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Analysis of Impact of Harmonic Disturbances on the Mechanical System of Wind Turbine

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Abstract: This paper analyzes the influence of harmonic frequencies on mechanical parts of wind turbines. Pitch system and drive train behavior of both doubly fed induction generator (DFIG) and full converter (FC) based wind turbines will be analyzed in detail.

Keywords: renewable generation; harmonic interaction; harmonic resonance; drive train; wind turbine

1. INTRODUCTION

With the development of renewable energy in the power systems, converters that interface with renewable generations are becoming new potential sources of harmonics. Harmonics may lead to problems such as damage of capacitors due to overheat, increased mechanical vibration of inductors, wrong trig of power system controllers and unintended shutdown of renewable generations. Moreover, the renewable generations are increasingly connected to the distribution weak systems and voltage source converter (VSC) based HVDC systems, where the whole system harmonic resonance behaviors should be considered in detail [Karaagac, U. (2012), Bozhko, S., (2007), Flourentzou, N., (2009), Cespedes M., (2014)].

According to the published researches, power electronic circuits' external harmonic behavior can be characterized by the impedances measured at the DC and the AC terminals. The analyses of harmonic and resonance stability between the renewable generations and the grid can be carried out by applying the Nyquist stability criterion (the ratio between the grid impedance and the converter impedance). The researches are focusing on the harmonic interactions between renewable generation and power system [Cespedes M., (2014), Song, Y., (2017)].

This paper will concentrates on the wind turbine side and the influence of harmonic frequencies on the wind turbine mechanical part will be analyzed. Both doubly fed induction generator (DFIG) and full converter (FC) based wind turbines will be considered.

This paper is organized as follows: following the introduction, DFIG-, FC- wind turbine models and their controllers are introduced in Section 2. In Section 3, the main mechanic system of wind turbine is introduced. The method for analyzing the harmonic influences is introduced in Section 4. In Section 5, simulation results for verifying the proposed method are provided. Finally, brief conclusions are deduced.

2. WIND TURBINE MODELS

2.1 DFIG model

The basic configuration of a DFIG wind turbine is shown in Fig. 1. [Cai, L., (2012)].

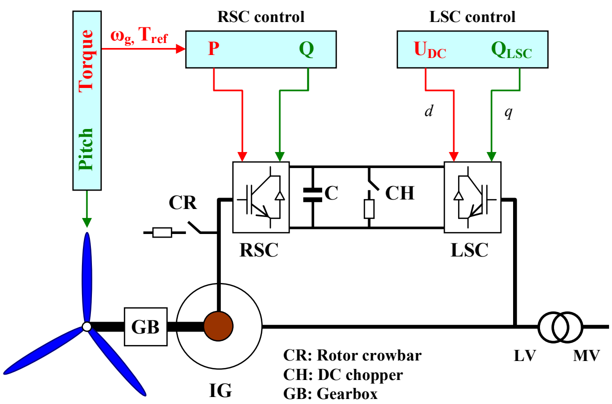


Fig. 1. Structure of DFIG.

The stator of the wound rotor induction machine is connected directly to the power grid and the rotor is connected to the power grid through an indirect AC-DC-AC converter system. The AC-DC-AC converter system consists of two three-phase pulse-width modulated (PWM) converters (line-side converter (LSC) and rotor-side converter (RSC)) connected by a DC bus. Both converters are of three-phase two-level type having three legs, each of which consists of two IGBTs and two anti-parallel diodes as illustrated in Fig. 2. Voltage control in these converters is done by pulse-width modulation using a carrier frequency in the order of kHz [Karaagac, U. (2012)]. In this paper, the general DFIG controllers are applied [Cai, L., (2012), EMTP-RV].

