DERri
Distributed Energy Resources
Research Infrastructures

ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	AFPM-W-H
User-Project Title	Testing locally manufactured axial flux permanent magnet generators for small wind and small hydro applications
Main-scientific field	Electric machines / Renewable Energy Sources
Specific-Discipline	Axial flux generators

Lead User of the Proposing Team:

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Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	Student – under graduate

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

Additional Users in the Proposing Team:

Name	
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Nationality	
Organization name, web site and address	
Activity type and legal status* of Organization	
Position in Organization	

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

Date of submission	29th June 2012
Re-submission	YES________ NO________
Proposed Host TA Facility	ICCS NTUA - TA9
Starting date (proposed)	3rd of September 2012

Summary of proposed research (about ½ page)

In small scale residential or rural applications, the use of small wind turbines and small hydro turbines for the production of electricity is a common practice, when connection to the grid is not an option or when favorable feed in tariffs exist. The use of permanent magnets in a coreless axial flux generator makes the construction process easier and suitable for locally manufactured wind and hydro power generation applications. Such generators have often been studied in literature and the construction process is openly documented in detail in relevant construction manuals, resulting in the use of many small wind turbines of this type in rural electrification projects throughout the world.

Similar work has been undertaken at the HTW Berlin with an emphasis on the educational benefits that such construction workshops provide for undergraduate students. As the DERri consortium includes members such as ICCS-NTUA with expertise in this field of research, the proposed Transnational Access project can significantly aid in further understanding the aspects of designing and testing locally manufactured axial flux permanent magnet generators. Specifically, small wind and hydro turbines of this type have been constructed in ICCS-NTUA by students and are used as prototypes, based on free or low cost design manuals.

The main objective of this research is to analyze the performance of these generators and thus validate the most commonly used designs for such applications and to further evaluate the educational benefits of such applications in universities.

State-of-the-Art (about 1 ½ page)

In the past years, there has been an increasing interest for the use of axial flux permanent magnet (AFPM) generators in wind power generation applications. Their most prominent characteristics are the relatively simple manufacturing processes through which they are constructed and the capability of placing large numbers of poles in the rotor, thus avoiding the use of a gearbox (transmission). The absence of a gearbox makes the construction much cheaper and more reliable. Moreover, AFPM generators are suitable for small wind turbines [1]. Such turbines can play an important role in sustainable power generation and environmental protection. In developed countries, small wind turbines, can play a major role as distributed generation resources feeding microgrids [2]. More important, small wind turbines can be used for rural electrification applications in the domestic or small business scale, especially in developing countries. Since 1/3 of the planet's population is estimated to have no access to electricity [3], development of such applications can have a great impact.

The AFPM generators on question consist of a coreless stator and two rotor discs which carry the permanent magnets. A double layer concentrated winding, cast in polyester resin, is used for the stator. The double rotor single stator coreless generator is a common topology and various open design manuals for small wind turbines of nominal power of up to 3kW can be found in Europe [4] and the US [5]. In literature there is only a small record of AFPM generator studies for small wind turbine applications [6], [7], [8].

It is thus a significant task to test in laboratory conditions AFPM generators for such applications in order to validate their performance. Bench tests for generators with the use of a DC variable speed motor are common, while important characteristics of the generator such as its efficiency can be measured experimentally and its overall behaviour can be validated when connected to batteries or to the grid.

The results of the tests can prove this type of small wind and hydro turbines to be appropriate in providing quality production of electrical power from the wind and from moving water, at a lower cost for the user, since the initial capital required can be up to one third that of a commercial product.

In conclusion, the emerging technology of open source hardware small wind and hydro turbines will be tested, validated and potentially improved in order to provide additional scientific information on the technical aspects of this technology, only to come as an addition to its positive social, environmental and economic effects. Further more, small wind turbine testing is strongly promoted in European countries such as Denmark, UK, the Netherlands and Germany among others. Yet, unlike big wind applications, no common quality certification protocol for generator performance exists in Europe, that can satisfy the rapidly growing global market of small wind turbines, and to this direction the research proposal presented aims to contribute.

