Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-27 (2016) 395–399

Using WAMS for HVDC Control

K. Máslo*. M. Vrba*

*ČEPS, a. s.; Prague, Czech Republic
(e-mail: maslo@ceps.cz; vrba@ceps.cz).

Abstract: The paper presents how a combination of two progressive technologies - high-voltage direct current (HVDC) and wide area monitoring system (WAMS), can contribute towards secure power system operation and enable flexible power flows control. A new control algorithm based on WAMS for HVDC connection has been proposed and tested on a dynamic model of the future Central East European region.

Keywords: Central East Europe, dynamic model, HVDC, WAMS

1. INTRODUCTION

The European power system is confronted with important changes. The growing share of intermittent renewable energy sources (RES), often located far from load centres, and increasing short-time ahead cross-border trading cause increased usage of transmission infrastructure. To cope with these challenges, investment in smarter network infrastructure is needed.

Long-term network development is one of the core missions of European transmission system operators (TSOs) - the Ten Year Network Development Plan (TYNDP) being their main instrument. The latest available TYNDP (2014) describes the needs of the electricity transmission infrastructure up to 2030. The need for further network expansion up to 2050 was investigated in the e-Highway 2050 project (see Sanchis at al., 2015). The project concluded that creation of North-South corridors and reinforcements of the North and the South connections with the Central Continental Europe area are necessary for secure integration of wind power from the Baltic area (e-Highway2050, 2015). Eser at al. (2015) analysed the effects of changes in power mix and grid topology in 2020, including impact of new HVDC lines in Germany, on the Central West and Central East European (CEE) regions. The paper described problems with unplanned loop and transit flows in this region caused by inadequate transmission capacity, high penetration of renewables in Germany and market coupling between Germany and Austria not respecting internal transmission grid limits (see Joint study (2013) for more information).

Long-term dynamic simulation is used for testing innovative HVDC control with the help of the Wide Area Measurement System (WAMS). Bhatt (2011) proposed several WAMS applications and also pointed out angular difference between locations as an instantaneous measure of power system stress.

2. THE ANGULAR DIFFERENCE AS THE MAIN INPUT

The angular difference is used as a control variable for the innovative HVDC control algorithm in the presented paper. The objective of the proposed control algorithm is to maintain power flows in the AC grid on a level secure for stable operation. The feasibility of the control algorithm is tested on a simplified reduced model of the pan-European power system for 2030. The simulation results show the validity of the proposed method for the purposes of power flows control.

Many different voltage source control (VSC) HVDC models and their controls have been published. A synchronous generator emulation control strategy for the VSC-HVDC station is presented in Guan at al. (2016). The VSC-HVDC with this control strategy has synchronous generator properties like inertia, and primary and secondary frequency control ability. A similar synchronverter concept was presented by Aouiniat at al. (2016). The resulting synchronverter-based HVDC connection behaves like two synchronous machines connected to HVDC terminals.

A similar approach is used in this paper. HVDC is considered as a synchronverter-based HVDC and it is modeled as two synchronous machines according to Fig. 1

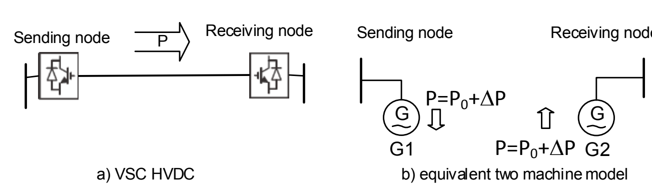

Fig. 1. Modelling VSC HVDC by synchronous machines

The synchronous machine connected into the sending node consumes active power P and the second one connected into the receiving node generates the same power P (HVDC losses are neglected). The initial value P_0 is modulated by additional power ΔP, which is the output of a simple PI controller depicted in Fig. 2. This controller regulates angular difference $\Delta\vartheta$ to a desired reference value $\Delta\vartheta_{REF}$ with dead band DB. The output of the controller is limited to values R_{min}-R_{max}. Reactive power of the synchronous machines is regulated to maintain terminal voltage.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.765

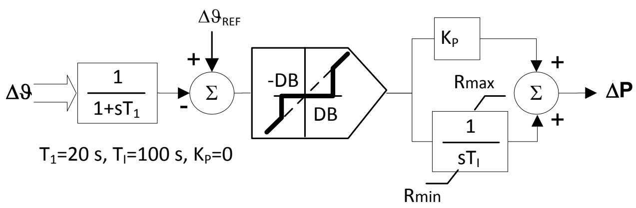

Fig. 2. HVDC controller block scheme

3. DYNAMIC MODEL OF CEE REGION

A simplified dynamic model was developed for the purpose of the long-term dynamic simulation. This model was based on initial TYNDP 2030 load flow data. The simplification consisted of a topological reduction. The number of nodes and branches were decreased by an elimination algorithm, which is described in Machowski at al. (1996). Control areas of the model were managed as follows:

1. the Czech transmission system was left unchanged,
2. neighbouring areas of the CEE region (AT, DE, HU, PL and SK) and IT were reduced into border nodes (all tie lines were retained), cluster and X nodes and one hub node with concentrated generation and consumption of the control area,
3. the remaining 15 areas were substituted by two equivalent areas WEST and BALKAN with one hub node.

