



Cairo University

VOLTAGE AND FREQUENCY CONTROL OF STAND-
ALONE DOUBLY-FED INDUCTION GENERATORS
FOR VARIABLE SPEED WIND ENERGY
CONVERSION SYSTEMS

By

Mohamed Mahmoud Anwar Mohamed Sharawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRICAL POWER AND MACHINES ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
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Title of Thesis:

Voltage and Frequency Control of Stand-Alone Doubly-Fed Induction Generators for
Variable Speed Wind Energy Conversion Systems

Key Words:

Stand-Alone Wind Energy Conversion Systems; Aerodynamics of Wind Turbine;
Dynamic Modeling of Doubly-Fed Induction Generator; Indirect Vector Control;
Maximum Power Point Tracking

Summary:

Self-excited induction generators usually suffer from variable output voltage frequency and magnitude with variation of wind speed when they are used in stand-alone variable speed Wind Energy Conversion Systems (VSWECS). The doubly-fed induction generators (DFIGs) have been used in stand-alone VSWECS applications. Controlling the magnitude and frequency of the stator output voltage for DFIG achieved by controlling the rotor input voltage, magnitude and frequency. The maximum power point tracking control technique is applied to DFIG for optimum operating point.

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Table of Contents

ACKNOWLEDGMENTS	I
TABLE OF CONTENTS.....	II
LIST OF TABLES	IV
LIST OF FIGURES	V
NOMENCLATURE.....	VIII
ABSTRACT	XII
CHAPTER 1 : INTRODUCTION.....	1
1.1. INTRODUCTION	1
1.2. INTRODUCTION TO WIND ENERGY CONVERSION SYSTEM.....	1
1.3. TYPES OF WIND TURBINES USED IN WECS.....	2
1.3.1. Vertical Axis Wind Turbine (VAWT)	2
1.3.2. Horizontal Axis Wind Turbine (HAWT).....	3
1.4. COMPONENTS OF HAWT USED IN WECS	4
1.5. TYPES OF ELECTRICAL GENERATORS USED IN FIXED AND VARIABLE SPEED WECS	7
1.5.1. Direct Current Generators	7
1.5.2. AC Synchronous Generators (SGs)	7
1.5.3. AC Asynchronous (Induction) Generators.....	8
1.5.3.1. Squirrel- Cage Induction Generators (SCIGs)	9
1.5.3.2. Wound-Rotor (Slip Ring) Induction Generator.....	10
1.5.3.2.1. Limited Speed WECS Mode of Operation	10
1.5.3.2.2. Variable Speed WECS Mode of Operation.....	11
1.6. STAND-ALONE WIND ENERGY CONVERSION SYSTEM	12
1.7. THESIS OBJECTIVES	13
1.8. THESIS ORGANIZATION	13
CHAPTER 2 : MODELLING OF WIND TURBINE.....	15
2.1. INTRODUCTION	15
2.2. AERODYNAMIC MODEL	16
2.3. MATLAB/ SIMULINK OF WIND TURBINE	19
CHAPTER 3 : MODELLING OF DOUBLY-FED INDUCTION GENERATOR	23
3.1. INTRODUCTION	23
3.2. DFIG MODEL EXPRESSED IN THE ABC REFERENCE FRAME	23
3.3. DFIG MODEL EXPRESSED IN THE D-Q REFERENCE FRAME	29
3.4. MATLAB/ SIMULINK MODEL FOR DFIG	38
CHAPTER 4 : CONTROL AND MPPT OF STAND-ALONE DFIG USED IN WECS	43
4.1. INTRODUCTION	43

4.2.	EFFECTS OF ROTOR INPUT VOLTAGE OF DFIG	43
4.2.1.	Sub-Synchronous Speed Mode of Operation	44
4.2.2.	Super-Synchronous Speed Mode of Operation.....	45
4.3.	FUNDAMENTALS OF VECTOR CONTROL OF INDUCTION MACHINES ...	47
4.4.	VECTOR CONTROL IMPLEMENTATION OF DFIG.....	50
4.5.	MAXIMUM POWER POINT TRACKING FOR DFIG USED IN WECS	53
4.5.1.	Characteristics of Wind Turbines for MPPT	53
4.5.1.1.	Low-Speed Region.....	54
4.5.1.2.	Moderate-Speed Region.....	54
4.5.1.3.	High-Speed Region.....	54
4.5.2.	Maximum Power Point Tracking Control Algorithms.....	55
4.5.2.1.	Algorithms Based on Wind Speed and Turbine Speed	55
4.5.2.2.	Algorithms Based on The Output Power Measurement and Calculation	56
4.5.2.3.	Algorithms Based on Power Characteristic Curve	57
CHAPTER 5 : MATLAB/SIMULINK AND SIMULATION RESULTS.....		58
5.1.	INTRODUCTION	58
5.2.	DFIG POWER FLOW.....	58
5.3.	SUB-SYNCHRONOUS SPEED MODE OF OPERATION	60
5.3.1.	Mechanical Calculations	60
5.3.2.	Electrical Calculations	61
5.3.3.	Simulation and Results.....	63
5.4.	SUPER-SYNCHRONOUS SPEED MODE OF OPERATION.....	70
5.4.1.	Mechanical Calculations	70
5.4.2.	Electrical Calculations	72
5.4.3.	Simulation and Results.....	73
5.5.	MPPT FOR DFIG BASED ON POWER CHARACTERISTIC CURVE CONTROL STRATEGY	79
5.5.1.	MATLAB/SIMULINK Model Implementation Using MPPT Algorithm	80
CHAPTER 6 : CONCLUSIONS AND FUTURE WORKS		88
6.1.	SUMMARY	88
6.2.	FUTURE WORKS.....	89
REFERENCES		90

