Design, construction, simulation and performance of axial flux small wind turbines

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DESIGN, CONSTRUCTION, SIMULATION AND PERFORMANCE OF AXIAL FLUX SMALL WIND TURBINES

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Abstract

The 850W small wind turbine.

The subject of this study is the design, construction, simulation and performance evaluation of small wind turbines (SWT) with an axial flux permanent magnet generator for appropriate technology applications in the developing world, for grid and battery connection. In this framework a small 850W wind turbine was fully constructed based on existing plans originally realised by Hugh Piggott [1].

The basic characteristics of appropriate technology applications are presented and an overview of this particular application is realised, in order to understand how these characteristics are incorporated in the particular design.

The basic principles of rotor aerodynamics are briefly explained followed by a description of the construction of the wooden rotor blades, the yawing system and the passive aerodynamic protection system. Measurements of the aerodynamic characteristics of the 850W SWT rotor blades and power curve are conducted in the SWT test site of the electrical engineering department of NTUA.

The design method of the particular axial flux generator is presented, a simulation of the magnetic field is performed using the Finite Element Method Magnetics (FEMM) program and the induced electromotive force (EMF) is estimated as well as the performance of the generator. The construction of the generator is described and the results of experimental measurements conducted on the 850W generator, are being compared with the outcome of the simulation with satisfactory results.

An improved design of the small wind turbine is conducted, this time for 3kW nominal power and connection to the AC grid. An optimization of the magnet dimensions compared to the cost of the generator is carried out. The improved 3kW generator is constructed and tested.

Subsequently, two different ways of connecting the 850W small wind turbine to the DC bus of a microgrid [3] are examined. The operation of the wind turbine when connected either directly to a battery bank or with a maximum power point tracking (MPPT) converter is simulated in MATLAB. The power curve and other characteristic curves for both ways are being calculated. The annual energy yield is estimated for different mean wind speeds and comparisons are carried out.

When DC coupling without a MPPT converter is concerned, the possibility of increasing the produced power with the connection of an inductance in series is investigated [2]. The power curve and the annual energy yield are estimated and show a significant increase compared with the direct battery connection.

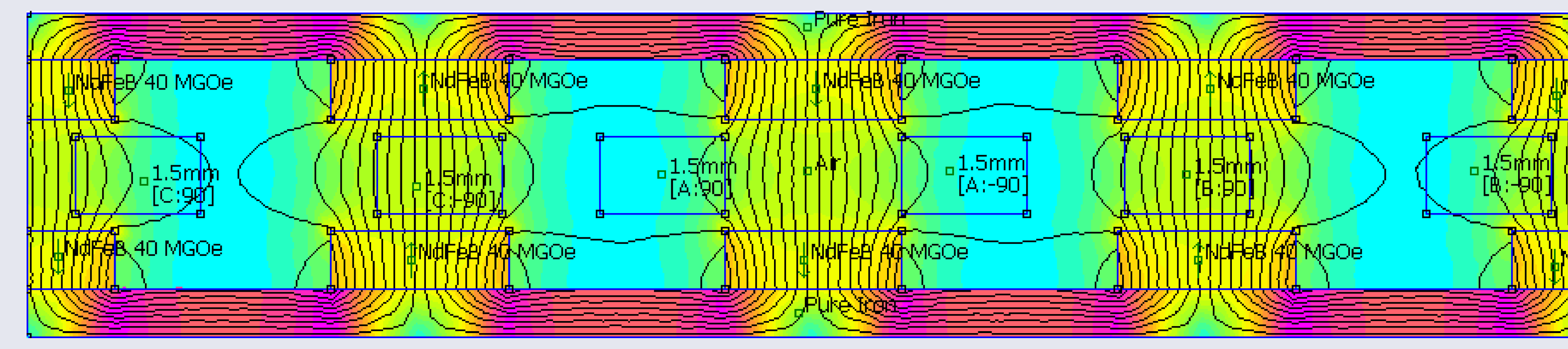
Objectives

Construction of the 850W small wind turbine wooden rotor.

