



**ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT**

**College of Engineering and Technology- Cairo**

***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  
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***Ashraf Saeed***

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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**

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

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

## 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.
$L_d, L_q$	d-and q-axis inductances.
$\frac{d}{dt}$	Differential operator.
$P$	Number of pole pairs.
$v_d, v_q$	d-and q-axis components of stator voltages.
$P_{wind}$	Wind power
$\rho$	Wind density
$A$	Blades swept area
$V$	Wind speed
$C_p$	power coefficient
$\lambda$	Tip speed ratio
$\beta$	pitch blade angle
$[c_1 \dots c_9]$	Characteristic constants for each wind turbine
$R$	Wind turbine radius
$\Theta$	Angle between phase a-axis and direct axis.
$v_{abcg}$	Three phase stator voltages
$i_{abcg}$	Three phase stator currents
$\Phi_{abc}$	Three phase stator flux
$R_a$	Resistance of the three phase stator winding
$\Phi_f$	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
$\omega_e$	Electrical angular frequency
$\omega_r$	Rotor mechanical angular frequency
$T_e$	Electromechanical torque
$T_L$	Load torque
$\omega_s$	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

$\widehat{V}_c$	Amplitude of the carrier signals
$P_{gen}$	Generator power
$P_{grid}$	Active power injected to the grid
$\varphi_{grid}$	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
$\delta$	Power angle
$\varphi_{sc}$	Angle defined from the compensator voltage to the rectifier voltage.

## ملخص البحث

تعد طاقة الرياح حالياً من مصادر الكهرباء الأسرع نمواً في العالم. حيث أن مولدات الرياح التي تستخدم في طاقة الرياح تتنافس مع غيرها من مصادر الطاقة من حيث الكفاءة و التكلفة الفعلية. تتناول هذه الرسالة دراسة الاستفادة من المولد متزامن مفتوح الملفات ذي مغناطيس دائم (PMSG) الذي يستخدم في طاقة الرياح. وتم التحكم في النظام المقترح باستخدام العاكس المساعد. و يتميز العاكس المساعد بأنه ليس سوى جزء صغير من إجمالي طاقة النظام. نظام التحكم يتكون من جزئين رئيسيين الأول يتحكم في السيطرة على طاقة المولد و الثانى يتحكم في الطاقة المرسله إلى الشبكة. تم دراسة تأثير الجهد المتوازن و غير 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 ايضاً تعريف المشكلة و هي ادارة الطاقة.

### الفصل الثانى:

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

### الفصل الثالث:

عمل نموذج لمولد متزامن مفتوح الملفات ذي 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 التي 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 التجريبي (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.