



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electrical Power and Machines Engineering

Enhancement of Renewable Energy Systems Contribution to Power System Frequency Regulation

A Thesis submitted in partial fulfilment of the requirements of the degree of

Doctor of Philosophy In Electrical Engineering

(Electrical Power and Machines Engineering)

by

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Master of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

Faculty of Engineering, University, year

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Cairo - (2019)



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Statement

This thesis is submitted as a partial fulfilment of Doctor of Philosophy in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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ملخص عربي

لضمان الحصول على تشغيل آمن وتحقيق مستوي استقرار وإعتمادية للأداء كافيين، تعتبر دراسة نظام القوى الكهربائية ونمذجتها من أهم الوسائل لتحقيق ذلك. من أكثر المتغيرات تأثيراً والتي يمكن بها تقييم أداء الشبكة وإمكانية التحكم فيها هما التردد والجهد.

في الجزء الأول من هذه الرسالة تمت نمذجة شبكة القوى الكهربائية المصرية لدراسة تأثير فصل أكبر وحدة توليد (الكريكات 650 ميجا وات) على الشبكة. تعني الدراسة في هذا الجزء بالتغير في التردد نتيجة هذا الفصل وتم إضافة نظام التحكم في القدرة والتردد إلى نموذج الشبكة المصرية عن طريق إجراء محاكاة لنموذج الشبكة بالإعتماد على بيانات واقعية لأعلى وأدنى تحميل للشبكة الكهربائية المصرية لسنة 2017. أظهرت نتائج المحاكاة شكل تردد الشبكة وإنحرافها عن القيمة الإسمية نتيجة لهذا الفصل وتعامل نظام التحكم في التردد والقدرة الحالي لإستعادة القيمة الإسمية لتردد الشبكة عن طريق توظيف كلا من نظامين التحكم في التردد الأولي والثانوي، بالإضافة إلى المقاومة الأولية للتغير الناشئة عن استغلال طاقة الحركة المخزونة في الأجزاء الدوارة في المولدات المتزامنة وكذلك الأحمال كمواتير الحث.

تماشياً مع الإتجاه العالمي لتعظيم الإستفادة من الطاقة الجديدة والمتجددة لتقليل الإعتماد على الوقود الإحفوري لإرتفاع سعره وقرب نضوبه من جهة و الحفاظ على البيئة عن طريق تقليل غازات الإنبعاث الحراري من جهة أخرى، تنتهج الدولة المصرية توجهه زيادة الإعتماد على توليد الكهرباء من مصادر الطاقة الجديدة والمتجددة المتوفرة في مصر مثل الطاقة الشمسية وطاقة الرياح. تستهدف الحكومة المصرية الوصول إلى 20% من إنتاج الكهرباء إعتماداً على الطاقة الجديدة والمتجددة لسنة 2022 متضمنة 6% من طاقة الرياح، تزيد هذه النسبة إلى 14% في سنة 2035. تحديداً، تعني هذه الرسالة بطاقة الرياح.

تختلف خصائص نظم تحويل طاقة الرياح عن الأنظمة الحالية الإعتيادية المستخدمة في توليد الكهرباء في الشبكة المصرية. ويعزى هذا الاختلاف في الأساس إلى الطبيعة المتغيرة والمتقطعة لطاقة الرياح، ومن ثم تطلب توفير نظم إلكترونيات القوى لتحويل الطاقة المستخرجة من الرياح إلى مستوي تردد وجهد الشبكة الكهربائية لإمكانية الدمج. بالرغم من أهمية وجود نظم إلكترونيات القوى للتغلب على الطبيعة المتغيرة لطاقة الرياح والإستغلال الأمثل لها إلا أن وجود مثل هذه الأنظمة أحدث فصلاً بين الشبكة وأنظمة تحويل طاقة الرياح، تحديداً مع زيادة نسب مشاركة أنظمة تحويل طاقة الرياح في الشبكة، مما ترتب عليه حرمان الشبكة من الإستجابة بالقصور الذاتي التي كانت المولدات المتزامنة تمد الشبكة بها تلقائياً، وأيضاً نتيجة تشغيل مولدات الرياح ذات السرعة المتغيرة في وضعية تتبع لإستخلاص أقصى قدرة ممكنة من طاقة الرياح مما نتج عنه عدم وجود فائض من القدرة الكهربائية للإعتماد عليه أثناء التغير في التردد.

