Ain Shams University
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Power Quality Enhancement of Grid Connected Wind Energy System

By

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A Thesis Submitted for the Requirement of Master Degree of Sciences in Electrical Power Engineering

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Statement

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Sciences in Electrical Engineering.

The work included in the thesis was carried out by the author at the department of Electrical Power and Machines, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Signature:
Date:

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C_p	Power Coefficient
I_d	d-axis Current
I_q	q-axis Current
P_w	Wind Power
P_m	Turbine Mechanical Power
p	Operator d/dt
R	Radius of the Turbine
R_f	Line Resistance
R_s	Stator Resistance
λ	Tip Speed Ratio
V_{dc}	DC-link Voltage
v_w	Wind Speed
β	Pitch Angle
λ_M	Rotor Magnet Flux
ρ	Air Density
ω_m	Mechanical Speed of Turbine Rotor
(λ_a, λ_b & λ_c)	Flux Linkages of Phases
(L_{aa}, L_{bb}, and L_{cc})	Stator Windings Self-Inductances.
(L_{ab}, L_{ac}, L_{ba})	Stator Windings Mutual Inductances.
L_d	d-axis Inductance
L_q	q-axis Inductance
D	Duty Cycle
f_S	Switching Frequency of IGBT
Q_G	Reactive Power
L_f	Line Inductance
K_p	Proportional Gain
K_I	Integral Gain
M	Population Size
Pc	Crossover Rate
Pm	Mutation Rate

List of Abbreviations

ACO	Ant Colony Optimization
ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
DFIG	Doubly Fed Induction Generator
FACTS	Flexible AC Transmission System
GA	Genetic Algorithm
IGBT	Insulated Gate Bipolar Transistor
ITAE	Integral of Time Multiplied by Absolute Error
K.E	Kinetic Energy
LVRT	Low Voltage Ride Through
MPP	Maximum Power Point
OTC	Optimal Torque Control
PCC	Point Common Coupling
PI	Proportional Integral Controller
PLL	Phase Locked Loop
PMSG	Permanent Magnet Synchronous Generator
PSO	particle swarm optimization
PWM	Pulse Width Modulation
SCIG	Squirrel Cage Induction Generator
SVC	Static Var Compensator
SMC	Switch Mode Converter
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
TCR	Thyristor Controlled Reactor
THD	Total Harmonic Distortion
TSO	Transmission System Operator
TSR	Thyristor Switched Reactor
VSC	Voltage Source Converter
WECS	Wind Energy Conversion System
WT	Wind Turbine

ABSTRACT

Expanding wind energy utilization for producing electrical power has a big prominence in most countries due to its benefits and availability worldwide. In the former decades, the wind energy insertion to the network was small. Consequently, wind turbine disconnection from the network was not in consideration. Wind turbines could be disconnected from the grid in disturbances cases without consideration of impacts on the power system. Nowadays, enormous wind energy has been inserted to the network and this integration introduced technical issues which should be addressed. Wind power interconnection in the system network influences the power quality specifically in unstable operation. Immediately disconnection of the wind turbine from the grid is prohibited by operators according to grid codes in voltage sag or fault cases. Nevertheless, limitation of reactive power provided attends for additional reactive power compensator. This thesis focuses on modeling and controlling of variable speed grid-connected wind turbine based permanent magnet synchronous generator wind turbine combined maximum wind power capture technique. The second contribution of this research is developing control and power management strategy for static synchronous compensator STATCOM to ensure stability and reliable operation of grid-connected wind turbine under disturbances cases. STATCOM is utilized for mitigation voltage fluctuation and strengthens power quality. In this dissertation, Ant Colony Optimization method ACO is adopted for tuning STATCOM controller to reinforce dynamic performance during fluctuations in grid-connected wind energy system. The proposed method is compared with genetic algorithm optimization and the classic approach methods to show accurately the system dynamic enhancement. The system is performed by Matlab/Simulink and the consequences confirm the excellent response of the different dynamic changes of the system and improve their dynamic response.

CHAPTER 1
INTRODUCTION

1. 1 Background

The proportion of wind-generated power is increasing continuously in many countries around the world because of its availableness and climate-friendly merits. Wind energy has grown to emerge as amongst the ultimate economical renewable energy advanced technologies. Usage of wind energy is growing swiftly to decrease the dependence of fossil fuel consumed for generating electrical power and minimize the impact of fossil fuel on climate and environment. Plenty of turbines are connected to power systems and the global wind energy capacity increased every year, in 2018 more than 60 GW were inserted to the global wind energy capacity which were grown to 605 GW [1] as presented in Fig. 1.1.

