Cairo University

DESIGN AND IMPLEMENTATION OF A VARIABLE-STRUCTURE ADAPTIVE FUZZY-LOGIC PITCH AND MAXIMUM POWER POINT TRACKING CONTROLLERS FOR LARGE WIND TURBINES

By

Hanan Hany Aly Fawzy

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 Machine Department

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

Design And Implementation Of A Variable-Structure Adaptive Fuzzy-Logic Pitch And Maximum Power Point Tracking Controllers For Large Wind Turbines

Key Words:
Pitch Control; Maximum Power Point Tracking; Variable-Structure Fuzzy Logic; Processor-In -the-Loop.

Summary:
Increasing demand of energy versus decreasing in global reserves of non-renewable energy resources and its undeniable polluted effect on our environment leads to the global interest in renewable energy resources. In renewable energy resources the biggest challenge is how to control the energy produced from natural phenomena to reach the optimized usage. This thesis is concerned with wind energy in two challengeable issues. First is how to maximize the generated energy along a wide range of wind speeds which is known as maximum power point tracking. Second is protection against high wind speeds which is known as pitch control. Variable structure fuzzy logic control technique is used in both pitch control and power regulator controller in maximum power point tracking. The robustness and computability of variable structure fuzzy logic control with variable parameters plant

is shown by exposing the wind turbine to three different wind profiles. The verification of the designed controller is made not only by model-in-the loop verification technique using Matlab/Simulink simulation platform, but also an advanced step in controller design verification steps is done using processor-in-the loop verification technique. In this thesis Processor-in-the loop verification is held by downloading the designed controller on TMS320F28335 microprocessor using code composer studio software, and run it online with the simulink model of the wind turbine. A comparison will be made between the simulation results of model-in-the loop simulation and processor-in-the-loop simulation. It is sown that decreasing the sampling time in processor-in-the loop simulation make the simulation results closer to model-in-the loop simulation results.

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عنوان الرسالة:

التصميم والتنفيذ العملي لنظام تحكم ضبابي متوائم في تحريك شفرات تربينة الرياح وأيضا التحكم في استخراج أقصي قدرة من تربينة الرياح.

الكلمات الدالة:

طاقة الرياح، تحريك شفرات تربينة الرياح، المتحكم الضبابي المتوائم، تتبع مسار أقصي قدرة ، المعالج.

ملخص الرسالة:

لم تعد مصادر الطاقة الغير متجددة قادرة علي مواكبة النمو الزائد لاحتياجات الاستهلاك المختلفة للطاقة لذا فقد تحول مركز اهتمام الابحاث العلمية المختلفة لتوليد الطاقة بشكل كلي لتطوير وسائل توليد الطاقة الكهربية من الطاقة المتجددة و التحكم فيها لاستغلالها الاستغلال الأمثل و التغلب علي المعوقات التي تواجهها من أكبر المعوقات التي تواجهها. من أكبر المعوقات التي تواجه توليد الطاقة الكهربائية من الطاقة المتجددة هي اعتماد هذه المصادر علي ظواهر طبيعية متغيرة الكم و الكيف . من أمثلة ذلك طاقة الرياح ذات الطبيعة المتغيرة للرياح من حيث سرعتها و اتجاهها. موضوع هذه الرسالة يستهدف نقطتين هامتين من نقاط التحكم في طاقة الرياح . النقطة الأولي هي كيفية توليد أقصي طاقة يمكن توليدها عند سرعات الرياح المختلفة عن طريق التحكم في سرعة دوران المولد الكهربي . النقطة الثانية هي كيفية حماية المولد من زيادة تحميله في حالة سرعات الرياح العالية و التي تتعدي السرعة الاعتيادية المصمم للعمل عليها المولد و ذلك عن طريق تحريك شفرات التربينة المواجهة للرياح للتحكم في الطاقة المستخرجة من الرياح. كما سيتم تصميم المتحكم ذو الأداء الأفضل عمليا باستخدام أحد صور الحاكمات المنطقية المبرمجة من أجل التحقق من كفاءة أداء التحكم عمليا.