ومن ثم، في الجزء الثاني من هذه الرسالة، تم إضافة نموذج لمولد الحث ثنائي التغذية لنموذج محاكاة الشبكة الكهربائية لدراسة تأثير زيادة نسب المشاركة لأنظمة تحويل طاقة الرياح لدراسة تأثير هذه الزيادة على أداء الشبكة وعمل سيناريوهات مستقبلية بنسب مشاركة 10%، 20%، 50% لحالتين من التوليد القصوى والدنيا لسنة 2017. تمت دراسة التغير في التردد أثناء وبعد الفصل المفاجئ لأكبر وحدة توليد في الشبكة ولوحدتين متتاليتين.

بعد عمل المحاكاة أظهرت نتائج هذه الدراسة تدهور في أداء الشبكة من جهة التردد، حيث زادت قيم أدنى إنخفاض في التردد ومعدل التغير في التردد مما ترتب عليه إقتراح حل لتمكين مولد الحث ثنائي التغذية في المشاركة في التحكم في تردد الشبكة المصرية من خلال توصيل دائرة تحكم خارجية لنظام التحكم الخاص به لجعل مولد الحث ثنائي التغذية يحس بالتغير في تردد الشبكة ومن ثم يستجيب بضخ كمية أكبر من القدرة الفعالة لتعويض هذا التغير. هذه القدرة ناشئة من طاقة الحركة المخزونة في الأجزاء الدوارة لنظام تحويل طاقة الرياح. مما ترتب عليه نقص في سرعة دوران مولد الحث ثنائي التغذية. يتم تعويض الإنخفاض في السرعة عن طريق متحكم السرعة في نظام تحكم مولد الحث ثنائي التغذية. لتحسين مشاركة مولد الحث ثنائي التغذية في نظام التحكم في القدرة والتردد، إقترحت الأبحاث السابقة التوليف الأمثل لمعاملات المضخم التناسبي والتكاملي لمتحكم السرعة خاصته. هذا الضبط تم عن طريق إفتراض قيم عشوائية لمعاملات المضخم التناسبي والتكاملي لتحقيق أقل قيمة لمربع الخطأ التكاملي للإنحراف في التردد.

في الجزء الثالث من هذه الرسالة تم إقتراح تحسين مشاركة مولد الحث ثنائي التغذية عن طريق توليف معاملات المضخم التناسبي والتكاملي لمتحكم السرعة خاصته باستخدام طرق الحساب التطوري المعتمدة على الإستدلال المنطقي. بالتحديد تقنية التحسين بناءً علي محاكاة سرب الجسيمات للحصول علي أفضل قيم لمعاملات المضخم التردد، وعليه تمت دراسة ثلاث حالات متباينة وبنسب مشاركات مختلفة لطاقة الرياح. الحالة الأولى كانت بإفتراض عدم وجود مشاركة من مولد الحث ثنائي التغذية في نظام التحكم في القدرة والتردد. والحالة الثانية هي مشاركة مولد الحث ثنائي التغذية في نظام التحكم في القدرة والتردد وضبط معاملات المضخم التناسبي والتكاملي باستخدام الطريقة المتبعة بالأبحاث السابقة. والحالة الثالثة أيضا بمشاركة مولد الحث ثنائي التغذية في نظام التحكم في القدرة والتردد ولكن ضبط معاملات المضخم التناسبي والتكاملي تمت بمحاكاة سرب الجسيمات. وقد أظهرت النتائج تحسن في الأداء بمقارنة قيم مربع الخطأ التكاملي للانحراف في التردد للحالات الثلاث لنسب مشاركة طاقة الرياح المقترحة ولحالتين التحميل المختلفتين. وأيضا تحسن ملحوظ في قيم أدنى انخفاض في التردد ومعدل التغير في التردد.

كما قدمت الرسالة تحليل SWAT لدراسة مدى نقاط القوي والضعف بالإضافة إلي الفرص المتاحة والتهديدات المحتملة لصناعة أنظمة تحويل طاقة الرياح في السوق المصري.

بسم الله الرحمن الرحيم

”وَأَن لَّيْسَ لِلْإِنسَانِ إِلَّا مَا سَعَىٰ (39) وَأَنَّ سَعْيَهُ سَوْفَ يُرَىٰ (40)
ثُمَّ يُجْزَاهُ الْجَزَاءَ الْأَوْفَىٰ (41)“

صدق الله العظيم

النجم- الآيات (39-41)

Thesis summary

Modeling and studying of the generation mix of any power system is a vital means to ensure safe operation and to achieve sufficient stability and reliability levels of performance for the power system. The most important variables that largely affect the power system are voltage and frequency. This thesis is concerned with the frequency variable.