List of Tables

Table 1.1: comparison between VAWT and HAWT	3
Table 2.1: Turbine main parameters.....	19
Table 3.1: DFIG Main Parameters	38

List of Figures

Figure 1.1: Block Diagram showing the components of WECS connected to grid (dashed item is architecture dependent)	2
Figure 1.2: Horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) [3].....	4
Figure 1.3: Main Components of HAWT used in WECS	4
Figure 1.4: Contributions of main components for wind turbine in percentage terms to the overall cost.....	6
Figure 1.5: Schematic of a DC generator system	7
Figure 1.6: Configurations of synchronous generator used in variable speed WECS ((a) with gearbox and (b) without gearbox)	8
Figure 1.7: Grid connected-Fixed speed WECS using SCIGs	9
Figure 1.8: Grid connected-variable speed WECS using SCIGs	9
Figure 1.9: Stand-alone-variable speed WECS using SCIGs.....	10
Figure 1.10: Slip ring induction generator used in limited variable speed WECS.....	11
Figure 1.11: DFIG used in variable speed WECS.....	11
Figure 1.12: Proposed system of stand-alone DFIG used in variable-speed WECS.....	13
Figure 2.1: Block scheme of a variable speed wind turbine-generator systems model .	15
Figure 2.2: Different parts of wind turbine	16
Figure 2.3: Flow of air through wind turbine	16
Figure 2.4: Rotor blade and pitch angle of wind turbine.....	17
Figure 2.5: Betz Limit illustration	18
Figure 2.6: Schematic block diagram of the wind turbine MATLAB model system	20
Figure 2.7: The power Coefficient C_P as function of tip speed ratio λ and blades angle β at wind speed equal 5.5 m/s and rotor radius of 42 m	20
Figure 2.8: The power Coefficient C_P as function of tip speed ratio λ at $\beta = 0^\circ$	21
Figure 2.9: The wind turbine power P_t at low speed shaft with the rotor angular speed ω_t at different wind speed V_w	21
Figure 2.10: The wind turbine torque T_t at low speed shaft with the rotor angular speed ω_t at different wind speed V_w	22
Figure 2.11: The generator mechanical input torque T_G at high speed shaft with the rotor rotational speed N_G at different wind speed V_w	22
Figure 3.1: Ideal three-phase windings (stator and rotor) of the DFIG.....	24
Figure 3.2: DFIG electric equivalent circuit.....	25
Figure 3.3: Three phase winding machine representation.....	29
Figure 3.4: Transformed two-phase winding machine representation	29
Figure 3.5: Stationary frame a-b-c to d^s - q^s axes transformation	30
Figure 3.6: Stationary frame d^s - q^s to synchronously rotating frame d^e - q^e transformation	32
Figure 3.7: Dynamic d – q equivalent circuit of DFIG in synchronously rotating reference frame ((a) q-axis and (b) d-axis).....	37
Figure 3.8: Matlab M-file calculations for DFIG	39
Figure 3.9: Schematic block diagram for the dynamic modelling of DFIG using MATLAB/SIMULINK.....	40
Figure 3.10: Stator rms terminal output voltage V_t (V)	41
Figure 3.11: Stator output frequency F_s (Hz).....	41
Figure 3.12: Generator rotational speed N_g (rpm).....	42