References

[1] Wind Turbines-Part2: Design Requirements for Small Wind Turbines, CEI/IEC Std. 61400-2, 2006.

[2] “Microgrids”, Hatziargyriou, N.; IEEE Power and Energy Magazine, Volume 6, Issue 3, May-June 2008 Page(s):26 – 29 (2011)

[3] The Practical Action website. [Online]. Available: http://practicalaction.org/

[4] H.Piggott, A Wind Turbine Recipe Book-The Axial Flux Windmill Plans, 2009

[5] Bartmann D., Fink D., Homebrew Wind Power: Hands-on guide to harnessing the wind, Buckville Publications, 2009.

[6] J. R. Bumby, N. Stanard, J. Dominy, and N. McLeod, “A Permanent Magnet Generator for Small Scale Wind and Water Turbines” in Proc. of the 2008 International Conference on Electrical Machines, paper 733, p. 1.

[7] A. Parviainen, J. Pyrhonen and P. Kontkanen, “Axial Flux Permanent Magnet Generator with Concentrated Winding for Small Wind Power Applications” in Proc. of the 2005 IEEE International Conference on Electric Machines and Drives, p. 1187.

[8] K. Latoufis, A. Gravas, G. Messinis, N. Korres, N. Hatziargyriou, “Locally manufactured open source hardware small wind turbines for sustainable rural electrification”, 3rd World Summit for Small Wind, 15-16 March 2012, Husum, Germany

Detailed Description of proposed project : Objectives – Expected Outcome – Fundamental Scientific and Technical value and interest (2-3 pages)

The objectives of the proposed TA project have both technical, scientific and educational aspects and are summarised below:

1) Gaining educational expertise thorough practical and theoretical understanding as well as latest information on the state of the art of AFPM generator for locally manufactured small wind and hydro turbines. This will be achieved with the high quality tests and set-up that will be included in the TA project. At the same time the presence of undergraduate students in some of the test will provide valuable experience in the educational aspect of the project.

2) Important technical experience will be obtained in a unique laboratory set-up, as well as on laboratory procedures, equipment, potential problems, solutions, challenges etc. This aspect of the tests can provide a valuable insight into the accuracy required for quality testing and and also for the appropriate measuring techniques and set-up.

3) Important scientific results will be obtained in the operation of AFPM generators for small wind and hydro applications under different connection schemes. Such literature is limited and the contribution will be vital in the rapidly emerging field of microgeneration.

4) Long-term cooperation with the host-institution will be an objective, specifically on exchanging experience on AFPM generator design. Since HTW is planning to perform such tests on a permanent basis the co-operation between the two institutions will be valuable and such exchanges strengthen bonds between educational and research institutes.

5) Important input will be given to standardization bodies on small wind turbine testing and standardization activities in this filed will be updated. ICCS-NTUA is planning to compile the Greek standard for small wind turbine testing and HTW can assist in this direction by providing valuable experience from the German national procedure for small wind turbine testing. The results of these experiments can become input for all European national testing procedures.

In order to achieve these objectives with success the following tests will be carried out in the host institutions laboratory. The tests to be carried out are described in detail, along with the infrastructure required and the expected results:

Test A: Performance testing of an 850W AFPM generator for small wind and hydro turbines for connection to batteries. The first part of the test will include preparation of the experimental set-up for connection to a three phase ohmic load. This includes placing the generator on the bench test and alignment of its axis along with alignment of the toque meter. The connection will be set up along with the oscilloscope required to measure and record three phase voltage and a line current. The performance tests on the 850W small wind turbine AFPM generator connected to a three phase ohmic load will result in a complete evaluation of the generator i.e. the graphs of EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current will be ploted. The efficiency under different load currents will be calculated and also the harmonic content of the generator outputs will be recorded. Thermal tests will be conducted using an infrared thermometer. In the second part of the test the generator will be connected to 48VDC batteries via a rectifier. Results will include graphs for EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents, DC current vs rpm, DC voltage vs rpm, DC power vs rpm. Also the difference in harmonic content introduced by the connection to the rectifier and battery will be studied.

