ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT

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Power Management of Open Winding PM Synchronous Generator for Unbalanced Voltage Condition

by

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A Thesis submitted in partial fulfillment for the requirements for the degree of **Master in Electrical Engineering**

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ABSTRACT

Wind energy is currently the fastest growing electricity source worldwide. Since wind generators have to compete with other energy sources, their cost efficiency is effective. In this thesis, a system utilizing an open-winding Permanent Magnet Synchronous Generator (PMSG) is studied for wind energy generation. The proposed system controls generated power using an auxiliary voltage source inverter. The volt ampere (VA) rating of the auxiliary inverter is only a fraction of the system rated power. An adjusted control system, which consists of two main parts, the first is implemented to control the generator power and the second is control the active and the reactive power injected into the grid. Balanced and unbalanced voltage effects are studied for the wind generation model. Theoretical and experimental results are demonstrated which verify the validity of the proposed system to achieve the power management requirements for balanced and unbalanced voltage condition of the grid. The proposed system is designed and simulated utilizing MATLAB /Simulink software.

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List of Abbreviations

A/D	**Analogue to Digital**
CVVF	**Constant volt variable frequency**
D/A	**Digital to Analogue**
DFIGs	**Doubly fed induction generators**
DG	**Distributed generation**
DSP	**Digital Signal Processor**
GSC	**Grid side converter**
GB	**Gear box**
HAWT	**Horizontal-Axis Wind Turbines**
HCC	**Half-controlled-converters**
HEVs	**Hybrid electric vehicles**
HVDC	**High voltage direct current**
I/O	**Input-Output**
LVRT	**Low voltage right through problem**
MERC	**Magnetic energy recovery**
MPPT	**Maximum power point tracking**
NPC	**Neutral point clamped**
NREA	**New and Renewable Energy Authority**
NRSE	**Renewable Sources of Energy**
ORB	**Optimum relationship-based**
PCC	**Point of common coupling**
PID	**Proportional Integral Differential**
PLLs	**Phase-lock loops**
PM	**Permanent magnet**
PMSG	**Permanent Magnet Synchronous Generator**
PWM	**Pulse Width Modulation**
RSC	**Rotor-side converter**
RES	**Renewable energy source**
SCIG	**Squirrel-cage induction generator**

SSSC	**Static synchronous series compensator**
SHE	**Selective Harmonic Elimination**
WEC	**World Energy Council**
WPS	**Wind power system**
WRIG	**Wound rotor induction generators**
WRSGs	**Wound-rotor synchronous generators**
WT	**Wind turbine**
THD	**Total harmonic distortion**
TSR	**Tip speed ratio**
UPQC	**Unified power quality conditioner**
VA	**Volt ampere**
VAWT	**Vertical-Axis Wind Turbines**
VOC	**Voltage oriented control**
VSC	**Voltage source converter**
VSI	**Voltage source inverter**
VSR	**Voltage source rectifier**

LIST OF NUMENCLEATURE

i_d, i_q	d-and q-axis components of stator currents.
R_a	Generator resistance
J	Rotor and shaft moment of inertia.
L_d, L_d	d-and q-axis inductances.
$\frac{d}{dt}$	Differential operator.
P	Number of pole pairs.
v_d, v_d	d-and q-axis components of stator voltages.
P_{wind}	Wind power
ρ	Wind density
A	Blades swept area
V	Wind speed
C_p	power coefficient
λ	Tip speed ratio
β	pitch blade angle
$[c_1 \ldots\ldots c_9]$	Characteristic constants for each wind turbine
R	Wind turbine radius
θ	Angle between phase a-axis and direct axis.
v_{abcg}	Three phase stator voltages
i_{abcg}	Three phase stator currents
φ_{abc}	Three phase stator flux
R_a	Resistance of the three phase stator winding
φ_f	The amplitude of the flux linkages established by the permanent magnet
l_{aa}, l_{bb}, l_{cc}	Self-inductances of phase abc
$l_{ab} = l_{ba}$	Mutual inductance between phase a and b
$l_{bc} = l_{cb}$	Mutual inductance between phase b and c
$l_{ac} = l_{ca}$	Mutual inductance between phase a and c
ω_e	Electrical angular frequency
ω_r	Rotor mechanical angular frequency
T_e	Electromechanical torque
T_L	Load torque
ω_s	Supply voltage angular frequency
V_{PH}	RMS value of the phase voltage
f	Supply frequency
V_{LL}	Rms value line-to-line voltage.
m_a	Modulation index
$\hat{V}_m$	Amplitude of the modulating signals