التصميم والتنفيذ العملي لنظام تحكم ضبابي متوائم في تحريك شفرات تربينة الرياح وأيضا التحكم في استخراج أقصي قدرة من تربينة الرياح

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Chapter 1: Introduction and Thesis Objective

1.1. Introduction

Non-Renewable energy resources cannot follow the obvious growth of demand of energy around the world any more. Focus of energy researches since the past few decades have been completely redirected to renewable energy. Renewable energy depends on natural resources like sun, wind, and water. In this thesis our scope is wind energy and how to control the available aerodynamic power in variable speed wind. At law wind speeds maximum power point tracking algorithm is used to determine the required rotor speed to capture the maximum available power at every wind speed. At high wind speeds blade pitch control is used to limit the available power in wind to maintain the generated power from the wind turbine at the rated power. The wind farm plant used in this thesis is the 9 MW doubly fed induction generator Matlab wind farm. In this thesis both the Classical PD pitch controller and the classical PI controller used in the power regulator in wind turbine will be replaced by a variable structure fuzzy logic controller. The benefits of using adaptive control technique are introduced.

In any control problem, a plant model is prepared using a software tool (example: SIMULINK/Matlab). Then, a control technique is chosen (Variable Structure Fuzzy Logic control technique in our case). A controller is designed based on this control technique (Pitch controller) using the same software tool (SIMULINK). Model-in-the loop verification is held as a first step for verifying the designed controller by running the SIMULINK models of both the plant and the controller. An advanced step of verification is done using processor-in-the-loop verification technique by converting the designed controller to C-code, and downloading it on TMS320F28335 microprocessor using Code Composer Studio (CCS) software. Processor-in-the loop simulation results are obtained by running the downloaded controller on the microprocessor online with the SIMULINK model of the planet. A study of suitable sampling time in the Processor-in-the loop verification process is introduced. The next step in verification is hardware-in-the loop which is introduced as a future work.

1.2. Thesis Objective

Two of the most challengeable control topics in wind energy are pitch control and maximum power point tracking due to their significant effect on electrical power generated. This thesis is concerned with designing both a pitch controller and power regulator controller in maximum power point tracking using an adaptive control technique (Variable Structure Fuzzy Logic control) replacing the already used PID control in the model to get use of the adaptive technique suitability for variable parameters plants . The designed controller will be simulated using the traditional model-in-the loop verification technique (i.e. simulation using Matlab/SIMULINK). A further step in the verification of the designed controller, Processor-in-the loop verification technique will be held indicating its procedures, tools, affecting parameters, and simulation results.

1.3. Thesis Organization

Besides this introductory chapter, the thesis includes five chapters as follows:

Chapter (2) discusses the theoretical background of wind turbine control topics, and overview for 9MW Doubly Fed induction generator Matlab wind farm concerning its controller structures especially pitch control and maximum power point tracking.
Chapter (3) includes theoretical background of adaptive control technique (Variable structure Fuzzy Control), the construction of pitch controller and power regulator of maximum power tracking in the 9MW wind farm is also illustrated.
Chapter (4) Processor-in-the loop verification technique will be introduced; and verification procedures of the designed VS-FC pitch controller are indicated using TMS320F28335 DSP with 150 MHz clock.
Chapter (5) both model-in-the loop and processor-in-the loop simulation results will be discussed, and a comparative study between them is held using three different wind speed test profiles.

Finally, conclusion and future work is introduced.

Chapter 2: Overview of 9 MW Matlab DFIG Wind Farm

2.1. Introduction:

Wind energy conversion system Key element is wind turbine. Wind turbines can be classified from many aspects. One of these aspects is the control type used. Control type used depends on the capacity of the turbine; the range of control needed over wind speed and of course optimization between cost of control and its benefit in electrical power produced. In this chapter an overview of 9 MW Matlab DFIG wind turbine model which is used in this thesis. The way this wind farm deals with the challengeable topics of control in wind energy will be introduced.

2.2. SIMULINK model of 9 MW wind farm:

Figure (2.1) shows the construction of 9MW Doubly Fed Induction Generator (DFIG) wind farm [1]. It consists of 6 wind turbine each of 1.5 MW. The wind turbines used are horizontal axis wind turbines. From control aspect, it is considered variable speed variable pitch wind turbine which uses active pitch control system and DFIG to allow variable speed operation. In wind turbine the type of generator used determines the type and capabilities of control in that wind turbine. Next section introduces various generator types and how to control them.