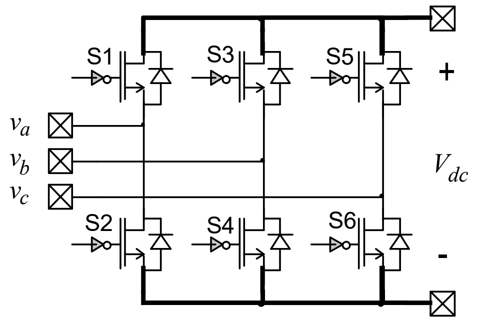


Fig. 2. Two level VSC circuit

2.2 FC wind turbine model

The typical configuration of the FC wind turbine is shown in Fig. 3. Usually, the generator used is a multi-pole synchronous generator designed for low speed. This allows for gearless design. The generator can either be electrically excited or permanent magnet synchronous generator. For allowing variable speed operation, the synchronous generator is connected to the grid through a full power frequency converter which converts the variable frequency output power of the generator into AC power with grid frequency [Karaagac, U. (2012), EMTP-RV].

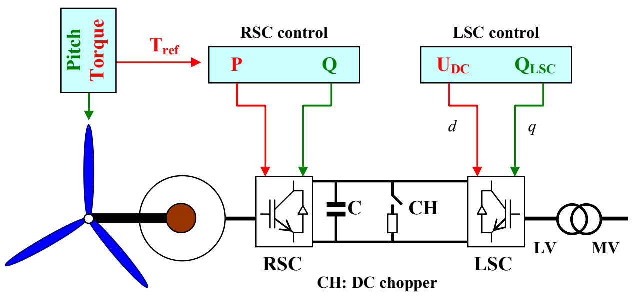


Fig. 3. Structure of DFIG

2.3 DFIG and FC controller

The controls of both DFIG and FC wind turbines are achieved by controlling the LSC and the RSC utilizing vector control techniques. [Karaagac, U. (2012)].

Vector control allows decoupled control of both active and reactive power. RSC is used to control the active and reactive powers delivered to the grid. LSC is used to maintain the DC bus voltage regardless of the magnitude and direction of the rotor power. The reactive power controllability of the LSC is always applied to reinforce FRT capability and provide grid voltage/reactive power control [Karaagac, U. (2012)].

3. MECHANICAL SYSTEM OF WIND TURBINE

The main mechanical system of wind turbine is given in Fig. 4. Different drive train models can be used for power system analysis [Sopanen, J., (2014)]. In this research, the one-mass model is applied.

Also the pitch system and aerodynamic are considered for their reactions on the harmonic disturbances.

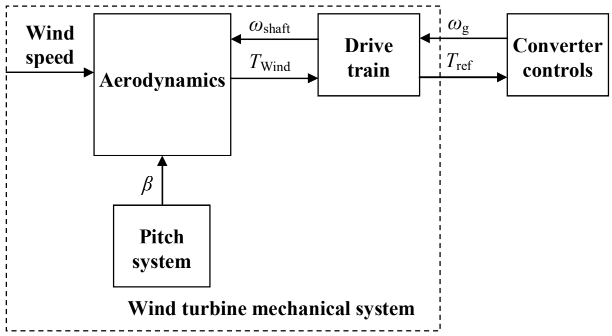


Fig. 4. Mechanical system of wind turbine

4. WIND TURBINE WITH HARMONIC DISTURBANCES

The harmonic disturbance on the DFIG and FC wind turbines are simulated and the system diagram is given in Fig. 5: the harmonic voltage source $U_{Har}(f)$ is applied for analyzing the DFIG and FC wind turbine behavior (mainly the mechanical systems) under harmonic disturbances.

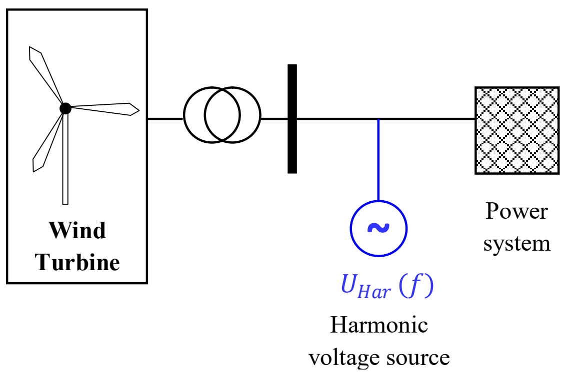


Fig. 5. Harmonic disturbance on the wind turbine

Single wind turbine with transformer is considered in this paper. In order to concentrate on the mechanical part of the wind turbine, the filters of wind turbines are not considered. The detailed parameters of the wind turbines are given in Table 1 to 3.

