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Frequency support capability of variable speed wind turbine based on electromagnetic coupler

Rui You [a, *], Braulio Barahona [b], Jianyun Chai [a], Nicolaos A. Cutululis [b]

[a] *Department of Electrical Engineering, Tsinghua University, Beijing 100084, PR China*
[b] *Department of Wind Energy, Technical University of Denmark, Risø Campus, Frederiksborgvej 399, 4000 Roskilde, Denmark*

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ABSTRACT

In the variable speed wind turbine based on electromagnetic coupler (WT-EMC), a synchronous generator is directly coupled with grid. So like conventional power plants WT-EMC is able to support grid frequency inherently. But due to the reduced inertia of synchronous generator, its frequency support capability has to be enhanced. In this paper, the frequency support capability of WT-EMC is studied at three typical wind conditions and with two control strategies—droop control and inertial control to enhance its frequency support capability. The synchronous generator speed, more stable than the grid frequency which is the input signal for Type 3 and Type 4 wind turbine frequency support controller, is used for the calculation of WT-EMC supplementary torque command. The integrated simulation environment based on the aeroelastic code HAWC2 and software Matlab/Simulink is used to build a 2 MW WT-EMC model and study the frequency support capability of a wind farm consisting of WT-EMC.

1. Introduction

With the wind penetration increase into power system worldwide, the power system dynamic characteristics have changed and the transmission system operators (TSOs) have to face the frequency stability challenge [1]. This is because synchronous generators are used in conventional power plants, whereas modern wind farms mainly composed of Type 3 or Type 4 variable speed wind turbines are different. In case of a power imbalance between generation and consumption, the grid frequency will change. The synchronous generator rotor speed is synchronous to the grid frequency, so the synchronous generator rotor speed and the kinetic power stored in the rotor will change, limiting the rate of change of frequency (ROCOF). The value of ROCOF is determined by the system inertia that is composed of the sum of all the synchronous generators inertia. The lower system inertia, the higher the ROCOF values after a power imbalance [2]. For Type 3 or Type 4 wind turbine a power electronic converter is employed, and it (partially) decouples the wind turbine speed and grid frequency, resulting in the reduced power system inertia [3,4]. The reduced system inertia is a particular concern to TSOs, especially in the context of high wind penetration, because larger numbers of synchronous generators are displaced by variable speed wind turbines. So the importance of wind turbine frequency support is emphasized [5].

Mimicking inertia in variable speed wind turbines implies that the kinetic energy stored in the wind turbine rotor and drive train is used as short-term additional power injection responding to a grid frequency drop [6]. Normally both Type 3 and Type 4 wind turbine operate at Maximum Power Point Track (MPPT) [7]. For the wind turbine control level, the converter torque command is calculated according to the predefined wind turbine optimal torque-speed curve. When the grid frequency changes, an additional torque term should be added to the normal torque command to increase the wind turbine output power. The additional torque term calculation can be implemented in different ways [8,9]. The two ways—droop control and inertial control are widely used [10–13]. The additional torque term is calculated according to the deviation of grid frequency from the nominal value for the first way and it is proportional to the frequency derivative df/dt for the second way.

In [14], the WT-EMC drive train is proposed. The synchronous generator is directly coupled with grid, so the wind turbine transient overload capability and grid voltage support capability are significantly improved. This also enables WT-EMC to have an inherent grid frequency support capability. An electromagnetic coupling speed regulating device (EMCD) is used to connect the gearbox high speed shaft and synchronous generator rotor shaft, transmitting torque to the synchronous generator. Because EMCD decouples the synchronous generator from the gearbox and wind

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* Corresponding author. Tel.: +86 10 62775559; fax: +86 10 62782296.
E-mail address: yourui1984@163.com (R. You).

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turbine rotor side of the drive train, the synchronous generator oscillation torque is not directly transmitted through the gearbox and to the rest of the drive train and wind turbine structure during the grid fault. This is a benefit for the drive train components, especially the gearbox. Furthermore, only one quadrant operation converter is needed and its capability is only a small fraction of the wind turbine rated power—1/6 of the wind turbine rated power. These are the main advantages of WT-EMC compared with Type 3 and Type 4 wind turbine.

In this paper, the frequency support capability of WT-EMC is studied with two different control schemes. A 2 MW WT-EMC model is built with Matlab/Simulink and the aeroelastic code HAWC2. The synchronous generator speed is used as the input signal to calculate torque command for the enhancement of WT-EMC inherent frequency support capability. The droop control and inertial control are respectively used to study the contribution of WT-EMC to the grid frequency improvement. Three typical wind conditions—low, medium and high wind speed—are simulated for full scope wind conditions. It is expected that WT-EMC under different wind conditions can improve grid frequency stabilization with suitable control schemes.