The cluster nodes correspond to a cluster European transmission system model proposed in the e-Highway2050 deliverable D4.3 (2015). The X nodes model connection with external systems (terminals of HVDC or AC connections outside Continental Europe). Table 1 compares numbers of objects in the initial (full) and the simplified model.

Table 1. Numbers of objects

Numbers of	Nodes	Lines	Generators
Full model	15268	21268	488
Simplified model	310	691	65

The model is depicted in a simplified way in Fig. 3.

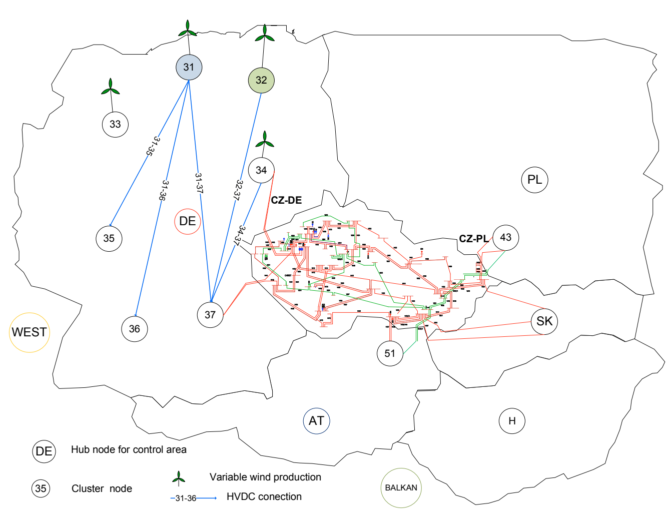

Fig. 3 Scheme of CEE dynamic model

Equivalent sources are connected into clusters in northern Germany (31-34) to simulate intermittent production of on-shore and off-shore wind farms. HVDC connections correspond to the future German HVDC corridors published by Fairley (2013) and Netzentwicklungsplan (2015). Table 2 gives an overview of HVDC parameters (HVDC capacities are estimated only for purpose of this model).

Table 2. HVDC connection in simplified model

HVDC	Capacity [MW]	P_0 [MW]	$\Delta\vartheta_{REF}$ [rad.]	DB [rad.]
31-35	4000	-600	0.2	0.2
31-36	4000	-600	0	0.5
31-37	8000	-600	0	0.5
32-37	2000	-1000	0	0.5
34-37	2000	-600	0	0.2

3.1 Synchronous generator model

Synchronous generators are modelled by a six – order model or a classical model. Generators are represented by the subtransient electromotive forces E" behind the subtransient reactance X" for the six-order model. Appropriate differential equations are described in in Machowski at al. (1996). In the classical model generators are represented by a constant transient electromotive forces E' behind the transient reactance X'. In both models a swing equation, for the per-unit speed ω and the rotor angle, is considered as follows:

$$T_M \frac{d\omega}{dt} = (P_M - P_G) \qquad \Omega_0 \frac{d\delta}{dt} = \omega \qquad (1)$$

where P_M is the mechanical power on the shaft and P_G is the generator power, both expressed in per units related to the generator apparent rating Sn. T_M is the mechanical time constant and Ω_0 is the nominal synchronous speed. The mechanical power P_M is an output from a turbine model.

The calculation of rotor angles enables a simulation

3.2 Turbine model

A simplified turbine model derived from a more complex IEEEG1 steam turbine model described in the IEEE technical report PES-TR1 (2013). The model is depicted in Fig. 4.

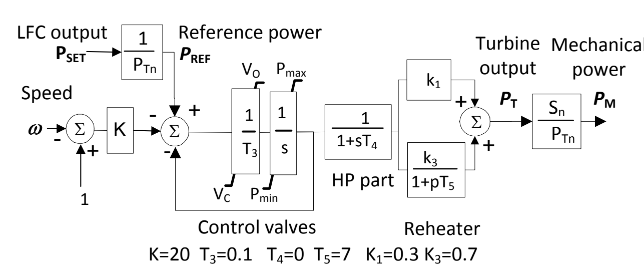

Fig. 4. Turbine model block scheme

Only the reheater and control valves operation is considered in this model. The reference power P_{REF} and the turbine output P_T are in per units related to the turbine nominal power $P_{Tn.}$