Renewable and Sustainable Energy Reviews 89 (2018) 1–15

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of harmonic elimination techniques in grid connected doubly fed induction generator based wind energy system

Anirban Mishra, P.M. Tripathi, Kalyan Chatterjee*

Department of Electrical Engineering, Indian Institute of Technology(ISM), Dhanbad India

ARTICLE INFO

Keywords:
Active filtering
Doubly fed induction generator (DFIG)
Grid side converter
Harmonic elimination
Power quality
Rotor side converter
Wind energy conversion system (WECS)

ABSTRACT

Wind energy is one of the developed forms of renewable energy which has seen a rapid increase in its demand by the utilities. The Doubly Fed Induction Generator (DFIG) based variable-speed wind turbine with pitch control scheme is the most popular wind power generator in the wind power industry. In this generator, a stator is directly connected to the grid, whereas rotor is connected to the grid via back-to-back power electronics converters. Due to this nonlinear devices connected to the grid, quality of power deteriorates. It draws a significant amount of harmonic currents. This leads to the generation of voltage harmonics in the grid due to the impedance of the transmission lines. A number of publications report related to the improvement of power quality, specifically, the harmonic elimination techniques for a wind energy conversion system. A critical assessment is required for making a choice on an exact harmonic elimination technique for a specific case. That is why an exhaustive review of all those techniques is very relevant. Only a countable number of attempts have been made in this regard. This paper emphasizes on various available harmonic mitigation techniques. This ensures the safeguarding of grid connected doubly fed induction generators from the harmful effects of harmonics. Thus, it helps in maintaining standards related to power quality.

1. Introduction

Exorbitant use of the conventional sources like fossil fuels causes environmental concerns such as pollution, global warming, etc. These are the reasons for the rapid development of renewable energy resources (RES), like wind, solar, fuel cell, etc. Diminishing reserves of conventional sources, an accelerated increase in power demand and the rising cost of fossil fuels are some of the reasons for the development and rise of renewable energy utilizations [1–5]. In this respect, wind energy is one of the most promising sources of electricity in today's world. According to the latest global wind market statistics released by World Wind Energy Association (WWEA), 54 GW of wind energy capacity was added in 2016. It represents an 11.8% annual increase (17.2% in 2015). The worldwide wind capacity reached 486 GW by the end of 2016. The worldwide capacity of wind turbines installed by the end of 2016 can meet around 5% of the world's electricity demand. Recent advancements in the field of power electronics lead to the support in wind power generation with acceptable power quality. Thus, the grid integration of wind turbine (WT) has become a challenging task for the power engineers. It can be seen that poor power quality from WT will affect the grid and poor power quality of the grid will consequently have detrimental effects on the WT system.

Wind Energy Conversion System (WECS) employs a WT and an electric generator for producing electrical energy using the wind. The entire setup consists of WT coupled to a prime-over either directly or using a gear box setup. It is also coupled with the generator's rotor shaft when the stator is either connected with standalone loads or with grid utility. This overall system converts mechanical energy into electrical energy via magnetic energy for the utility grids. The electrical system in WECS comprises of two main groups: fixed speed and variable speed. The generator in a Fixed Speed Wind Turbine (FSWT) has a relatively simple construction and utilities low priced electrical systems. It is directly connected to the grid while Variable Speed Wind Turbine (VSWT) is advantageous due to better power quality, reduction in noise

---

Abbreviations: **DFIG**, Doubly Fed Induction generator; **DG**, Distributed Generation; **DSP**, Digital Signal Processor; **DVR**, Dynamic Voltage Restorer; **FSWT**, Fixed Speed Wind Turbine; **GSC**, Grid Side Converter; **GW**, Gigawatt; **HSF**, High Selectivity Filter; **IDEA**, Integrated Doubly fed Electric Alternator/Active filter; **IEC**, International Electrotechnical Commission; **IEEE**, Institute of Electrical and Electronics Engineers; **LPF**, Low Pass Filter; **LSC**, Load Side Converter; **PCC**, Point of Common Coupling; **PI**, Proportional–Integral; **PIRC**, Proportional Integral Repetitive Controller; **PMSG**, Permanent Magnet Synchronous Generator; **PV**, Photovoltaic; **PWM**, Pulse Width Modulation; **RCC**, Rotor Current Control; **RES**, Renewable Energy Sources; **RSC**, Rotor Side Converter; **STATCOM**, Static Synchronous Compensator; **SVM**, Space Vector Modulation; **THD**, Total Harmonic Distortion; **UPQC**, Unified Power Quality Conditioner; **VSWT**, Variable Speed Wind Turbine; **WECS**, Wind Energy Conversion System; **WT**, Wind Turbine; **WWEA**, World Wind Energy Association

* Corresponding author.
E-mail address: chatterjee.k.ee@ismdhanbad.ac.in (K. Chatterjee).

https://doi.org/10.1016/j.rser.2018.02.039
Received 17 January 2017; Received in revised form 21 September 2017; Accepted 27 February 2018
1364-0321/

