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FACULTY OF ENGINEERING

Electrical Power and Machines Engineering

PQ for the Grid Supported with Wind Turbines

A Thesis submitted in partial fulfilment of the requirements of the degree of

Master of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

by

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Statement

This thesis is submitted as a partial fulfillment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Signature

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ABSTRACT

Wind energy is considered as one of the clean and renewable energy sources that can be used in the extraction of electric energy. This draws attention to increase the usage of such energy for electricity generation. The operation of Wind Energy Conversion System (WECS) introduces power quality challenges. These challenges motivate many researchers to overcome these power quality issues especially total harmonic distortion. In this work, the impact of connecting wind farms with different conversion systems on the quality of the produced power was studied. In the first part of the thesis, the power quality criteria will be presented focusing on the harmonics emissions, then the international standard IEEE519-2014, IEC 61400-21 and the national Egyptian wind farm grid connection code are presented. The Second part discusses wind energy conversion systems in details. The various types of wind turbines are studied. The different technologies of the commonly used generators in converting rotational energy of the wind to electrical power energy are also discussed showing the merits and demerits of each. Then, some optimization techniques were introduced, selecting the Particle Swarm Optimization technique (PSO) as one of the most important and frequent used technique. This technique is used in our work for optimizing the controllers' gains.

After that, the static compensation devices are clarified as one of the modern power conditional devices. These devices are able to perform voltage and reactive power regulation in order to enhance the performance of wind farms and compensate reactive power consumption from the grid. In this work, two of them are evaluated and compared, namely Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVC).

WECS has been modeled in MATLAB/Simulink, with the use of Doubly Fed Induction Generator (DFIG) and Synchronous Generator (SG) as two alternative scenarios recently used and with the modeling of the whole power grid as groups of step-up transformers, feeding lines and bus bars. Their response is studied together with the case when static compensation devices are implemented as compensation techniques.

The major contributions of this thesis are: (i) providing comprehensive comparative study for different types of generators in WECS, (ii) application of PSO technique in controllers' gains tuning and (iii)The compensation devices are optimally used to study their effect on the total harmonic distortion index measured at the point of grid connection.

Key words:-

Power quality, Total harmonic distortion(THD), static compensators, point of common coupling(PCC) & Fast Fourier Transform tool(FFT).

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List of Symbols and abbreviations

$\boldsymbol{A}$	Area swept by wind turbines
$\boldsymbol{C_p}$	Power coefficient.
DFIG	Doubly Fed Induction Generator.
FACTS	Flexible AC Transmission System.
FFT	Fast Fourier Transform.
IEC	International Electro-technical Commission.
IEEE	Institute of Electrical and Electronics Engineers
$\mathbf{K_I}$	Integral control gain.
$\mathbf{K_P}$	Proportional control gain.
$\boldsymbol{m}$	Mass of air.
PI	Proportional- integral controller.
PQ	Power quality.
PCC	Point of Common Coupling
POE	Point Of Evolution
THD	Total Harmonic Distortion
TDD	Total Demand Distortion
R	Turbine radius.
STATCOM	Static Synchronous Compensator.
SVC	Static Var Compensator.
SG	Synchronous Generator.
$\mathbf{S_n}$	Rated apparent power of wind turbine.
$\mathbf{S_k^*}$	Short circuit apparent power of the grid.
U	Kinetic energy.
WECS	Wind Energy Conversion System.
$\boldsymbol{\rho}$	Air density.
$\boldsymbol{\lambda}$	Tip speed ratio.
$\boldsymbol{\beta}$	Pitch angle.
$\boldsymbol{\Omega}$	Rotational speed of the turbine.

CHAPTER 1

INTRODUCTION

1.1 Research Motivation

The interest for renewable energy sources has increased greatly in the last years due to both environmental concerns and conventional fossil fuel increasing cost. Wind energy, as one of the most important and attractive renewable energy sources, has gained a lot of heavy investments from all over the world. It is estimated that about 16% of the world's electricity will be obtained from wind energy by 2020[1]. The wind power sector is suggested to meet a great growth in terms of total installed capacity. After an observable slowdown in 2013, the wind industry set a new positive record for annual installations in 2014. Globally, according to the global wind market statistics, 51473MW of new wind generating capacity was added in 2014[2]. The record points out that about 44% increase in the annual market and is a positive sign of the recovery of the industry after a rough patch in the past few years. Wind Energy Conversion Systems (WECSs) have become a focal point in the research of renewable energy sources. There are various technologies of generators used in WECSs [3]. Due to the uncertain nature of wind speed and power electronics converters used in the WECS of different generators, this affects the quality of power produced from the wind farm.

This thesis presents models of WECS of different generators and a comparative study of the total harmonic distortion index produced from the wind farm at the grid point of interconnection was performed. Also, the total harmonic distortion index is measured when FACTS are connected and the controllers' gains are optimized using Particle Swarm Optimization (PSO).

1.2 Literature Review

There are two operation modes of WECS, the fixed speed operating mode and the variable speed operating mode [1].

Fixed speed wind turbine, mainly include the Squirrel Cage Induction Generators (SCIG), led the market until 2003 when the DFIG began to spread and proved its performance as an excellent performance variable speed wind turbine [4].

Variable speed wind turbine includes different types of technologies of generators for which are synchronous generators and permanent magnet synchronous generators. Although their need to a full-scale converter, a great attention is drawn to it enhancing its market share in the past recent years [1].

The interconnection of the variable speed wind turbines equipped with power electronic devices introduces significant harmonics into the grid. Several international and national standards specify certain limits for the introduced harmonic contents [5][6][7][8].

Power quality problems consist of various terms as harmonic distortions, impulses, swells, and sags. Voltage sags are very serious and can cause a large amount of damage [9].

FACTS devices are a very good choice for regulating the voltage and compensating reactive power of the systems. In this thesis, STATCOM and SVC are chosen and are connected at B575 and their effect on THD was evaluated [10].

1.3 Objectives

Based on the review of the discussed points mentioned before, the following points of interest will be researched in this thesis, concentrating mostly on the use and optimize of PI-based controller for the STATCOM and SVC:

1. Model the WECS consisting of wind, wind turbine, gear box, power electronic converters, and generators.

2. Choosing two different alternative types of generators used in the WECS.

3. Simulate the proposed WECS using MATLAB Simulink environment.

4. Use elected FACTS device and show its effect on THD.

5. Introduce an optimization technique and use it to optimize the gains of the PI-controller of the FACTS device.

1.4 Thesis Outline

The thesis is structured as follows: Chapter 2 presents the power quality characteristics of wind turbines. It also describes the power quality terms, it's regulating standards, national and international codes recommendations.

Chapter 3 discusses and categorizes the types of WECS. It also presents the model of WECS with DFIG and SG.