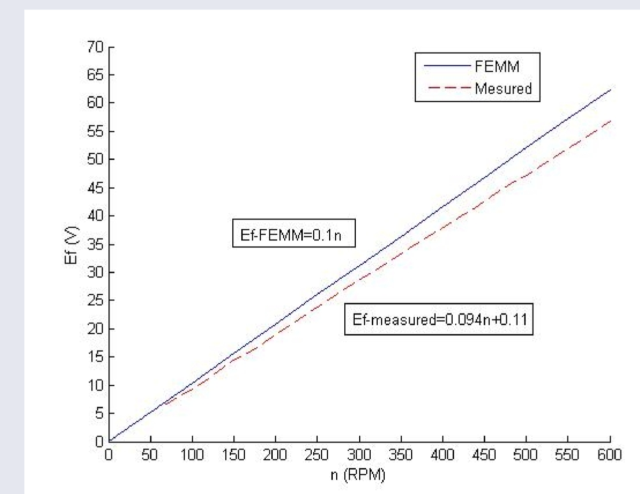
The 850W SWT was constructed in the framework of appropriate technology [4], mainly addressing rural areas of the developing world, intending to fulfill specific criteria such as:

1.Demand for small initial capital: The SWT that was constructed, has a total cost of 600 Euro for raw materials, not including the cost of the mast. **2.Emphasis on the use of local materials in order to reduce costs and supply problems:** The materials of the SWT are wood, iron, polyester resin, copper and neodymium magnets. All the materials can be sourced locally, except for the magnets that had to be bought from abroad. **3.More productive than a lot of traditional technologies, although relatively intense work is needed during the construction of the technology:** The SWT that was constructed, needed 600 working hours from unqualified students without previous experience to be completed, but produces electrical energy that can be used in many applications. **4.Small enough scale in order to be affordable on family or community level:** This type of SWT can be used in a domestic renewable energy system, either in a DC system for charging batteries, or in an AC system that is part of a community microgrid. **5.Understanding the technology's function, control and maintenance can be realized by the people who actually use the technology, without needing specific education:** The construction of the SWT was realized by a group of undergraduate students of NTUA, without specific technical knowledge. This construction has been created in many places of the world in the form of a practical and theoretical seminar, giving the ability of understanding, controlling and maintaining the SWT to the users. **6.The technology can be produced in small scale factories or workshops in villages or communities:** The SWT was constructed in a small workshop of the "Meltemi" summer camp in Rafina, near Athens, using the basic equipment of a small metal and wood workshop. **7.Collective work is needed from the community in order to improve its living conditions:** In total, five people worked for 3 months in order to complete the construction. **8.Flexibility and ability of adoption in different places and conditions:** The SWT can be designed for connection to an AC or a DC system and for different values of nominal power. In addition, a lot of alternative materials can be used, for example cedar for construction of the blades, emphasizing in this way on materials that are locally in abundance.