Table 1. Electrical parameters

System parameter	Value
Stator Generator Frequency (Hz)	60
Rated active power (MW)	1.5
Rated apparent power (MVA)	1.667
Generator Nominal Voltage (kV)	0.575
Collector Grid Nominal Voltage (kV)	20.5
Rated power of transformer (MVA)	1.75
Transformer inductance (pu)	0.05
Transformer resistance (pu)	0.002
Wind turbine inertia H (s)	4.32
Shaft spring constant (torque(pu)/rad)	1.11
Shaft mutual damping (torque(pu)/rad)	1.5

Table 2. Parameters of DFIG

System parameter	Value
Number of poles of ASM	6
Stator inductance (pu)	0.18
Stator resistance (pu)	0.033
Rotor inductance (pu)	0.16
Rotor resistance (pu)	0.026
Magnitizing inductance (pu)	2.9
Magnitizing resistance (pu)	2.9
Sampling frequency at GSC (Hz)	22500
Sampling frequency at LSC (Hz)	11250
PWM frequency at GSC (Hz)	4500
PWM frequency at LSC (Hz)	2250

Table 3. Parameters of FC

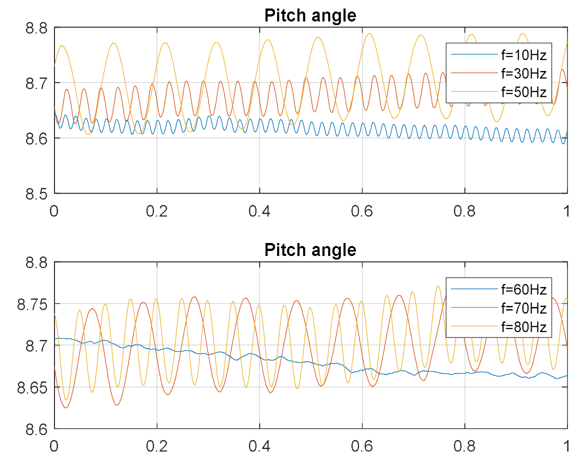
System parameter	Value
Number of poles of ASM	6
Stator inductance (pu)	0.05
Stator resistance (pu)	0.002
d-axis inductance (pu)	0.6
q-axis inductance (pu)	0.6
Sampling frequency at GSC (Hz)	12500
Sampling frequency at LSC (Hz)	12500
PWM frequency at GSC (Hz)	2500
PWM frequency at LSC (Hz)	2500

Harmoinc voltage source $U_{Har}(f)$ with amplitude of 3% nominal voltage of wind turbine is applied to analyze it's impact on the wind turbine mechanical part.

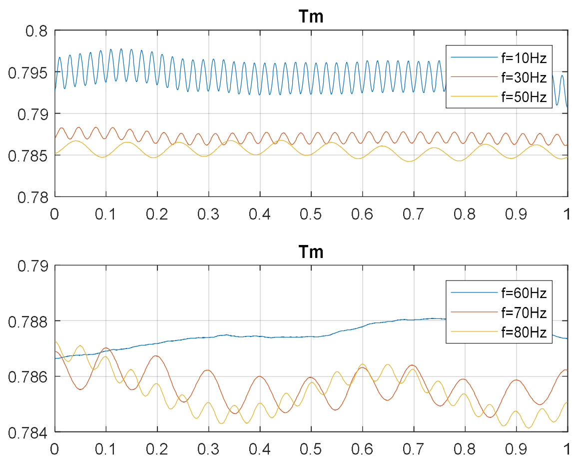
5. SIMULATION RESULTS

The harmonic voltage source $U_{Har}(f)$ is simulated with the frequency variation from 10Hz to 80Hz (from sub-synchronous to the super-synchronous area). The simulation results are given in Fig. 6 and Fig. 7.

