DERri
Distributed Energy Resources
Research Infrastructures

ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	SWT-AFPM
User-Project Title	Comparison of locally manufactured AFPM generator technologies for wind applications and field testing of small wind turbines
Main-scientific field	Electric machines / Renewable Energy Sources
Specific-Discipline	Axial flux generators

Lead User of the Proposing Team:

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Position in Organization	PhD Student

* 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:

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Organization name, web site and address	The University of Sheffield (http://www.shef.ac.uk/) EWB-Sheffield, Wind Project (https://ewb.shef.ac.uk/projects/wind/)
Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	Mechanical Engineering Undergraduate

* 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 March 2013
Re-submission	YES_______ NO_______
Proposed Host TA Facility	ICCS NTUA - TA9
Starting date (proposed)	1st July 2013

Summary of proposed research (about ½ page)

Axial flux permanent magnet (AFPM) generators have been employed in rural electrification projects around the globe to allow power to be extracted from the wind and provide access to affordable electricity in remote communities. The use of permanent magnets in a coreless axial flux generator simplifies the construction process by using only planar components and is therefore suitable for local manufacture close to the remote communities in which it will be installed.

Hugh Piggott's open-source design for an AFPM small wind turbine has been extensively studied by ICCS-NTUA, the University of Sheffield (TUoS), Engineers Without Borders Sheffield (EWB-Sheffield) and the Kathmandu Alternative Power and Energy Group (KAPEG). The proposed Transnational Access project is a collaboration between members of these four organisations to share their knowledge in this area and make use the extensive testing facilities for AFPM at ICCS-NTUA.

The proposed test schedule begins with the comparison of performance characteristics of 850W AFPM generators with neodymium and ferrite magnets, as recent price fluctuations in rare earth metals and the issue of corrosion has diminished the reputation of the more powerful neodymium magnets, making their cheap and widely available ferrite counterparts a wiser choice.

Wind turbines are notoriously unreliable, so the second half of the proposed test schedule is based around comparing results from the bench test with data we will obtain from the wind turbine in normal operation on the ICCS-NTUA field testing rig. The aim is to develop a set of simple tests to characterize generator performance and diagnose any potential faults. These tests must be able to be performed in a remote community with only basic tools available, as this would be a significant advantage over carrying a heavy generator all the way back to the nearest workshop.

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 importantly, small wind turbines can be used for rural electrification in developing countries to provide power for domestic or small business or community applications [3]. The simple design of the AFPM opens up the possibility of manufacturing small wind turbines locally instead of importing technology from abroad. This has the potential to boost the local economy, create a shorter and stronger supply chain for spare parts and empower communities to take control of their own development by providing their own electricity [4].

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 [5] and the US [6]. In literature there is only a small record of AFPM generator studies for small wind turbine applications [7], [8], [9], [10] although in recent years there has been an increasing research interest. Such generators have been analysed for grid-connected and off-grid systems, while basic methodologies for their design aiming at local manufacturing, have been developed.

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 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 turbines [11] 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 [12].

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] Leary, J., A. While, R. Howell (2012). "Locally manufactured wind power technology for sustainable rural electrification." Energy Policy 43(0): 173-183.

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

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

[7] 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.

[8] 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.

[9] K. Latoufis, G. Messinis, P. Kotsampopoulos, N. Hatziargyriou “Axial flux permanent magnet generator design for low cost manufacturing of small wind turbines”, Wind Engineering, Volume 36, No. 4, 2012

[10] P. Freere, M. Sacher, J. Derricott, B. Hanson, “A Low Cost Wind Turbine and Blade Performance”, Wind Engineering Vol. 34, No. 3, 2010, pp289-302

[11] 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

[12] P. Ghimire, R. Sharma, C. Lamichhane, P. Freere, R. Sinha, P. Acharya. “Kathmandu Alternative Power and Energy Group: Our Experience in Promotion of Low-Cost Wind Energy Technology in Nepal”. International Workshop on Small Scale Wind Energy for Developing Countries. 14-16 Sep. 2009, Nairobi, Kenya.

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 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 tests 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 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 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 EWB-Sheffield and KAPEG are already performing simplified versions of such tests. the co-operation between the two institutions will be valuable and such exchanges strengthen bonds between them.

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 neodymium small wind turbine AFPM generator (typical design). 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 torque 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 torque vs current, terminal voltage vs line current, power vs current will be plotted. 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 an 850W ferrite small wind turbine AFPM generator. Test B involves following and identical procedure as Test A to obtain comparable results for the ferrite generator.

Test C: Field testing of one of the generators will be carried out by assembling it with the blades, tail and tower to installing it in the wind turbine test area. Performance will be monitored live using LabView software and instantaneous readings of the key variables mentioned above will be compared to averaged values representative of those recorded by a datalogger in the field.

