DERri
Distributed Energy Resources
Research Infrastructures

ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

User-Project Acronym	FRECLE
User-Project Title	Frequency Responsive Control of Large Heating Element
Main-scientific field	Power Quality
Specific-Discipline	Demand Side Management

Lead User of the Proposing Team:

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Position in Organization	Head of Power Systems

* 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)

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Activity type and legal status* of Organization	(4) – Large private enterprise
Position in Organization	Network Services Manager

* 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)

(Repeat for all Users)

Date of submission	31 May 2010
Re-submission	NO
Proposed Host TA Facility	Flexible Power Grid Lab (FPGL), KEMA - Arnhem
Starting date (proposed)	August 2010

Summary of proposed research (about ½ page)

The aim of the proposed project is to increase the proportion of electricity supplied from renewable sources by exploiting the potential for demand side management to play a role in system balancing and frequency control. The learning outcomes from this project will contribute to the understanding required to construct the sustainable low carbon electricity networks of the future. As part of this project Smarter Grid Solutions (SGS) are proposing to design, build, and test an active network management (ANM) system to oversee the frequency responsive demand provided by a large heating element planned for installation on part of Scottish Hydro Electric Power Distribution's (SHEPD) network. The scale and nature of this type of demand side management is novel and it is anticipated that successful testing will lead to the first frequency responsive installation of this type in the world. The adoption of this means of frequency responsive demand side management holds promise to permit greater connection of renewable generation to the existing grid and demonstrate important technical and commercial learning for the global power industry. It is anticipated that such schemes will be rolled out elsewhere if successful.

State-of-the-Art (about 1 ½ page)

Demand Side Management (DSM) means altering or influencing the demand for electricity to achieve a particular objective. That objective might be to shift demand to other times, either to flatten the overall demand profile, make demand coincident with variable supply, or otherwise minimise costs associated with variations in supply and demand. Demand might also be modified to satisfy network constraints such as power flows, voltages or frequency. This might be done in planning timescales to defer new network investment, temporarily to help deal with disruptions, or as part of regular system operation.

Interest in DSM has increased recently in Great Britain and elsewhere, driven by a range of factors. By making demand a more active participant in system balancing, DSM offers the prospect of a more efficient electricity system that relies less on expensive and highly polluting peaking plant. The expansion of renewable energy, particularly wind power, is leading to a reassessment of reserve requirements and DSM seems to offer part of the solution. Much of the existing network infrastructure is reaching the end of its life but the wide range of challenges, from uncertainty over future generation sources and demand requirements to restrictions on the construction of new lines, means that there is a greater call for approaches like DSM, which offer additional flexibility that can mitigate uncertainty and exploit existing or new assets most effectively.

Some of the changes in demand may open new opportunities for DSM. The increased use of electrical heating and cooling offers scope for exploiting thermal inertias and energy storage. The anticipated expansion in electric vehicles will present new challenges with potentially significant increases in demand in certain areas but it is anticipated that it will be possible to shift and control that demand to some degree. Future electric vehicles might provide wide-scale distributed energy storage offering opportunities for control of demand and supply. Meanwhile, continuing developments in information and communication technologies is an enabler for DSM making it cheaper and easier to implement the necessary control systems. The roll-out of smart meters is expected to deliver new capabilities in DSM, although this will rely upon the installation of suitably controllable loads.

The focus for this work is frequency regulation and the scope for a large water heating load to offer an alternative to conventional frequency control services. Among energy storage options, storage of heat is the most cost-effective, although the applications are limited to locations where the heat can be effectively used within suitable timeframes. Storage of hot water can be achieved at a relatively low cost using a well insulated hot water tank. The technology is relatively simple and conventional, and can be integrated with existing heating systems.

Frequency control is defined in terms of targets and limits with different control actions being triggered as different limits are breached. The frequency response of generators is normally characterised in terms of droop, which is the change in power output for a change in frequency.

The droop characteristic is supplemented by the time in which the response must be achieved, e.g. 10 s for speed governor control. The parameters commonly used to characterise frequency control services from generators are also applicable to demand side control. The speed of response, ramp rates and limits on maximum and minimum power consumption will depend on the specific characteristics of a load. The differences will be in the availability of the service, particularly in terms of repeatability or as a function of what has gone before, and any metering associated with payments for providing a frequency control service.

Large generators are normally required to provide frequency response as soon as frequency deviates from the target. Smaller generators connected to distribution systems may operate in a limited frequency sensitive mode, which means their output is insensitive to frequency until it breaches certain limits. Industry rules in the UK also define automatic low frequency demand disconnection; the network operators are obliged to disconnect certain amounts of demand when frequency drops too low. At a national level, demand customers, particularly large industrial and commercial users, are invited to offer balancing services. This might be arranged for single large users or might be aggregated across a number of loads.