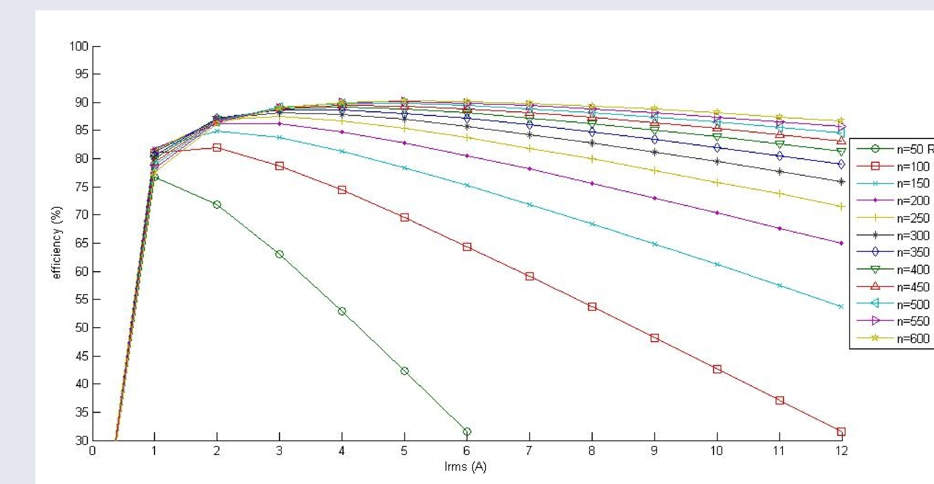
Results



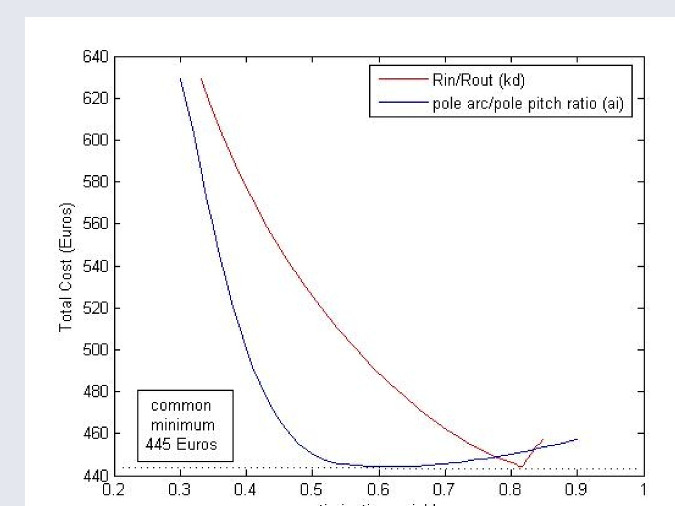
Solution of the static magnetic problem using the finite element method (FEMM)



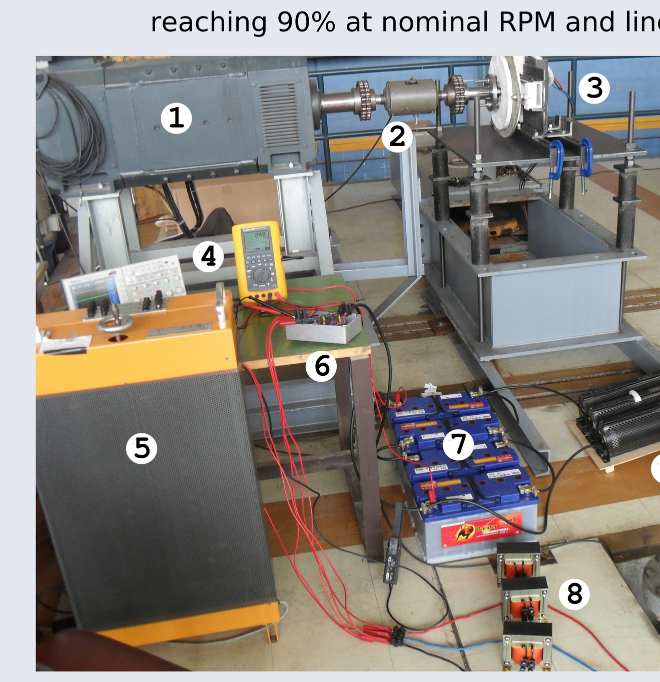
The relationship between the phase electromotive force (EMF) and the rotational speed (RPM) from MATLAB simulation results and from laboratory test measurements for the 850W SWT generator show a 9.9% deviation at nominal RPM.