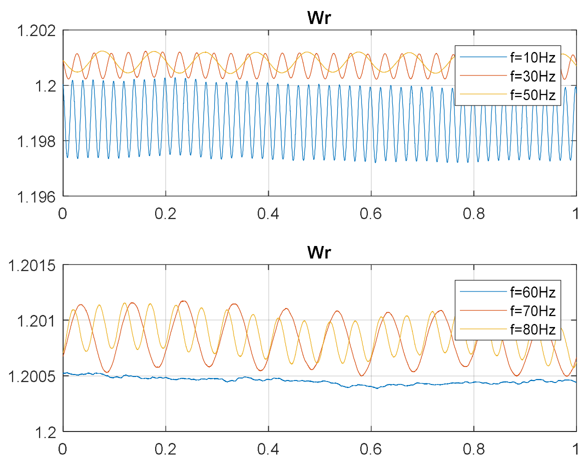
As given in Fig. 6 (a), with harmonic disturbance, the maximal pitch angle oscillation of the DFIG is around 0.2 degree. However, from Fig. 7 (a), the maximal pitch angle variation of FC is only 0.05 degree. It is clear that the harmonic disturbance has more impact on the DFIG pitch actuator.



(a)



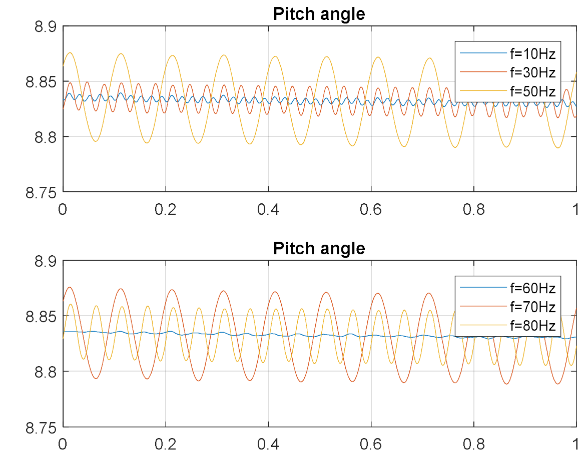
(b)



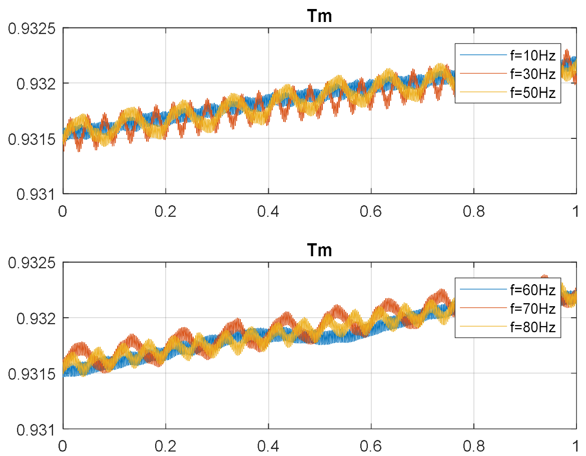
(c)

Fig. 6. Harmonic impact on DFIG

From Fig. 6, it is obvious that oscillation frequency on the mechanical part of wind turbine is the difference between nominal frequency and the harmonic disturbance frequency.