2.2.1 Various Generator Types Used In Wind Turbines:

Wind turbine can be classified according to the range of wind speed at which electrical power can be generated. Two main types of wind turbine are fixed speed wind turbine and variable speed wind turbine. Power can be generated from variable speed wind turbines at wider range of wind speeds, although fixed speed wind turbine generates power at only one fixed speed. The key distinguishing element between these two types is the generator type. Fixed speed wind turbine uses squirrel cage induction generator. Variable speed wind turbine can be classified into sub-class according to the speed control type used which will be illustrated at section (b).

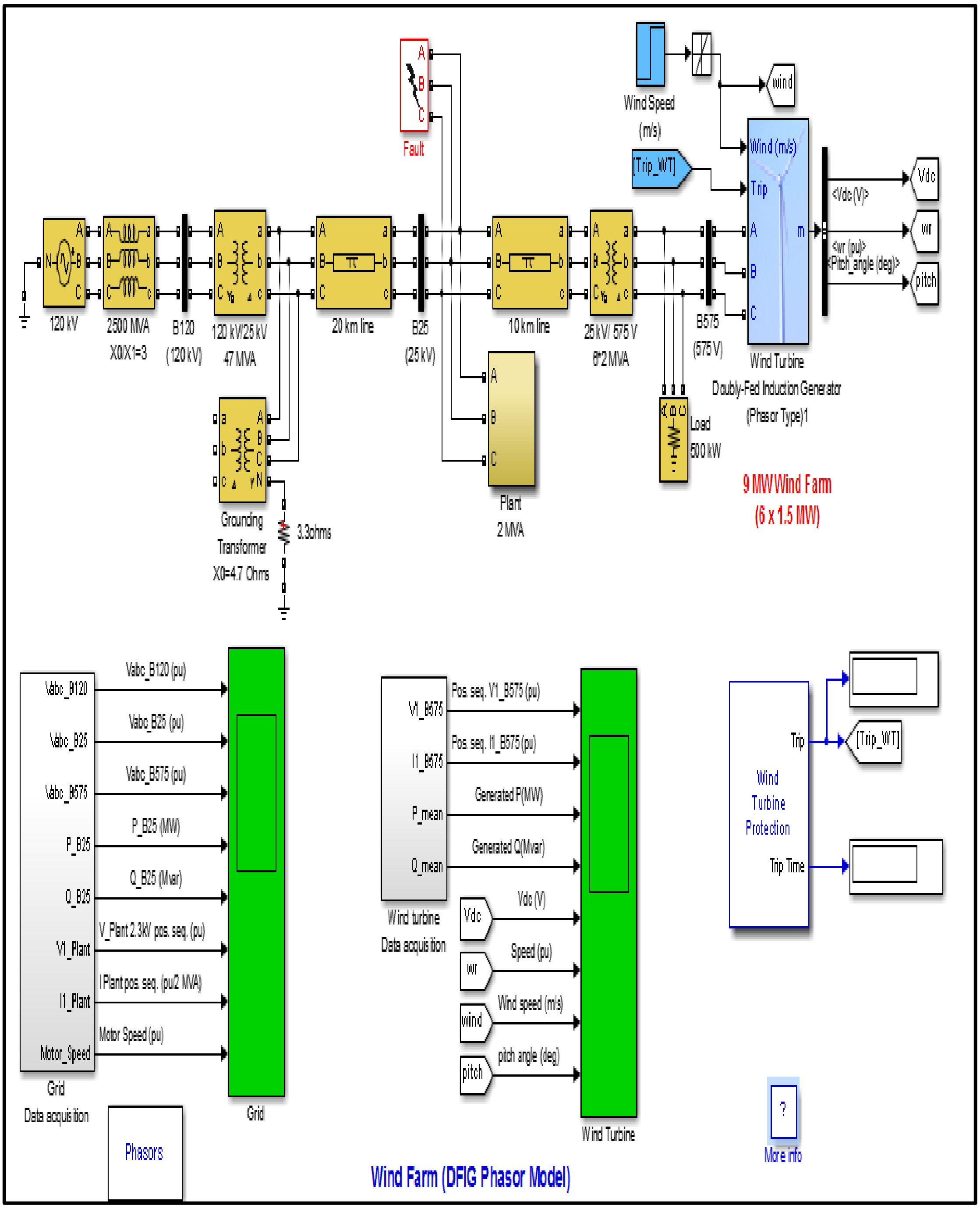

Figure 2.1: 9 MW DFIG Matlab wind farm

a. <u>Fixed speed wind turbine:</u>

Figure (2.2) illustrates the construction of fixed speed wind turbine [2]. Squirrel cage induction generator (SCIG) is used. The rotor is connected to the high speed shaft of the turbine. The stator is connected to the grid to inject power to it. The advantage of this system is the simplicity and law cost. The disadvantage is the variation of generated electrical power during gusts or high speed wind which affects the power quality of the grid.