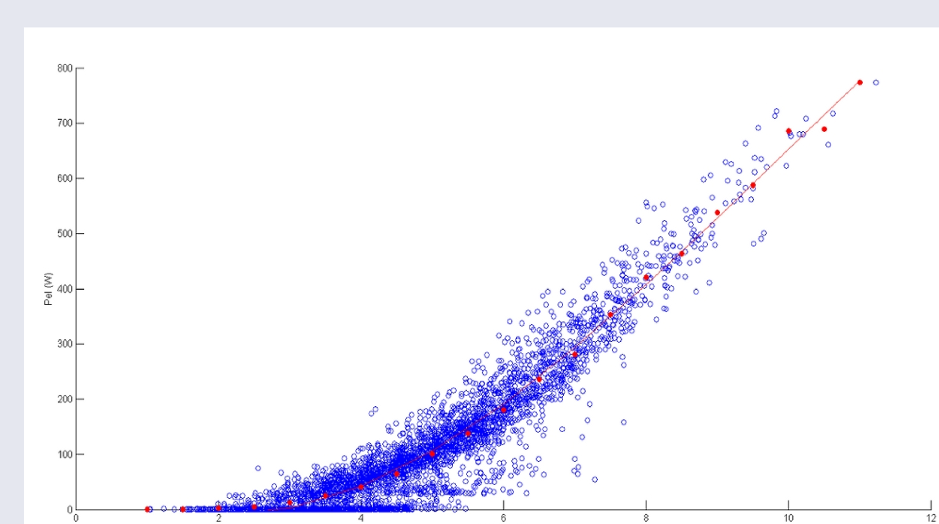
Efficiency of the 850W SWT generator as simulated in MATLAB for different line currents and rotational speeds, reaching 90% at nominal RPM and line current.



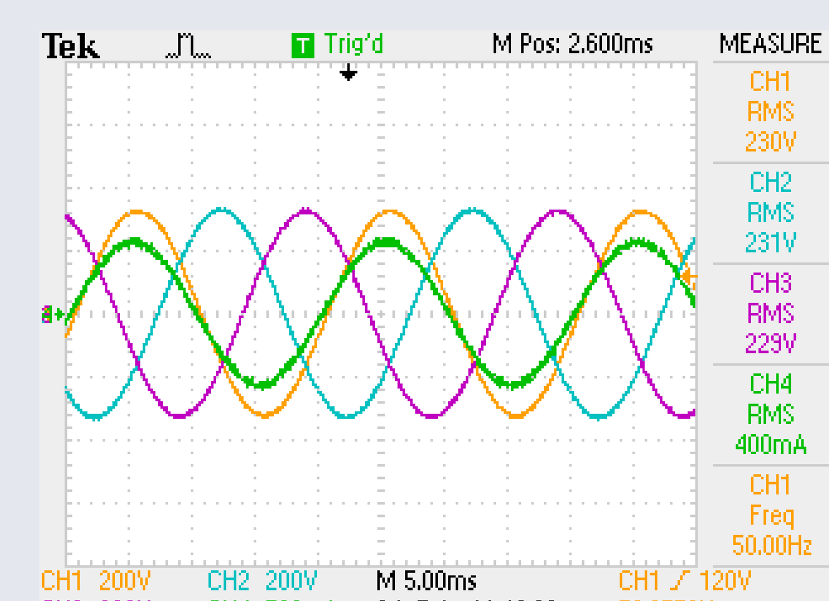
The orthogonal magnet shape is optimized for minimum cost of the 3kW SWT generator at ai=0.62 and kd=0.82.



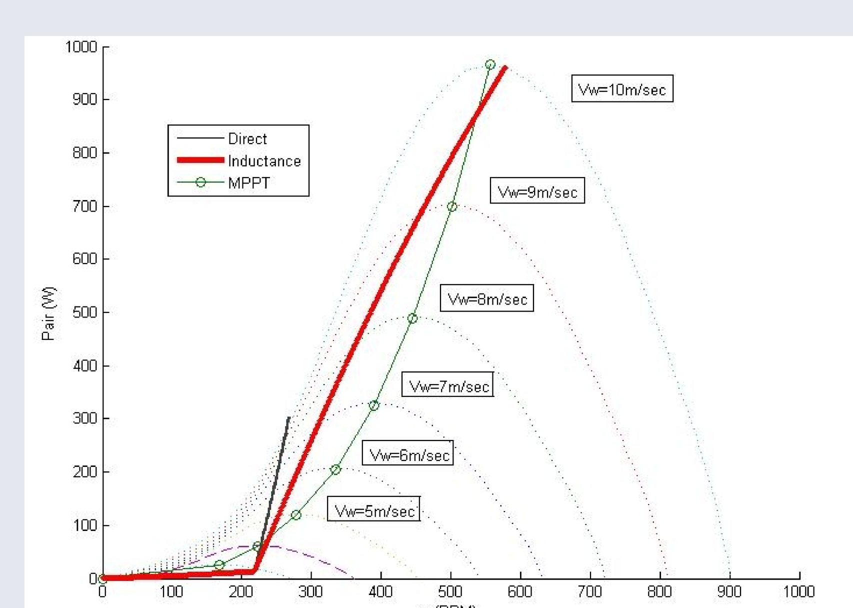
Laboratory setup:
(1) DC motor
(2) Torque meter
(3) 850W SWT generator
(4) Oscilloscope
(5) Three phase ohmic load
(6) Three phase bridge rectifier
(7) 48V Battery
(8) Three phase series inductance
(9) DC ohmic load.



