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

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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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Nomenclature

A	The swept surface area = πR^2 (m^2).
C_P	The power coefficient.
DFIG	Doublly-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_{qs} , 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_{crcr}	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 torqe 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_{qs} , 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).
$V_{cut\text{-}in}$	The cut-in wind speed of wind turbine.
$V_{cut\text{-}out}$	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/m3 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).