Figure 3.13: Generator electromechanical torque T_g (N.m)	42
Figure 4.1: Transformation of rotor abc reference frame to d_r - q_r synchronously rotating reference frame at sub-synchronous speed	45
Figure 4.2: Transformation of rotor acb reference frame to d_r - q_r synchronously rotating reference frame at super-synchronous speed	46
Figure 4.3: Separately excited DC motor control	47
Figure 4.4: Vector-controlled induction machine	48
Figure 4.5: Implementation of vector control principle	49
Figure 4.6: Vector control of DFIG	50
Figure 4.7: Phasor diagram for stator flux oriented vector control	52
Figure 4.8: Mechanical power against rotor speed for different wind speeds	54
Figure 4.9: Ideal power curve of wind turbine	55
Figure 4.10: Tip speed ratio control of WECS	56
Figure 4.11: HCS Control Principle	56
Figure 4.12: WECS with hill climb search control	57
Figure 4.13: Power signal feedback control	57
Figure 5.1: Power flow diagram of DFIG	59
Figure 5.2: Turbine power with generator rotational speed at wind speed 5.5 m/s	60
Figure 5.3: Generator mechanical torque with rotational speed at wind speed 5.5 m/s	61
Figure 5.4: Control scheme for the stand-alone DFIG	63
Figure 5.5: SIMULINK /Model of DFIG connected to wind turbine	64
Figure 5.6: Quadrature axis of the rotor input current I_{qr} (A)	65
Figure 5.7: Direct axis of the rotor input current I_{dr} (A)	65
Figure 5.8: Instantaneous value of the rotor input voltage v_{abcr} (V)	66
Figure 5.9: Zoom view of Figure 5.8 between 24.5 and 27 second	66
Figure 5.10: Frequency of the rotor input voltage F_r (Hz)	67
Figure 5.11: Generator rotational speed N_g (rpm)	67
Figure 5.12: Rotor power P_r (W)	68
Figure 5.13: Instantaneous stator output voltage v_{abcs} (V) of DFIG	68
Figure 5.14: Stator rms terminal output voltage V_t (V)	69
Figure 5.15: Stator output frequency F_s (Hz)	69
Figure 5.16: Stator output and reference power (W)	70
Figure 5.17: Generator electromechanical torque T_g (N.m)	70
Figure 5.18: Turbine power with generator rotational speed at wind speed 7.5 m/s	71
Figure 5.19: Generator mechanical torque with rotational speed at wind speed 7.5 m/s	71
Figure 5.20: Quadrature axis of the rotor input current I_{qr} (A)	73
Figure 5.21: Direct axis of the rotor input current I_{dr} (A)	74
Figure 5.22: Instantaneous value of the rotor input voltage v_{abcr} (V)	74
Figure 5.23: Zoom view of Figure 5.22 between 25 and 30 second	75
Figure 5.24: Frequency of the rotor input voltage F_r (Hz)	75
Figure 5.25: Generator rotational speed N_g (rpm)	76
Figure 5.26: Rotor power P_r (W)	76
Figure 5.27: Instantaneous stator output voltage v_{abcs} (V) of DFIG	77
Figure 5.28: Stator rms terminal output voltage V_t (V)	77
Figure 5.29: Stator output frequency F_s (Hz)	78
Figure 5.30: Stator output and reference power (W)	78
Figure 5.31: Generator electromechanical torque T_g (N.m)	79
Figure 5.32: The wind turbine power P_t with the rotor angular speed ω_t	80
Figure 5.33: MPPT based on Power characteristic curve (Regulation of power)	80

Figure 5.34: PSF control strategy and lookup table	81
Figure 5.35: Wind speed profile	82
Figure 5.36: Quadrature axis of the rotor input current I_{qr} (A)	82
Figure 5.37: Direct axis of the rotor input current I_{dr} (A)	83
Figure 5.38: Instantaneous value of the rotor input voltage v_{abcr} (V)	83
Figure 5.39: Zoom view of Figure 5.38 between 61 and 62 second	84
Figure 5.40: Frequency of the rotor input voltage F_r (Hz)	84
Figure 5.41: Generator rotational speed N_g (rpm)	85
Figure 5.42: Rotor power P_r (W)	85
Figure 5.43: Instantaneous stator output voltage v_{abcs} (V) of DFIG	86
Figure 5.44: Stator rms terminal output voltage V_t (V)	86
Figure 5.45: Stator output frequency F_s (Hz)	87
Figure 5.46: Stator output and reference power (W)	87