Test B: Performance testing of a 3kW AFPM generator for small wind and hydro turbines for connection to the grid. The first part of the test will include preparation of the experimental set-up for connection to a three phase ohmic load. This includes placing the generator on the bench test and alignment of its axis along with alignment of the toque meter. The connection will be set up along with the oscilloscope required to measure and record three phase voltage and a line current. The performance tests on the 3kW small wind turbine AFPM generator connected to a three phase ohmic load will result in a complete evaluation of the generator i.e. the graphs of EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current will be ploted. The efficiency under different load currents will be calculated and also the harmonic content of the generator outputs will be recorded. Thermal tests will be conducted using an infrared thermometer. In the second part of the test the generator will be connected to the grid via a grid tie inverter. Results will include graphs for EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents. Also the difference in harmonic content introduced by the connection to the rectifier and inverter will be studied.

Test C: Performance testing of a 350W small hydro turbine for connection to the grid through a grid tie inverter. The first part of the test will include preparation of the experimental se-tup for connection to a three phase ohmic load. This includes placing the generator and turbine in the appropriate channel and varying water flow and head pressure with a variable pump. The connection will be set up with the oscilloscope required to measure and record three phase voltage and a line current. The performance tests on the 350W small hydro turbine connected to a three phase ohmic load will result in a complete evaluation of the small hydro. Results will include graphs such as the EMF vs rpm for variable water flow, terminal voltage vs line current, power vs current and the harmonic content at nominal operation will be studied. The second part of the test will include performance tests on the 350W small hydro turbine for connection to the grid through a grid tie inverter. Results will include graphs such as the EMF vs rpm for variable water flow, terminal voltage vs line current, power vs current and the harmonic content at nominal operation will be studied.

Originality and Innovation of proposed research – Broader Impact (1-2 pages)

Open source hardware (OSH) applications are newly emerging original technological innovations. OSH applications have certain characteristics from a design, construction and maintenance perspective which makes then more compatible with certain types of applications. The products concerned are easier to maintain by the users, since they probably have participated in their construction, and are made to suit local conditions so they have better adaptation. The cost of ownership of the product is small, since only the materials are usually bought and since maintenance and support are performed by the users, in communication with the open source hardware network. Research and development can be performed with transparency in the design. This increases the reconfigurability of the product while debugging of processes and equipment is made faster and more effectively. In this manner, robust machines can be developed, while development expenses can be shared by the network. Of course certain preconditions need to be met for the development of such an open hardware network. An active community of participants who are designers and users of the technology is essential. The designs need to have a low cost in order to allow for experimentation and for the possibility of sharing the costs of design failures. A pre-existing design that has been tested can act as a basis on which the community can work on and improve. The participants of the network need to have certain technical backgrounds and skills according to the application and also a medium for effective information sharing, such as the internet or an open source hardware design tool. Finally, typical limitations to this process are language barriers, cultural barriers, lack of internet access, lack of collaboration infrastructure such as open design tools and lack of funding.

Small wind and hydro turbines that can be manufactured locally in the form of OSH described earlier can provide multiple benefits for the local economy, can empower communities and also reduce green house gas emissions from burning fossil fuels for the production of electrical energy. Specifically, local manufacturing can be achieved at a small scale production level which can provide new jobs and strengthen local economies. This can also increase European competitiveness as a whole. Additionally, social integration can be achieved through technologies developed at a community level. Finally, this project can assist in the standardization procedures for small wind turbines in Europe, a very popular subject in recent years due to the increasing demand of these products in the global market.

The experimental validation of their performance in a systematized and scientific manner is considered essential for the further development of these innovative applications. It is thus an objective of this TA project to provide more information to the scientific community and to the general public and users of small wind and hydro turbines regarding this OSH design and investigate its performance characteristics and research whether it is a robust and safe design.

