



**AIN SHAMS UNIVERSITY**  
**FACULTY OF ENGINEERING**  
**Electrical power and Machines Engineering Department**

**Development of integrated control system for hybrid renewable  
energy systems using artificial intelligence**

**A Thesis**

Submitted in partial fulfillment of the requirements of the degree of  
Ph.D. in Electrical Engineering

**Submitted by**

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M.Sc. of Electrical Engineering  
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## **STATEMENT**

This dissertation is submitted to Faculty of Engineering, AIN SHAMS University for the degree of Ph.D. in Electrical Engineering (Electrical power and Machines Engineering). The author carried out the work included in this thesis at Electrical power and Machines Engineering Department, Faculty of Engineering, AIN SHAMS University, Cairo, Egypt. No part of this thesis was submitted for a degree or a qualification at any other university or institution. All parts in this thesis is my own work and any cited work and or material are referenced.

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## **Curriculum Vitae**

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## **ABSTRACT**

The recent global status reports of Renewable Energy Source (RES) show that, wind and solar energy have the highest growth rate and installation capacities among all other renewable sources. In addition, reviewing the recent related researches proves that, combining two or more renewable energy sources in hybrid topology can increase the total system reliability and efficiency especially when they have a complementary nature. A good example of that is combining solar and wind energy in a hybrid topology since they complement each other. However, the most of HRES sources have intermittent nature of power generation due to dependency on weather conditions. So, controlling and optimizing hybrid renewable energy systems (HRES) have big challenges in order to synchronize the operation between different sources so that the total generated power is maximized and realizing system reliability. In addition, a good optimization method should be used to optimize the utilization of the generated power. In this research, a complete HRES control system has been designed, mathematically modeled and simulated, and experimentally implemented. The research conducted a comprehensive survey on couple of hundreds of recent researches on HRES and performed statistical and data mining-based calculations to extract statistics and rule sets to be considered in the proposed system. The proposed system includes general PV model and battery model which can represent different types and sizes of PV modules and batteries. In addition, it includes a novel wind turbine emulator (WTE) to emulate wind turbines of different types, axis orientations, and physical attributes i.e. counts of blades, diameter, and tower height. The coined WTE has been implemented by controlling the speed and torque of a series excited DC motor by using microcontroller according to the wind speed profile and wind turbine attributes. All static and dynamic characteristics have been investigated to show the capabilities of the developed emulator. In addition, an integration test has been conducted on real time conditions of wind speed profile and working load for 24 hours to check the reliability of the proposed emulator. The proposed emulator can handle operation under cut-in wind speed and above cut-off wind speed as well by utilizing torque control and pitch angle control respectively.

Furthermore, the proposed WTE includes awesome graphical user interface (GUI) to help end users to manage system operations. In addition, it includes SQLite database as a repository of wind turbines physical attributes in addition to the optimum tip speed ratio (TSR) at every wind speed. Furthermore, a new Maximum Power Point tracking (MPPT) technique has been designed based on integrating binary search algorithm with particle swarm optimization technique. The new MPPT technique is utilized to follow the maximum power point at PV and Wind energy systems more accurate and faster than the conventional MPPT techniques. The proposed HRES system has add-on feature of remote access to be able to record all system parameters for later investigating, researching, and analysis. Moving to the optimization of the proposed system, a novel genetic algorithm (GA) based technique has been developed to optimize the utilization of the generated power economically and environmentally in addition to satisfying the load requirements and system security. The system is mathematically modeled and simulated by using MATLAB Simulink and a complete prototype has been implemented based on Atmel 8-bit AVR microcontroller. The simulation results have been compared with the experimental results for validation and they are agreed and show accurate and efficient results of the proposed emulator and significant improvements in energy utilization, total efficiency and reliability of the proposed HRES system. The thesis is divided into eight chapters and organized as follows:

**Chapter One** introduces the importance of HRES and presents the different components, topologies, Software and tools, and control and optimization techniques of HRES systems. In addition, it highlights the challenges and obstacles in controlling and optimization of HRES. Finally, it outlines the rest of the thesis.

**Chapter two** presents the results of comprehensive review of couple of hundreds of the recent papers of the literature on HRES. In addition, it presents the results of the statistical and data mining-based calculations that have been conducted on the reviewed papers showing the most commonly used system components, optimization techniques including environmental and economical method, control techniques, optimization software and tools, topologies of HRES.

**Chapter three** shows the main components of HRES system, which is composed of PV, Wind. and battery banks. It introduces different control techniques of PV and Wind energy conversion, different types of converters for connecting PV, Wind, and battery to the common bus, economical and environmental optimization methods, and the different HRES topologies.

**Chapter four** demonstrates the mathematical model of all components of the proposed HRES including the general PV model, general wind turbine model, the novel proposed WTE, the general battery model, the DC-DC and AC-DC converters and bridge rectifiers for connecting batter banks, PV, and wind respectively. In addition, it presents all proposed methods including the new proposed MPPT technique for PV and Wind, the constant current constant voltage (CCCV) multistage battery charging technique, and the Novel proposed optimization technique for utilizing the generated power.

**Chapter five** depicts and discusses the simulation results of the proposed WTE and the whole proposed HRES system including the unit testing for validating system components individually and integration testing for verifying the correctness of operation of the whole HRES system. In addition, it presents the validation of the simulation results with the results of the manual calculations based on the used system equations.

**Chapter six** introduces the implementation of the proposed HRES system prototype including the proposed WTE, control and optimization techniques, power electronic circuits of converters and inverters.

**Chapter seven** presents and discusses the experimental results of the proposed WTE and the whole HRES system. In addition, it conducts a comparison between the simulation and experimental results for validation.

**Chapter eight** concludes the work showing all contributions of the presented research work. Moreover, it introduces the recommendations for future work.

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