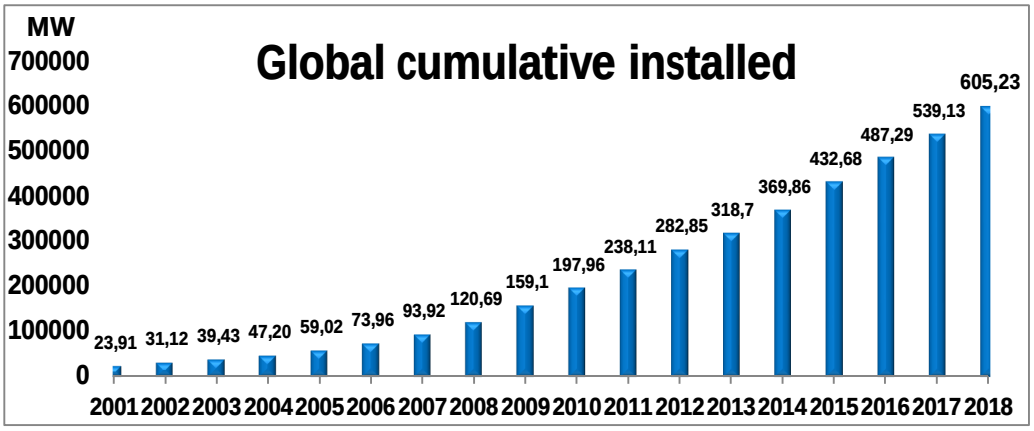

Fig. 1. 1. Global wind power capacity

Over the last decade, the capital cost of technologies of wind generation is decreased for the sake of progressive technology development and competition of turbine technologies manufacture including taller towers, longer blades and gearless generators. These advanced technologies participate to decrease the cost of wind turbine and making it promised competing power resources.

As result of this tendency, large amount of wind power is inserted to global electrical power market. Incorporation of enormous wind plants in stable power systems gives some problems that have to be classified, such as system operation, system stability and power quality [2]. The important problem upon wind generators connecting to the grid is the interrupting of the wind generators in condition of a lowering of network voltage under a standard value like voltage sag case. Disconnection of high wind energy penetration is not agreeable by grid operators [3].

1.2 Problem Statement

Recent streams in wind energy system announce considerable increase in adopting wind turbine based permanent magnet synchronous generator (PMSG) with gearless direct drive technology due to enormous advantages of these types. The turbines are linked to the network via power converter. These configurations are designed to have strengths of controlling voltage, reactive power and frequency. This configuration preserves stability of operation and keeps the turbine in grid- connected operation under various situations. Insertion scale of wind energy into network is growing. Accordingly, it is indispensable to design a functional and effective control strategy of wind turbine based PMSG to achieve grid code demand. This research investigates the control of wind turbine based PMSG. The prime targets of this research comprise modeling and controlling of maximum power generation of wind turbine. Besides, adopting improved controller design and implementation of static synchronous compensator (STATCOM) to assure dynamic voltage stability and powerful system operation. In the former, the insertion amount of wind power to the network is low and it was not a major consideration problem. Increasing of wind turbine penetration level now is considerable and it is important to address the power quality issues associated with penetration. Grid operator's commitments are stability, reliability and continuous operation of the system. In this thesis, power quality issues with wind turbine based PMSG integration to the grid are discussed and implementation of STATCOM are presented to reinforce behavior of a grid connected W.T. based PMSG. Grid operator seeks to

continuous inserting of wind power to the network through disturbances and faults via supporting reactive power. Wind turbines must have the ability for keeping Connection to the network under unstable operation cases regards to grid code demand. STATCOM has capability for providing voltage backup by injecting or pick up reactive power from the grid under unstable cases.

1.3 Objectives of the Dissertation

The prime objective of the dissertation is developing reliable and effective control strategy for wind turbine based PMSG to ensure reliable and continuous integration to the grid.

The prime works of the Dissertation are:

1- Mathematical analyses and modeling wind turbine based permanent synchronous generator

2- Incorporating MPPT of W.T.

3- Development control strategy for a STATCOM with to reinforce operation of grid-connected W.T. voltage sag, swell and fault.

1.4 Dissertation Outline

The dissertation consists of six chapters:

Chapter 1 represents a brief introduction to the thesis, the motivations of the thesis, the work objectives and the thesis outline.

Chapter 2 reviews the literature related issue and impacts of wind turbine insertion to network. Besides different W.T. configurations are presented. Also this chapter includes a brief survey for available techniques in literature ranging from the fundamental work to the current research.

Chapter 3 presents the mathematical analysis and modeling of wind turbine. W.T characteristic and aerodynamics power control strategy is investigated.

Besides, it presents the analysis and modeling of PMSG used in this research. Modeling of PMSG in d-q Reference and its equivalent circuit are presented. Also discusses control strategy for W.T based PMSG. The modeling, analyses and controlling of W.T using switch-mode rectifier and maximum power extraction technique are presented.

Chapter 4 presents the issue and impact with W.T insertion to the power network. The operation and control of STATCOM are investigated to reinforce dynamic behavior of a grid-connected W.T.

Chapter 5 discusses the simulation results of the proposed system.

Chapter 6 is the conclusion chapter which summarizes the results of this thesis and highlights the achievements of this work. In addition, some topics for further research are also suggested.