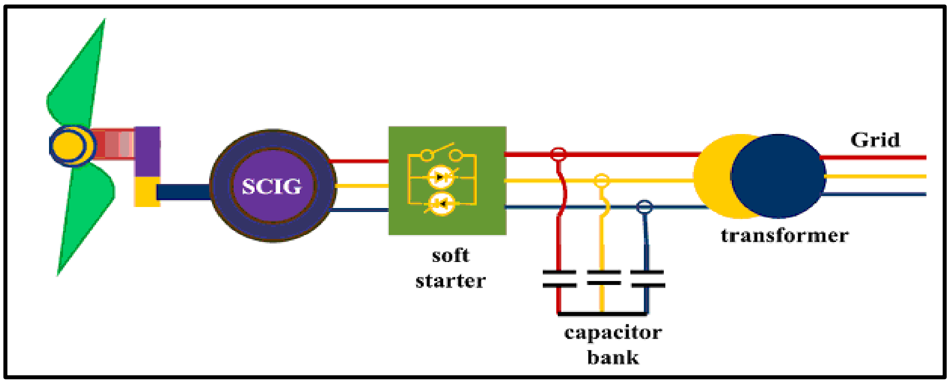

Figure 2.2: Fixed speed wind turbine using SCIG

b. <u>Variable speed wind turbine:</u>

There are three main generator types used for variable speed operation:

1- <u>variable resistance wound rotor induction generator:</u>

A wound rotor induction generator is used with its rotor connected to a variable resistance to change the rotor current and hence allow variable speed operation but still at limited speed range. Its construction is shown at Figure (2.3).

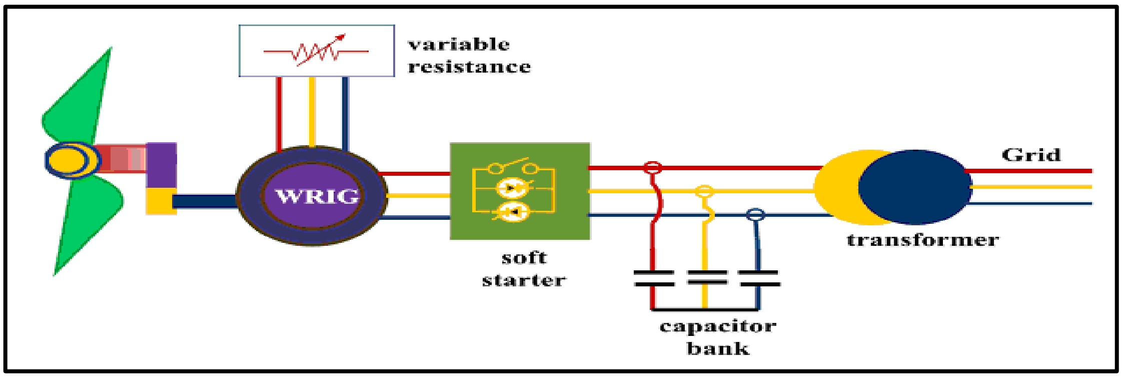

Figure 2.3: Limited variable speed wound rotor induction generator using variable resistance

2- <u>Full converter wound rotor induction generator:</u>

In order to allow full variable speed operation the stator of wound rotor induction generator is connected to the grid through variable speed power converter. The advantage is obviously the full speed power control. The disadvantage is the high cost due to that the power converter handles all the stator power, so its rating is the full rated power the, the high cost of permanent magnets, and the big diameter. Its construction is indicated at Figure (2.4).