Proposed Host TA Infrastructure/Installation – Justification (about one page)

The electrical energy systems laboratory of ICCS-NTUA - TA9 is an excellent laboratory for performing the experiments proposed.

The laboratory is equipped with powerful low rpm 50HP Mawdsley's variable speed DC motor drive that can drive generators of up to 10kW at 150rpm, with a TDE Macno speed drive. The motor shaft is equipped with an accurate Datum torque meter measuring up to 500Nm for measuring mechanical torque on the shaft and a wide variety of chain shaft couplings are available while the appropriate bench to accompany and correctly install all the components mentioned is available. A Tektronix four channel digital oscilloscope can measure and record three phase voltages and one line current through high voltage AC probes and a AC/DC current clump. A variety of Terco ohmic resistive loads to suit the tests are available, as well as Banner lead acid batteries. Aurora and Wind Master grid tie inverters and rectifiers are available in order to perform connection to the grid. Also, variable water flow and dynamic head are provided for the small hydro tests through a pumping system.

In addition, small wind and hydro generators and turbines can be provided by ICCS-NTUA for experimental tests in the range of 350W to 3kW.

Synergy with ongoing research (about ½ page)

Both HTW and the host institution are involved in ongoing research in the field of AFPM generators for small wind and hydro turbines in undergraduate and post graduate level. Such projects include final year undergraduate projects as well as small scale manufacturing projects. Synergy will be sought in between these kinds of projects and the TA project in terms of sharing information and ideas.

Specifically, during some of the working days when tests will be performed during the TA project, the tests can be open for observation for undergraduate students involved with similar research projects in the electrical systems laboratory of ICCS-NTUA, in order to share the benefits and the experience of the TA project.

Dissemination – Exploitation of results (about ½ page)

Common publications between HTW and ICCS-NTUA in scientific conferences will be performed in order to reach a wider audience. The results will also be published in international and national scientific journals in collaboration with the host institution in order to express the scientific values of such work.

The experience gained through these experimental tests on small wind turbines can be provided to relevant standardization bodies in order to assist in the process of testing standards on small wind turbines in Europe and contact with relevant bodies will be sought.

The results will also be presented in HTW and ICCS-NTUA during small wind and hydro construction courses with undergraduate students in order to enhance the educational benefits of these applications.

Finally, publications will be made in the internet in small wind turbine portals and forums in Europe and the US, through which a wider audience can come into contact with the tests performed on the emerging technology of locally manufactured open hardware small wind turbines.

Time schedule (about ½ page)

A brief description of the time schedule for the proposed TA project:

3rd of September 2012: Introductions, presentation of research activities in ICCS-NTUA regarding locally manufactured AFPM small wind and hydro turbine, presentation of research activities in HTW on performance analysis and evaluation of electrical machines of wind and hydro turbines, tour of the laboratory premises, introduction of basic measuring equipment (variable speed DC motor drive, torque meters, digital oscilloscope, loads, inverters, rectifiers, batteries, pump drive).

4th of September 2012: Preparation of the experimental set-up for testing an 850W small wind turbine AFPM generator connected to a three phase ohmic load (placing the generator on the bench test and alignment of axis and torque meter, connection set-up, load set-up, measuring set-up).

5th of September 2012: Performance tests on the 850W small wind turbine AFPM generator connected to a three phase ohmic load (EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents, harmonic content).

6th of September 2012: Performance tests on the 850W small wind turbine AFPM generator for connection to 48V DC batteries (EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents, harmonic content, DC current vs rpm, DC voltage vs rpm, DC power vs rpm).

7th of September 2012: Preparation of the experimental set-up for testing a 3kW small wind turbine AFPM generator connected to a three phase ohmic load (placing the generator on the bench test and alignment of axis and torque meter, connection set-up, load set-up, measuring set-up).