The paper is organized as follows. Firstly, the control of WT-EMC is introduced and the supplementary frequency controllers for WT-EMC are described. Secondly, a 2 MW WT-EMC is modeled and the models of main components in the drive train are described in detail. Then with the built model the contribution to the grid frequency improvement from a wind farm consisting of WT-EMC under different wind conditions is studied. Finally, the suitable controller selection is analyzed and discussed considering the impact on wind turbine loads.

2. Frequency support controller for WT−EMC

The overall structure, including the control loops, of WT-EMC is illustrated in detail in Fig. 1.

EMCD is composed of an electromagnetic coupler and a one quadrant operation converter. The converter is supplied from the synchronous generator terminal voltage. Because the front shaft speed is always lower than the back shaft speed during wind turbine operation, only one quadrant operation converter is needed and its capability is only a small fraction of the wind turbine rated power—1/6 of the wind turbine rated power. The EMCD transmission efficiency was calculated on a built 1.5 MW WT-EMC experimental platform, where it was found to reach up to 98% around the rated condition. The length is 2.5 m and weight is 6.5 ton for the built electromagnetic coupler used in 1.5 MW WT-EMC. Based on those metrics, preliminary calculations indicate that a 1.5 MW WT-EMC should have a cost comparable to the Type 3 wind turbine with same power rating.

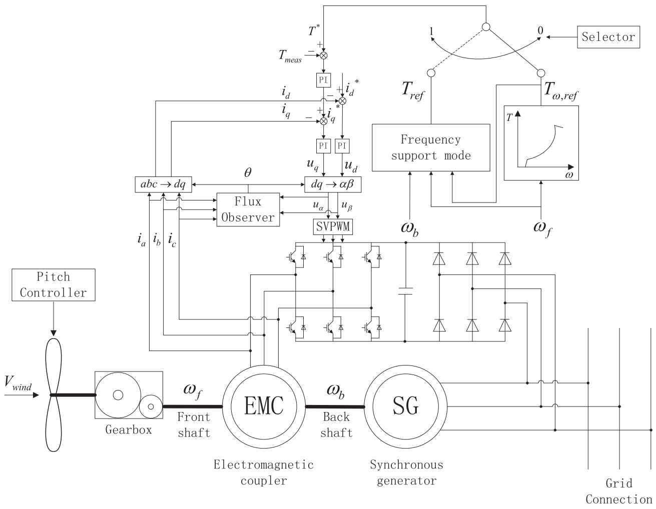

Fig. 1. Overall configuration and control of WT-EMC system.

Normally the converter torque command is calculated according to the predefined wind turbine optimal torque-speed curve to capture the maximum wind power [15]. The front shaft speed ω_f is used as the input signal for the torque command calculation. In case of a power imbalance resulting in changes of the grid frequency and synchronous generator speed, the torque command calculation is switched to the frequency support mode when the grid frequency change is estimated to be outside the dead band. Then the torque command is calculated from the controllers designed to enhance the inherent frequency support capability of WT-EMC and improve grid frequency. Once the frequency support mode is over, the torque command calculation will be switched back to the normal mode to make the turbine rotor accelerate if it decelerated during the frequency support mode and keep WT-EMC in the normal operation again.

The pitch controller aims at reducing the power imbalance between the turbine mechanical power and the WT-EMC output electrical power when the wind speed is high. The PI controller whose input is the speed difference between the turbine speed set point ω_t^* and its actual value ω_t is used to calculate the pitch command. The turbine speed set point is the turbine rated speed during the normal operation.

In Type 3 and Type 4 wind turbine, the grid frequency is used as the input signal of the frequency support controller. This can raise some challenges, because the grid frequency calculation is sensitive to the grid harmonics and disturbance. On the contrary, the synchronous generator is mechanically, through the speed, synchronized to the grid, offering a far more stable and easily and accurately measured reference for the frequency support controller. This is an important advantage that WT-EMC has compared to Type 3 and Type 4 wind turbine. Therefore the synchronous generator speed replacing the grid frequency is used as the input signal of the frequency support controller for WT-EMC. The frequency support controller design will be discussed as follows.

2.1. Droop controller

A governor with droop characteristic is used to share the load change for synchronous generator in proportion to its rating in conventional power plants [16]. The droop characteristic is expressed as:

$$\overline{\Delta P} = \frac{\overline{\Delta \omega}}{R} \tag{1}$$

where $\overline{\Delta P}$ and $\overline{\Delta \omega}$ are respectively the per-unit quantities of synchronous generator power change and speed change. R is the droop. The droop controller as illustrated in Fig. 2 is designed to

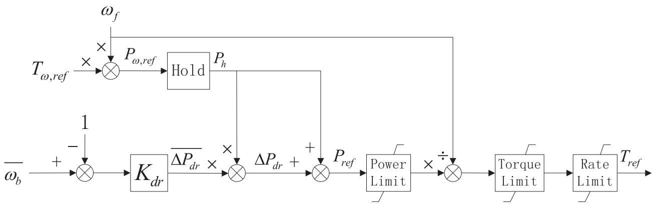

Fig. 2. Droop controller diagram.