Investigation and Development of Converter-Inverter set for Wind Power Generation

By

Molla Biweta Yimer

A Dissertation Submitted to the Department of Electrical and Computer Engineering
School of Electrical Engineering and Computing

Presented in Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Electrical Power Engineering

Office of Graduate Studies
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DEDICATION

This dissertation work is fully dedicated to my beloved wife Birknesh Tadesse and daughter Rediet Molla for their endless encouragement and motivation during my doctoral study!

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Molla Biweta Yimer have read and evaluated his dissertation entitled "Investigation and Development of Converter-Inverter set for Wind Power Generation" and examined the candidate. This is, therefore, to certify that the dissertation has been accepted in fulfillment of the requirement for the degree of Doctor of Philosophy in Electrical Power Engineering.

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DECLARATION

I hereby declare that this PhD dissertation is my original work and has not been presented for a degree in any other university and all sources of material used for this dissertation have been duly acknowledged.

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This PhD dissertation entitled “Investigation and Development of Converter-Inverter set for Wind Power Generation” has been submitted for examination with my approval as dissertation Supervisor.

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Signature: _____________________________

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Molla Biweta Yimer

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C	Capacitance
C_p	Power coefficient
C_Q	Torque coefficient
f	Electric frequency
I	Steady-state value of variable current
I_{dc}	DC-link current
i_{ds}	Direct-axis current in the rotor reference frame
I_i	Integral term of current controller
i_{qs}	Quadrature-axis current in the rotor reference frame
I_u	Integral term of voltage controller
iαs,	ibs,, ics Instantaneous stator current of phase-A, B, C
J	Moment of inertia
K_{pi}	Proportional gain of current controller
K_{pu}	Proportional gain of voltage controller
L_d	Direct-axis stator inductance
Lq	Quadrature-axis stator inductance
Ls	Stator inductance
n	Rotational speed
P	Number of pole pairs
P	Active power
P_T	Turbine power
Q	Reactive power
R	Rotor radius
Rs	Stator resistance
Te	Electromagnetic torque
T_{wt}	Turbine torque
Usd	Direct-axis stator voltage
Usq	Quadrature-axis stator voltage
U	Steady-state value of variable voltage
V	Wind speed
V_{dc}	DC-link voltage
X	Reactance
θr	Rotor position angle
λ	Tip-speed ratio
Ψ	Flux linkage
ωe	Angular electrical speed

ωr	Rotor angular velocity
ρ	Air density

LIST OF ABBREVIATIONS

AC	Alternating Current
CSC	Current Source Converter
DC	Direct Current
DD	Direct Drive
DFIG	Doubly-Fed Induction Generator
DTC	Direct Torque Control
EMF	Electromotive Force
EMI	Electro-Magnetic Interference
FF	Feed Forward
FOC	Filed-Oriented Control
FSWT	Fixed Speed Wind Turbine
FVFF	Fixed Voltage Fixed Frequency
GSC	Generator Side Converter
HAWT	Horizontal Axis Wind Turbines
HF	High Frequency
HVDC	High Voltage DC
IM	Induction Machine
LSC	Load Side Converter
NPC	Neutral-Point Clamped
PI	Proportional-Integral
PM	Permanent Magnet
PMSG	Permanent Magnet Synchronous Generator
PWM	Pulse Width Modulation
RPM	Revolution per Minute
SCIG	Squirrel Cage Induction Generator
SVM	Space Vector Modulation
SVPWM	Space-Vector Pulse Width Modulation
VAWT	Vertical Axis Wind Turbines
VC	Vector Control
VFD	Variable-Frequency Drive
VOC	Voltage Oriented Control
VSC	Voltage Source Converter
VSFP	Variable-Speed Fixed Pitch
VVFF	Variable Voltage Fixed Frequency
VVVF	Variable Voltage Variable Frequency
WECS	Wind Energy Conversion System
WRIG	Wound Rotor Induction Generator
WT	Wind Turbine

ABSTRACT

Wind energy conversion system (WECS) model development for steady and dynamic state analysis and design has been research issue in recent years. This investigative research work presents a new block-based approach for WECS dynamic modelling. The blocks (modules) developed by Aalborg University - Denmark, RISO national laboratory based on Kaimal Spectra have been customized, updated and integrated into Matlab/Simulink platform and then utilized to simulate performance of 5kW WECS based on Permanent Magnet Synchronous Generator (PMSG). In addition to the developed block sets, in this research work, a proportional-integral controller is designed to control the turbine pitch and integrated with the simulation models. The simulation results demonstrate that the model outputs are in agreement with what is expected.

Moreover, in this research work, alternative closed-loop control strategy of generator and load side converters are presented for which an investigation and simulation of two-level, back-to-back voltage source converter has been carried out using PLECS software on Matlab/Simulink. Both rotor speed of the PMSG side and the DC-link voltage of load side are controlled by a PI controller. This control strategy has been achieved by using field oriented control (FOC) often referred as vector control method. Using PLECS software packages for modeling and simulation of circuit-oriented electric and electronic dynamic systems, is considered as special feature for high-speed simulations in graphic modeling (block diagram) method that is commonly used in control engineering. The validity and performance of the applied control scheme has been verified by simulation results and the simulation results demonstrate that the controller is capable of maintaining constant DC-link voltage under varying supply voltage (250V - 400 V) and frequency (25Hz -50Hz) from the source and different electrical load conditions (DC and AC).

KEYWORDS: Wind Energy Conversion system (WECS), Permanent Magnet Synchronous Generator (PMSG), Field Oriented Control (FOC), Modeling and Simulation, Plecs, Matlab/Simulink.