Comparison of this data with that obtained from Tests A and B will allow any correlation between the two methods to be found and therefore a simplified method for performing similar tests in the field using only simple tools can be derived.

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

Open source hardware (OSH) applications are newly emerging original technological innovations. OSH products are easier to maintain by the users, as they have probably have participated in their construction, and can be adapted to suit local conditions. The cost of ownership of the product is often lower, since construction, installation and maintenance can be 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 effective. In this manner, robust machines can be developed, while development expenses can be shared by the network.

An active community of participants who are designers and users of the technology is essential for the development of such an open source hardware network. 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 turbines that can be manufactured locally in the form of OSH, as 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. Additionally, enhanced social integration can be achieved through technologies developed at a community level.

Wind Empowerment is an association for the development of locally built small wind turbines for sustainable rural electrification. The vast majority of the member organisations are using AFPM generators for wind power generation, however many of them have raised concerns about the reliability of the technology and the unsustainability of using neodymium in the permanent magnets.

Neodymium is a rare earth metal exported almost exclusively from China. Neodymium Iron Boron (Nd-Fe-B) magnets are one of the key components in most current designs of AFPM generator as their power density is many times that of the material they superseded, ferrite. However, the price of neodymium exported from China doubled in 2010 and has continued to rise [1]. Corrosion issues also frequently cause the magnets to swell up, especially in hot, humid, tropical environments, bringing the generator to a halt in just a few years. This research hopes to address this issue by comprehensively evaluating whether a return to ferrite magnet technology is justified, based upon the material costs of the two magnetic materials, the difference in expected lifetime due to corrosion issues, the difference in tower-top weight and the difference in performance.

A particular issue facing field workers that are returning to AFPM small wind turbine installations to perform maintenance is how best to determine whether the generator is functioning correctly. Ideally, the wind turbine would be lowered, taken apart and the generator taken back to the main workshop for testing. However, the main workshop could involve many hours walk and over a day's travel on unpaved roads, making this approach impractical. A set of simple tests that could replicate some of the most important characterisation tests performed in the ICCS-NTUA bench testing rig would be invaluable in determining whether the generator is performing as expected and if not, what the fault could possibly be.

This research hopes to provide Wind Empowerment and other AFPM wind turbine constructors with relevant and practical advice for how to address the two issues listed above.

[1] Magnet Source - http://www.magnetsource.com/Solutions_Pages/NEOproperts.html Accessed 28/3/13

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.

The small wind turbine test site is equipped with a meteorological mast consisting of the following sensors: anemometer NRG #40C, wind vane NRG #200P, temperature sensor NRG 110S, humidity sensor NRG RH5 and barometric pressure sensor NRG BP20. For electrical measurements voltage transducers LV25-P/SP5 and current transducers CSNR151 are used. All data are collected from a data acquisition board NI 6225 USB and displayed and recorded by LabView. The site also includes a small wind turbine tower and its tilt-up pole.

The infrastructure described above can provide an ideal environment for the development of the proposed research.

Synergy with ongoing research (about ½ page)

Research at Kathmandu's Alternative Power and Energy Group (KAPEG) main focus has been concentrated particularly on the development of axial flux permanent magnet generators. A particular generator has been developed for a 300W small wind turbine using ferrite magnets. After the initial design and construction activities, the generator followed lab experiments and modeling procedures. The overall system was put on a vehicle test for performance analysis at various wind speeds. Dynamic load variation was performed during the vehicle test in order to precisely match the power and speed of the rotor blades and the generator. The measurements collected from the vehicle test were processed and the power curve and performance curves were plotted. Based on the analysis from the vehicle testing the most suitable generator configuration was identified for the particular rotor blades and adjustments were made on the generator parameters such as the number of turns in the windings, the air gap and the copper wire thickness. KAPEG's work has been focused primarily on these activities with aims to come up with a final product and is currently conducting field tests on the prototype system.

Similarly current work at EWB-Sheffield and the ongoing work at TUoS, involving power curve testing of AFPM wind generators in the Scottish Highlands, match the intent of the project activity on various levels.

The relevant users in this project and the access to the electrical system laboratory of ICCS-NTUA will create an environment of cooperation with people from different countries and common fields of interest, while at the same time creating an opportunity to exchange knowledge.

Dissemination – Exploitation of results (about ½ page)

Common publications between KAPEG, TUoS, EWB-Sheffield and ICCS-NTUA in academic journals such as Wind Engineering or Renewable Energy will be performed in order to reach a wider audience.