(a)



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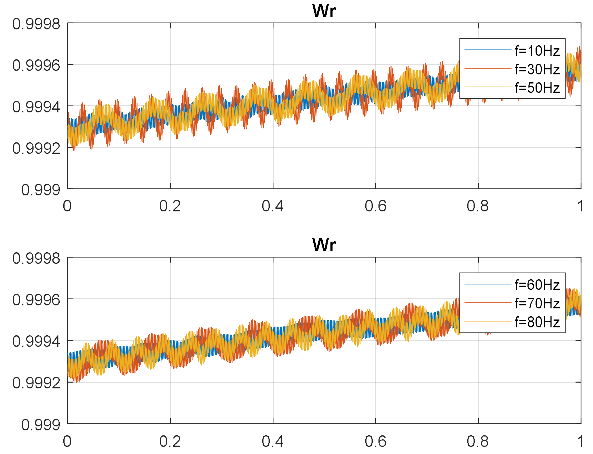
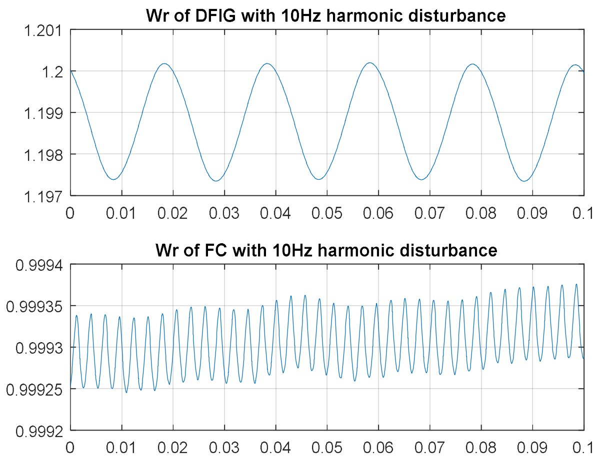


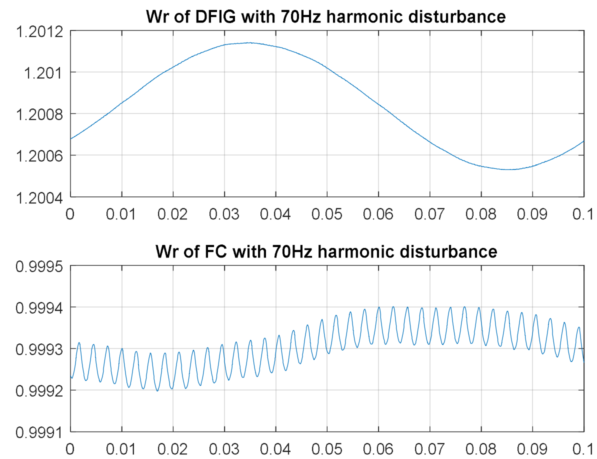
(c)

Fig. 7. Harmonic impact on FC

As shown in Fig. 6 (b), with harmonic disturbance, the maximal torque oscillation of the DFIG is around 0.005 pu. From Fig. 7 (b), the maximal torque variation of FC is only 0.0003 pu. It is clear that the harmonic disturbance has more impact on the DFIG drive train.



(a)



(b)

Fig. 8. Harmonic impact on FC

Also by comparison of the rotation speed of the DFIG and FC turbine, as illustrated in Fig. 6 (c) and Fig. 7 (c), the oscillation of DFIG is much higher than that of the FC turbine.

A detailed comparison of a 10Hz and 70Hz harmonic disturbances on the DFIG and FC is given in Fig. 8. As stated the oscillation amplitude of the DFIG is more than the FC. However, the oscillation frequency of the FC is higher than the DFIG.

Therefore, it can be concluded that the harmonic disturbance has more impact on the DFIG wind turbine mechanical systems.

Furthermore, in this research, only typical wind turbine parameters are used. For practical applications, detailed wind turbine parameters and controllers should be considered for evaluating the harmonic impacts on the turbine mechanical systems.

6. CONCLUSION

This paper analyzes the influence of harmonic frequencies on mechanical parts of DFIG and FC wind turbines. Harmonic voltage source is applied on the high voltage side of the wind turbine transformer. Pitch system and drive train behavior under harmonic disturbance are analyzed in detail. The simulation results show that the harmonic disturbance has relative more impact on the DFIG wind turbine mechanical systems.

7. ACKNOWLEDGEMENT

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