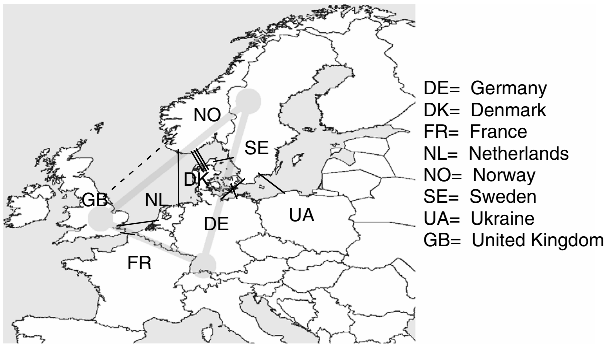

Fig. 1. Geographical map of the trilateral coupling (triangle) of the synchronous areas of Great Britain, Nordic, and Continental Europe and their operational HVDC interconnections (solid black line) and the planned HVDC between United Kingdom and Norway (dotted black line).

Europe (CE), former UCTE), operated by the Dutch TSO TenneT and the British TSO National Grid [16], has been executed. This study work extends this pilot and the ongoing research by investigating a trilateral synchronous area balancing cooperation, which could become practice between GB, CE and NE when the planned HVDC interconnection between United Kingdom and Norway will be commissioned [17], geographically depicted in Fig. 1. This depends on market developments and economic drivers in both United Kingdom and Norway as indicated in [18].

Please note, this European trilateral balancing coupling consists of power systems with different size, different HVDC interconnection capacity, and cooperation can be performed in different ways. This all has its effect on the resulting frequency quality and HVDC power transfer for balancing within and between the power systems, respectively. It is expected, without alignment and coordinated cooperation, that balancing arrangements might lead to disproportional support, frequency oscillations, reserve non-compliance and unreliability, and network constraints. Therefore, this work researches the active power balancing performance of five balancing cooperation concepts. Therefore a new high-level load-frequency control model is developed capable to simulate the frequency performance of multi-coupled power systems and to compute power transfers over the DC interconnections. This work contributes by recommending adequate balancing cooperation arrangements in line with the European cooperation concepts as defined in the Network Code Electricity Balancing [19], and how to consider HVDC control settings with the objective to secure frequency quality, and prevent adverse effects.

The article is organised as follows. Section 2 briefly overviews cooperation for frequency quality between power systems and the possible challenges it might face. Section 3 elaborates on the European cooperation concepts proposed by ENTSO-E. The modelling part is introduced in Section 4 and results are shown in Section 5, where frequency responses and DC power transfers as a function of power imbalances are computed. Section 6 provides recommendations how to ensure that each synchronous area remains reserve compliant and how to optimise cooperation in frequency support. Finally in Section 7, conclusions are drawn.

2. Cooperation for frequency quality

This section briefly overviews frequency quality, defined as the occurrence, duration, and magnitude of frequency deviations, and it introduces the trilateral balancing coupling of synchronous areas.

2.1. Frequency quality targets

System frequency must be maintained between certain thresholds [6], to prevent activation of automatic protection mechanisms, leading to e.g. activating under-frequency load shedding. To not compromise the supply of electricity to a large number of connected customers, ENTSO-E embodies frequency quality parameters which are values to be considered for the design of control processes and reserve dimensioning [8]. In Fig. 2. The three targets considered in this work are depicted for a frequency response during an exemplarily infeed loss. For a small Rate of Change of System Frequency (ROCOF), system inertia is essential. The maximum instantaneous frequency deviation (frequency nadir) allowed after the occurrence of the dimensioning incident in European synchronous areas are for GB 800 mHz, for CE 800 mHz, and for NE 1000 mHz [6]. The maximum steady-state frequency deviation is the maximum allowed frequency deviation at which the oscillating system frequency stabilises after the dimensioning incident [8], for GB 500 mHz, for CE 200 mHz, and for NE 500 mHz.

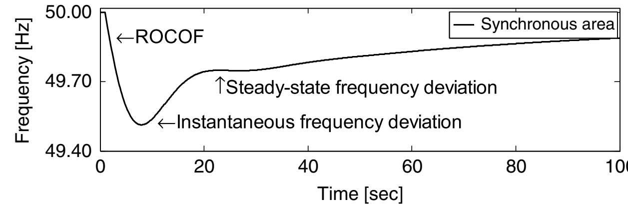

Fig. 2. The frequency quality targets of ENTSO-E considered in this work.

2.2. Frequency containment process

The Frequency Containment Process (FCP), alias primary control, is the automatic and collective process of all Load-Frequency Control Blocks (LFC Blocks) within a single synchronous area to stabilise system frequency after a power imbalance, by injecting or withdrawing additional power to the system. Primary control (speed droop) acts as a proportional control function, similar to the inherent response of frequency sensitive loads [20] and fully activates Frequency Containment Reserves (FCR) within 30 seconds, compliant to [8].

2.3. Pilot BritNed-interconnector

A European inter-synchronous area cooperation for primary control is the pilot testing of BritNed (HVDC interconnection between the Netherlands and United Kingdom), where the DC submarine cable is equipped and operated with a droop controller with settings pursuant to the Network Code [21]. Additional balancing power on top of commercial transaction is transferred [22], as a function of the frequency difference between GB and CE. Conditions of the pilot are maximum balancing transfer of ±100 MW, with an applied droop of 4% (sensitivity factor in physical units of 500 MW/Hz).

The performance of the droop control on the HVDC interconnector is depicted in Fig. 3, with actual measurements of the frequency difference between GB and CE depicted in the top plot. In the bottom plot, the total power transfer (trading + balancing) on the BritNed HVDC interconnector is depicted. A clear positive correlation between frequency differences and power transfers is visible. From the time interval 20:30–21:30, the market transfer is 1000 MW. The BritNed interconnector is designed to be capable of transporting up to 1200 MW (dynamic rating) for two hours [23]. Therefore, balancing capacity can implicitly made available for this pilot without withdrawing capacity from the market. The maximum measured ramp-rate of power transfer over the BritNed interconnector is ≈45 MW/s. In a previous study for frequency control through BritNed [23], a maximum ramp-rate of 100 MW/s was supposed for balancing purposes. These values will be addressed later on in this work for the ramp-rate requirement per cooperation concept.