EWB-Sheffield will also use the knowledge they have gained to perform similar tests on their 700W AFPM wind generator back in Sheffield with undergraduate students in order to enhance the educational benefits of the project.

KAPEG are currently developing a similar AFPM small wind turbine, so the experience of using the huge range of equipment available at ICSS-NTUA will be invaluable in the development of their own testing facilities in Kathmandu

The results will be directly relevant to ongoing work at TUoS, involving power curve testing of AFPM wind generators in the Scottish Highlands, as they will allow a greater understanding of the role of the generator in power production and how they interact with the blades.

Finally, a technical brief will be written up for Wind Empowerment, so that the global audience of practitioners can directly benefit from the results of the research. Wind Empowrment also runs a series of webinars, which would also make an ideal platform with which to disseminate the findings.

Time schedule (about ½ page)

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

1st of July 2013: Introductions, presentation of research activities in ICCS-NTUA regarding locally manufactured AFPM small wind turbines, presentation of research activities in TUoS on performance analysis of locally manufactured small wind turbines and presentation of the evaluation of AFPM generators for wind turbines from KAPEG. Tour of the laboratory premises, introduction of basic measuring equipment (variable speed DC motor drive, torque meters, digital oscilloscope, loads, inverters, rectifiers, batteries).Tour of the small wind turbine test site premises, introduction of basic measuring equipment (for meteorological and electrical measurements). Introduction to the IEC standard 61400-12-1: Power performance measurements of electricity producing wind turbines.

2nd of July 2013: Preparation of the experimental set-up for testing an 850W Neodymium 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).

3rd of July 2013: 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).

4th of July 2013: 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).

5th of July 2013**:** Tilt-up of the 2.4m 850W Neodymium or 2.4m 850W Ferrite small wind turbine and preparation for starting a measuring campaign. Initial on-site measurements.

8th of July 2013: Preparation of the experimental set-up for testing a 850W Ferrite 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).

9th of July 2013: Performance tests on the 850W Ferrite 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). Tests 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).

10th of July 2013: Power performance measurements of the small wind turbine in the test site according to the IEC standard 61400-12-1. Logging and analysing meteorological and electrical data on the database.

11th of July 2013: Application of the fault detection on site methodology for a small wind turbine generator in operation. On site instantaneous measurements and long term measurements from data logger.

12th of July 2013: Development of a methodology for the on site characterisation of the generator. Validation will be performed using the comparison of the bench tests with the on site measurements.

Description of the proposing team (as long as needed)

Tom Wastling is studying Mechanical Engineering at the University of Sheffield, UK and Project Leader of the EWB-Sheffield Wind Turbine project. EWB-Sheffield is a branch of EWB-UK, an international development organisation which aims to remove barriers to development through engineering. EWB-Sheffield's wind project has now been running for 4 years and provides students with the opportunity to gain hands-on experience building, testing and improving wind turbines. It promotes renewable energy as a tool for sustainable development and aims to equip students with the skills they need to tackle the global issues surrounding energy poverty.

Jon Sumanik-Leary sits on the executive board of Wind Empowerment, an association for locally manufactured small wind turbines for sustainable rural electrification and is a lead researcher on the subject and conducts research on the subject at the E-Futures Doctoral Training Centre, University of Sheffield, UK. During this research in Peru, Nepal, Scotland and Nicaragua, he has investigated critical factors that influence the success or failure of small wind power in their particular local context, such as the level of community participation in the manufacture. He is also currently working with Hugh Piggott, the original designer of the vast majority of the AFPM wind generators in use today worldwide and has had experience in power curve measurement and market analysis of this technology.

Kimon Silwal is currently the project manager at Kathmandu Alternative Power and Energy Group. He completed his undergraduate studies in electrical engineering from Kathmandu University and has been working in the company for about 2 years. He has been actively involved in the currently running wind project from the very beginning and is also handling other renewable energy projects.

KAPEG is a research organization established by a group of electrical engineers previously actively involved in applications oriented in electrical engineering research at Kathmandu University in Nepal. The group is continuing its past research activity through KAPEG and looking for opportunities to get involved in new research and development in multidisciplinary engineering fields which support local industry and academia. It has been involved mainly on the research and development of renewable energy such as small scale wind power and micro-hydro power over the past several years. KAPEG has been focusing on the development of renewable energy applications in Nepal using locally available materials/resources and local capacity building in partnership with national and international expertise and organizations. After the completion of an international project for wind turbine technology development based on natural materials which was jointly conducted with Practical Action and RISOE Technical University of Denmark, KAPEG is still continuing the research and development work of the overall wind turbine system as one of the projects of Renewable Nepal. “Development of Commercially Viable Wind Power System” is one of the current wind projects the company has been running and is on its way of completion.