10th of September 2012: Performance tests on the 3kW small wind turbine AFPM generator connected to a three phase ohmic load (EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents, harmonic content).

11th of September 2012: Preparation of the experimental set-up for testing a 3kW small wind turbine AFPM generator for connection to the grid through a grid tie inverter (connection set-up, load set-up, measuring set-up).

12th of September 2012: Performance tests on the 3kW small wind turbine AFPM generator for connection to the grid through a grid tie inverter (EMF vs rpm, mechanical toque vs current, terminal voltage vs line current, power vs current, efficiency under different load currents, harmonic content).

13th of September 2012: Preparation of the experimental set-up for testing a 350W small hydro turbine for connection to the grid through a grid tie inverter (placement of the hydro turbine and alignments, connection set-up, load set-up, measuring set-up).

14th of September 2012: Performance tests on a 350W small hydro turbine for connection to the grid through a grid tie inverter (EMF vs rpm for variable water flow, terminal voltage vs line current, power vs current, harmonic content).

Description of the proposing team (as long as needed)

The **Hochschule für Technik und Wirtschaft (HTW) of Berlin** offers a broad set of engineering courses. Already since 1996 the HTW offers a complete course in environmental engineering focused on renewable energy systems [1]. The extensive research in the various areas of renewable energy has offered a solid basis for the work of many companies, institutes and

NGOs.

One mayor field of activities is the performance analysis and evaluation of electrical machines of windmills and hydro installations.

During the current summer semester 2012 the HTW has introduced a new course on the construction, analysis and simulation of the mentioned axial flux permanent magnet generators. The main purpose of the course is the combination of different learning methods and to provide a teamwork- based and self-organized study atmosphere. By combining theory and practice in a hands-on manner, the educational benefits are way beyond the traditional one-way teaching methods of lectures. [2]

The assignment has been realized under Professor Jochen Twele [3], with Joerg Alber (lead user) being the assistant for the practical teaching process.

The course has achieved the building and analysis of a complete windmill installation. Due to the very positive outcome and feed-back from the participants, a follow-up course has been arranged at the HTW, this time with a focus on laboratory tests of the generator, the 3-bladed wooden rotor as well as the electrical components of the battery-based island system.

The analytical methods the team at the ICCS-NTUA is developing in order to understand and better the generator's performance in the laboratories are particularly interesting for the development and structure of the mentioned courses at the HTW. At the same time, the teaching experiences at HTW could be very helpful regarding similar activities at ICCS-NTUA. A TA project in the framework of the DERri would offer great possibilities for future collaborations, both in terms of educational activities and rural electrification projects.

Joerg Alber is currently finishing his undergraduate course in Environmental engineering – Renewable Energy Systems at the HTW- Berlin. In the framework of a practical semester he is teaching the mentioned windmill construction course as an assistant of Professor Jochen Twele.

As part of his work at the independent Reiner Lemoine Institute [4], he is involved in a set of different research projects on renewable energy systems:

- Design, construction and testing of rotor-blades for vertical axis windmill turbines (VAWT) at one of the wind- channel labs of the Technical University (TU) of Berlin
- Various installation and performance tests of a small-scale wind turbine on an old chimney structure in Berlin.
- Wind data and site evaluations applying different simulation programs.

Beyond the technical projects, he works on political and social aspects of energy systems such as problematic working conditions in the German and European solar energy sector as well as concepts of decentralized community-owned renewable energy structures as a viable alternative to the monopolized fossil fuel-based electricity market [5].

References:

[1] http://www-en.htw-berlin.de/studying/study_programmes/programme.html?courseID=226

[2] Berliner Abendblatt (local newspaper on the course), "Was das Zeug im FEZ hält": http://www.meinschoeneweide.de/attachments/2792_berliner-abendblatt_2012-06-02_windrad-htw-fez.pdf

[3] http://www-en.htw-berlin.de/FHTW/persons/index.html?name=twele#

[4] www.rl-institut.de

[5] http://energiewendeundarbeitskampf.org