In the first part of this thesis, a model for the Egyptian electric power system is developed, according to the latest declared data, to study the effect of outage of largest generation units (Kuriemat 650 MW) on the grid. The study in this part will focus on the frequency variation due to this outage. The Load Frequency Control (LFC) is added to the developed model. A simulation is carried out depending on two actual data sets for the highest and lowest loading conditions for the year 2017. The simulation result shows the power system frequency variation and its deviation from the nominal frequency as a response to the outage. It also shows how the LFC responds to restore the power system nominal frequency through both the primary and secondary frequency control schemes. In addition to the power system inertial response obtained from releasing the stored kinetic energy of the synchronous generators' rotating shafts and loads such as induction motors. The results of the study done in this part will be used as a core for testing the impact of generation outage on the frequency variation as will be discussed in the second part when increasing the penetration levels of wind energy to the Egyptian power grid.

The general global trend is leveraging the exploiting of new and renewable energy to reduce the dependency on fossil fuel because of its high price and risk of being depleted from one side and environmental concerns in terms of elimination of greenhouse gases emissions from the other side. Hence, adopting the same approach, and due to the large availability of renewable energy resources such as wind and solar energies, the Egyptian government puts into consideration the increase of relying on renewable energy-based electric generation. By numbers, the target is to reach 20% of renewable energies-based electric generation in 2022 including 6% wind energy; this percentage will be increased to 14 % by the year 2035. This thesis is concerned with the study of wind energy.

The characteristics of Wind Energy Conversion Systems (WECS) is different from those of the current installed conventional generators, this difference is mainly attributed to the intermittent and fluctuating nature of wind energy. Due to this difference, power electronic converters is employed to convert the extracted wind energy to the needed voltage and frequency levels to enable integrating of the WECS into the current operating electric power system. This integration has its shortcomings particularly if deployment of WECS takes place in high percentages. As it is important to include power electronic converters to overcome the variable nature of wind energy, the presence of these devices decouples the WECS from the electric power system and therefore deprives the grid from the inherited inertial response that was previously provided by conventional synchronous generators. Moreover employing

Variable Speed Wind Turbine (VSWT) follows the Maximum Power Point Tracking (MPPT) curve to extract maximum power from wind energy that will allow no active power reserve to be injected in the power system during frequency excursions.

In the second part, a model for the Doubly Fed Induction Generator (DFIG) is added to the Egyptian power system control model to study the impact of increasing the penetration levels of WECS into the Egyptian electric power system. Futuristic scenarios are considered with different penetration levels 10%, 20% and 50% with two extreme loading conditions for the year 2017. The power system frequency variation is studied due to the outage of the largest generation units.

The simulation is carried out and the results show deterioration in the power system frequency response in terms of less Rate of Change of Frequency (ROCOF) values and minimum frequency values (nadir). Therefore, a suggested solution is proposed to enable the DFIG to participate in frequency regulation through adding an external control loop to its control system to sense the change in system frequency and respond by injecting active power obtained from the stored kinetic energy in wind turbine blades, hence the DFIG rotating speed is reduced and the speed reduction is compensated through the DFIG speed controller. To optimize the contribution of the DFIG to the Power system LFC, previous research efforts propose optimum tuning to the DFIG Proportional Integral (PI) speed controller gain parameters. The optimization process considered random gain parameter assumptions and the adopted objective function is the minimization of the Integral Squared Error (ISE) of the frequency deviation.

In the third part, an enhancement to the contribution of the DFIG through the tuning of its PI speed controller gain parameters is implemented. The tuning of the PI gains is optimized by using one of the evolutionary computing techniques that depends on meta-heuristics optimization methods, particularly, Particle Swarm Optimization (PSO) technique. PSO is adopted to find out the optimum gains while fulfilling the objective function of minimizing the value of the ISE of the power system frequency deviation.

Three cases are examined and compared; the first case represents the frequency variation without contribution from the DFIG to the power system LFC, the second case is adopting the previous research method of optimizing the DFIG PI speed controller gain parameters, while the third case is adopting the PSO technique to optimize the PI speed controller gain parameters. For the two loading conditions and for three levels of penetration, the simulation was carried out and the obtained results show an improvement in the values of ROCOF and Nadir for the case adopted the PSO-based optimization technique over that adopted by the previous research optimization method.

Additionally, this thesis presents Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis to study the strengths and weaknesses, opportunities and possible threats that may face any investor to manufacture WECS in the Egyptian market.

Key words: Load Frequency Control (LFC), Wind Energy Conversion Systems (WECS), Doubly Fed Induction Generator (DFIG), Particle Swarm Optimization (PSO).

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