Nomenclature

A	The swept surface area = πR^2 (m ²).
C_p	The power coefficient.
DFIG	Doubly-fed induction generator.
EESG	Electrically excited synchronous generator.
GSC	Grid side converter.
HAWT	Horizontal axis wind tyrbine.
HCS	Hill-climb search.
i_{as} , i_{bs} and i_{cs}	The stator currents of phases a, b, and c (A).
i_{ar} , i_{br} and i_{cr}	The rotor currents of phases a, b, and c (A).
i_{qs} , i_{ds} , i_{qr} , i_{dr}	The stator and rotor currents component respectively (A).
I_a	The armature current of separately excited DC motor (A)
I_f	The field current of separately excited DC motor (A).
J	The rotor inertia (Kg.m ²).
K	The machine constant (N.m/A.Wb).
LSC	Load side converter.
L_{ls}	The stator leakage inductance per phase (H).
L_{ms}	The stator magnetizing inductance per phase (H).
L_{asbs} , L_{ascs} , L_{bsas} , L_{bscs} , L_{csas} and L_{csbs}	The stator-to-stator mutual inductance per phase (H).
L_{arar} , L_{brbr} and L_{crer}	The rotor self-inductances per phase (H).
L_{lr}	The rotor leakage inductance per phase (H).
L_{mr}	The rotor magnetizing inductance per phase (H).
L_{arbr} , L_{arcr} , L_{brar} , L_{brcr} , L_{crar} and L_{crbr}	The rotor-to-rotor mutual inductance per phase (H).
L_{sr}	The peak value of mutual inductance between a stator and a rotor winding per phase (H).
MPPT	Maximum power point tracking.
mmf	Magnetomotive force.
N_G	Rotational speed of the generator shaft (rpm).
n_s	DFIG stator winding number of turns per phase.
n_r	DFIG rotor winding number of turns per phase.

PMSG	Permanent magnet synchronous generator.
PSF	Power signal feedback.
PWM	Pulse width modulation.
P_t	The extracted mechanical power from the turbine (W)
p	The number of poles of DFIG.
P	The number of pole pairs of DFIG.
P_o	The output power from doubly-fed induction generator (W)
P_s	The stator power (W).
P_r	The rotor power (W).
P_s	The stator electrical output power (W)
P_r	The rotor electrical (in/out) power (W)
P_{cus}	The stator copper losses (W).
P_{cur}	The rotor copper losses (W).
P_m	The mechanical input power (W).
P_{max}	The optimum or maximum power extracted from a wind turbine (W).
Q_s	The stator reactive power respectively (VAR).
Q_r	The rotor reactive power respectively (VAR).
RSC	Rotor side converter.
R	The radius of rotor blades (m).
R_s	The stator winding resistance per phase (Ω).
R_r	The rotor winding resistance per phase (Ω).
R_L	The load resistance per phase (Ω).
SCIG	Squirrel cage induction generator.
SG	Synchronous generator.
s	The slip.
TSR	Tip speed ratio.
T_t	The turbine torque (N.m).
T_e	The electromagnetic torque developed by the DFIG (N.m).
T	the electro-magnetic torque of separately excited DC motor (N.m).
VAWT	Vertical axis wind turbine.
VSCF	Variable speed constant frequency.

V_w	The wind speed (m/s).
v_{as}, v_{bs} and v_{cs}	The applied stator voltages (V).
v_{ar}, v_{br} and v_{cr}	The applied rotor voltages (V).
$v_{qs}, v_{ds}, v_{qr}, v_{dr}$	The stator and rotor voltages component respectively (V).
v_{ar}, v_{br}, v_{cr}	The instantaneous value of the rotor input voltages per phase (V).
V_m	The amplitude of the rotor input voltage per phase (V).
V_{cut-in}	The cut-in wind speed of wind turbine.
$V_{cut-out}$	The cut-out wind speed of wind turbine.
β	The pitch angle of the rotor blades (degree).
θ_m	The angle between the magnetic axes of stator phase winding, A, and rotor phase winding (electrical degree).
θ_e	The angle between the q-axis of the stationary reference frame fixed on the stator and rotating q-d axes (electric degree).
θ_r	The angle between the q-axis of the stationary reference frame fixed on the rotor and rotating q-d axes (electric degree).
λ	The tip speed ratio.
λ_{opt}	The optimum tip speed ratio.
ρ	The air density = 1.225 kg/m ³ at 15°C and normal pressure.
Φ	The phase shift angle (in degrees).
ψ_{as}, ψ_{bs} and ψ_{cs}	The stator fluxes (Wb. turn). The stator side electric variables.
ψ_{ar}, ψ_{br} and ψ_{cr}	The rotor fluxes (Wb. turn).
ψ_a	The armature flux of separately excited DC motor (Wb).
ψ_f	The field flux of separately excited DC motor (Wb).
ψ_{ds}	The d-axis component of the stator flux.
ψ_s	The stator flux.
WECS	Wind energy conversion system.
WRIG	Wound rotor induction generator.
ω_t	The rotor angular velocity of the turbine (mechanical rad/sec).
ω_s	The angular frequency of the voltages and currents of the stator windings (elec.rad/s).
ω_r	The angular frequency of the voltages and currents of the rotor windings (elec.rad/s).
ω_m	The rotor angular frequency of the generator (elec.rad/s).

ω_{opt}

The optimum turbine rotor speed (mec.rad/sec).

Ω_m

The mechanical angular speed of the rotor (mech.rad/s).