$\hat{V}_c$	**Amplitude of the carrier signals**
P_{gen}	**Generator power**
P_{grid}	**Active power injected to the grid**
φ_{grid}	**Grid power factor angle**
Q_{grid}	**Reactive power injected to the grid**
Q^{*}_{grid}	**Reference for the reactive power**
v_{di}	**Decoupled controller in the d-axes**
v_{qi}	**Decoupled controller in the q-axes**
L_{1k}	**Leakage inductance**
I_a	**Armature current**
V_{gen}	**Generator output volt**
V_{sc}	**Compensator voltage**
V_{rect}	**Rectifier voltage**
δ	**Power angle**
φ_{sc}	**Angle defined from the compensator voltage to the rectifier voltage.**

ملخص البحث

تعد طاقة الرياح حاليا من مصادرالكهرباء الأسرع نموا في العالم. حيث أن مولدات الرياح التى تستخدم فى طاقة الرياح تتنافس مع غيرها من مصادر الطاقة من حيث الكفاءة و التكلفة الفعلية. تتناول هذه الرسالة دراسة الاستفادة من المولد متزامن مفتوح الملفات ذى مغناطيس دائم (PMSG) الذي يستخدم في طاقة الرياح. وتم التحكم فى النظام المقترح باستخدام العاكس المساعد. و يتميز العاكس المساعد بانه ليس سوى جزء صغير من اجمالي طاقة النظام. نظام التحكم يتكون من جزئين رئيسيين الأول يتحكم فى السيطرة على طاقة المولد و الثانى يتحكم في الطاقة المرسلة إلى الشبكة. تم دراسة تاثير الجهد المتوازن وغير المتوازن لنظام المقترح. وأظهرت النتائج النظرية والتجريبية من صلاحية النظام المقترح لتحقيق متطلبات إدارة الطاقة لحالة الجهد المتوازن و الغير متوازن من الشبكة. تم تصميم النظام المقترح ومحاكاة باستخدام برنامج MATLAB / SIMULINK.

وتحتوي هذه الرسالة علي ستة فصول، تم تناولها على النحو الآتي:

الفصل الأول:

يتناول بعض المفاهيم الأساسية حيث يقدم انواع الطاقة المتجددة و خاصة طاقة الرياح. كما يعرض جميع انواع المولدات التي يتم استخدامها.حيث يعرض ايضا تعريف المشكلة و هي ادارة الطاقة.

الفصل الثانى:

يعرض هذا الباب مسحاً علمياً شاملاً للأبحاث و الدراسات التي أجريت و المتعلقة للفكرة التى تم دراستها.

الفصل الثالث:

عمل نموذج لمولد متزامن مفتوح الملفات ذى مغناطيس دائم بواسطة محاكاة برنامج MATLAB / SIMULINK. و يعرض نظرة عامة عن نظام التحويل في طاقة الرياح.

الفصل الرابع:

يقدم شرح لنظام المقترح تعريفه واستخداماته وطريقه اتصاله ومميزاته. و يعرض نتائج البرنامج MATLAB / SIMULINK علي الحالات التى تم دراستها. وأظهرت النتائج النظرية من صحة النظام المقترح لتحقيق متطلبات إدارة الطاقة لحالة الجهد المتوازن و الغير متوازن من الشبكة.

الفصل الخامس:

هذا الفصل يوضح العمل التجريبى (العملي). ففي الجزء الأول، يتم توضيح وتحليل النظام. و تم استخدام DSP لتوليد نبض تعديل العرض (PWM) و تم دراستها والنتائج أظهرت صحة النظام المقترح لتحقيق متطلبات إدارة الطاقة لحالة الجهد المتوازن.

الفصل السادس:

يشمل خلاصة البحث والتوصيات المقترحة والدراسة المستقبلية.