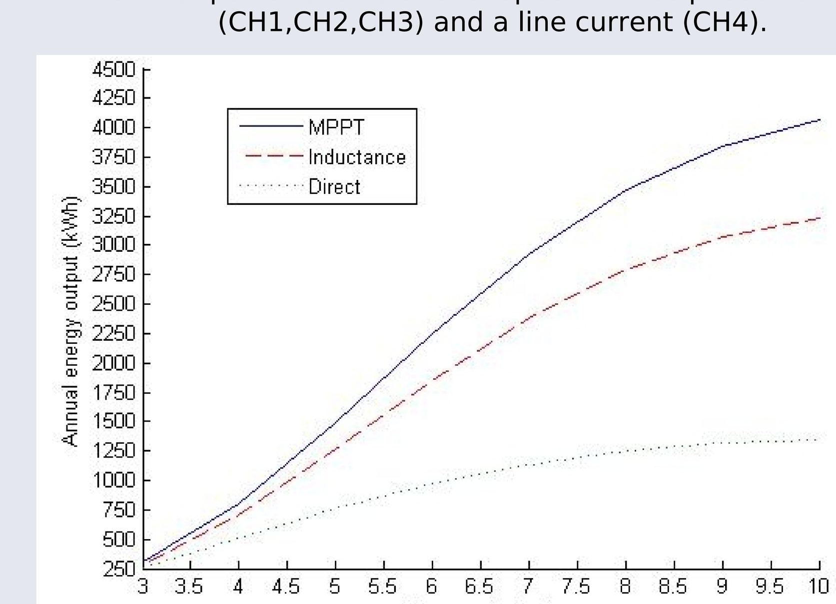
The 850W SWT power curve as measured at the electrical systems' laboratory test site at NTUA. Cut in speed 3m/s and nominal power at 11m/s.



The 3kW SWT generator on a three phase ohmic load at nominal power and rotational speed - three phase voltages (CH1,CH2,CH3) and a line current (CH4).



The relationship between aerodynamic power and rotational speed for three different connections of the 850W SWT, in the same diagram with the curves of aerodynamic power of the rotor blades against rotational speed for different wind speeds.



The annual energy yield against different mean wind speeds, for the three different connections of the 850W SWT ie. with MPPT (MPPT), with direct battery connection (Direct) and with a series inductance and battery connection (Inductance).

Conclusions

Small axial flux wind turbines for grid and direct battery connection, constructed in small community workshops at low cost, can provide a quality and robust solution to meet the electrical energy needs of rural communities in developing countries by empowering them with appropriate technology.

References

[1] Piggott H., "A Wind Turbine Recipe Book – The axial flux alternator windmill plans 2009".
[2] Rossouw F., "Analysis and Design of Axial Flux Permanent Magnet Wind Generator System for Direct Battery Charging Applications", thesis MScEng, Stellenbosch University, 2009.
[3] Hatziargyriou N., "Microgrids [guest editorial]", IEEE Power and Energy Magazine, Volume 6, Issue 3, May-June 2008, Page(s): 26 – 29.
[4] Consortium for Sustainable Village-Based Development (www.villageearth.org).

Construction of the 850W small wind turbine generator.

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