Nomenclature

v	Wind Speed
M	Magnetizing Inductance
C	DC bus capacitor
J	Total inertia constant (DFIG and turbine)
f	Total friction factor (DFIG and Turbine)
R	Turbine radius
P	Pole pair number
i_s, i_r	Stator Current and Rotor Current
i_p, i_l	linear load current and nonlinear load current
i_G	Grid Current
I_s, I_r	stator and rotor current vectors
V_{dc}	DC-link voltage
V_p	Stator output voltage at the point of common coupling
V_s, V_r	Induced stator voltage and rotor voltage
V_g	PCC voltage
V_{NS}	the nonlinear voltage drop on the internal stator impedance
V_P	Stator output voltage at the point of common coupling
U_s, U_r	stator and rotor voltage vectors
L_S, L_r, L_m	Stator, rotor and mutual inductances.
L_g	Line Inductance
L_m	mutual inductance
$L_{\sigma s}$, $L_{\sigma r}$	stator and rotor leakage inductances
R_S, R_r	Stator and rotor per phase winding resistance
R_g	Line resistance
ω_s, ω_r, ω_{sl}	Synchronous, rotational rotor and slip speeds
$\omega_{s'}$, $\omega_{r'}$	Stator and rotor angular frequency
θ_s, θ_r, θ_{sl}	Synchronous, rotational rotor and slip voltage angles
λ_s, λ_r	Stator and rotor flux
Ψ_s, Ψ_r	stator and rotor flux linkage vectors
σ	Total Leakage factor
$d/dt.\Delta$	Differential operator and error value.
T_{em}	Electromagnetic torque
P_S, Q_S	Stator active and reactive powers
Q_{PCC}	PCC reactive power
ω_t	Turbine Speed
Ω_g	DFIG Speed
δ	Gear box ratio

Superscripts

1, 5, 7	Fundamental synchronous, fifth & seventh reference frames.
$*$	Reference values

Subscripts

d, q	Synchronous rotating d-q axes
s, r	Stator, rotor
a, b, c	Stationary three phase axes
1, 5, 7	Fundamental, fifth and seventh sequence components.
α_s, β_s	Stationary α_S β_S axis

and mechanical stress on WT. The most widely used VSWT is a wound rotor induction machine using a converter connected to rotor circuit, which is popularly called as DFIG [6–8].

DFIG has the ability to use mechanical power to produce electrical power over a broad ambit of variable speed maintaining a constant frequency. The rotor frequency is adjusted at different mechanical speed using two back-to-back power electronic converters. This is one of the main advantages of DFIG. This system is also advantageous because of the fact that the power consumption of these converters is 30% of the normal generator power [9,10].

But with the use of power electronic converters, harmonics may get generated in the grid. The interaction of harmonic distortions from WECS with already present harmonic network distortions causes undesirable effects. Such effects are caused by excitation of a resonant point due to involvement of few harmonic frequencies [11]. Harmonic resonance is the result of interaction between capacitive and inductive elements. Many elements can resonate with each other like capacitor banks, power cables, transformers, etc. inside a WECS. A resonance occurs when a current or voltage frequency experiences a capacitive element reactance becomes equal to an inductive element reactance [12]. At constant grid frequency (f_s) during sub-synchronous/ super-synchronous speed the rotor voltage with slip frequency can controls the active & reactive power of DFIG. The control, protection and maintenance require detailed harmonic studies of DFIG which incidentally has been a subject of great interest for many researchers [13]. Depending on the construction, DFIG has been classified into three parts: rotor, stator and mechanical, where mechanical and stator parts are usually the output and the input ports of power respectively while rotor part is the bi-directional port [14]. These 3 parts are the main cause of harmonics in the system.

Rotor side converter (RSC), saturation of core, the rotor winding faults and non-sinusoidal flux distribution [8–10,13,15–18] are the prime sources of the rotor side harmonics. The harmonic sources of stator part are stator winding structure, winding faults, voltage unbalance, flicker and voltage disturbances of grid fault [13,19–22]. The major harmonic sources in torque and speed due to the mechanical parts are wind shear, gear box faults, tower shadow, wind speed, blade unbalance and bearing-faults [13,19–22]. For better power quality, the harmonics of DFIG must be in line with IEEE-standard 519, IEEE 1547 & IEC 1400 standards [23].

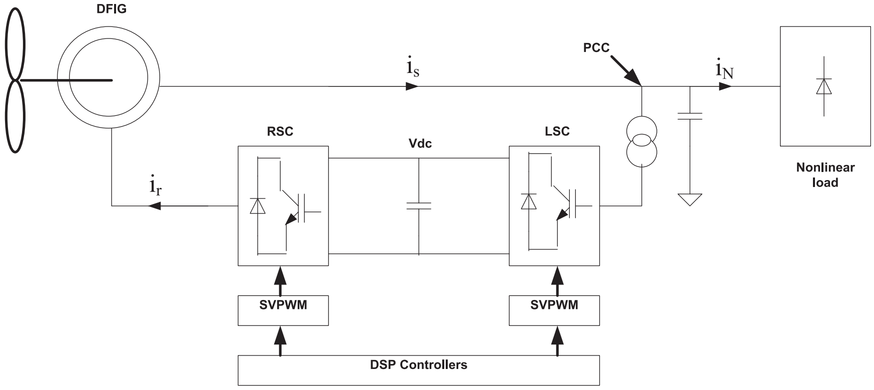

Fig. 1. A generalized DFIG set in stand-alone mode coupled to a non-linear load [50].