Finding alternative means of controlling frequency will provide the network operators with the means to facilitate increased access for renewable generators and low carbon technologies that would potentially be limited based on the existing frequency control arrangements, which on island systems can be quite different from those used at national level. For DSM as envisaged in this project the availability of frequency response will depend on the prevailing level of hot water usage. The previous use of DSM and limits on temperature in the hot water tank will limit the response available.

There are several examples of existing systems or prior art that can inform the work intended to be undertaken, these are now discussed.

The small electrical system on Fair Isle has been reliant on frequency control using renewable energy, diesel generators and DSM since 1982. There are a number of wind turbines on the network that provide the bulk of the electricity consumed on the island. The system operator of the Fair Isle network makes use of remote frequency sensitive static relays that control heating appliances in the individual buildings of the community to provide frequency responsive demand. Originally, dump loads had been installed to assist the wind turbines in achieving the appropriate speed to connect to the system.

The Isle of Eigg has an electrical system that relies on battery storage and controllable loads to manage the variable output of wind, photovoltaic and hydro sources. The batteries play the leading role in managing supply and demand but when there is an excess of power there are a number of heating loads that can be switched on. These include heaters in community facilities and churches as well as a dump load linked to the wind turbines. The heaters respond to frequency and voltage and incorporate random time delays to prevent sudden excessive load restoration.

The company RLTec provide frequency responsive demand side management solutions. RLtec's technology transforms electrical appliances like fridges, air-conditioners and heaters into smart devices that respond to changes on the national grid to improve its efficiency and save carbon, energy and money. The technology has undergone laboratory testing and is now being trialled with a UK energy supplier. In the first phase of the trial, 300 fridges have been fitted with dynamic demand and will be distributed to consumers. This will allow analysis of how the technology works in appliances in everyday use. In the second phase of the trial, a total of up to 3000 fridges and freezers of different types and models will be deployed so that the carbon savings from dynamic demand can be measured in a wide variety of situations.

The Grid Friendly Appliance controller developed at Pacific Northwest National Laboratory (PNNL) in the USA senses grid conditions by monitoring the frequency of the system and provides automatic demand response in times of disruption. The computer chip can be installed in household appliances and turn them off for a few minutes or even a few seconds when there is a frequency dip. The controllers can be programmed to autonomously react in fractions of a second when a disturbance is detected. They can also be programmed to delay restart instead of all coming on at once after a power outage to ease power restoration. When a communication system becomes available between network operator and customer, the system has the capability to perform more sophisticated negotiation and control, such as reducing peak loads. It is claimed that this simple, cost effective technology can become the basis from which ever more sophisticated aspects of the smart grid concept can grow.

The IEA Demand Side Management Programme is an international collaboration of 20 countries working together to develop and promote opportunities for DSM. The IEA identify several projects in the area of balancing small and renewable generation:

- Smart-A, Germany, Demonstration, Renewable and cogeneration, Domestic load shifting
- EEG – Integration of wind energy, Austria, Research, Wind, All types of demand
- Green VPP, Austria, Research, Renewable, All types of demand
- VPP and DSM, Austria, Research, Wind, Heating, cooling, washing, drying and dish washing
- Viselio, Italy, Research, Solar, Heat storage and biomass plant
- Renewable buffering on minor islands, Italy, Research, Renewable, Hydrogen storage or desalinated water production
- EU-Deep – Task Force 1, Europe, Demonstration, Wind, All demand and local generators
- Solar Cities, Australia, Field Tests, PV, Energy Efficiency
- Acciona Solar Building, Spain, Exists, PV, Energy Efficiency in one building
- Antondegi, Spain, Exists, Solar, Wind, Biomass, Energy Efficiency
- Sarriguren, Spain, Exists, Solar, Wind, Biomass, Energy Efficiency

References

List relevant references

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3. The Grid Code, Issue 4, 24th June 2009, National Grid Electricity Transmission plc, www.nationalgrid.com/uk/Electricity/Codes/gridcode/
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8. www.communityenergyscotland.org.uk/userfiles/file%5CCase%20studies%5CIsle%20of%20Eigg%20electrification%20case%20study.pdf
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11. http://www.ieadsm.org/

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

The objective of the testing is to validate the proposed control solution in a realistic test environment. It is expected that if successful testing is completed, the installation will be deployed on a HV network at 11 kV; therefore, similar voltage and power levels for testing are desirable. It is envisaged that the heating element will be >1 MVA and the control system, various components, measurements and interfaces will need to perform satisfactorily in this environment.

The objectives and format of the testing are expected to be as follows:

- Perform integration testing of off-the-shelf control solution components.
- Confirm the accurate measurement and processing of frequency, current and voltage.
- Confirm the fail safe elements of the proposed solution and control state transitions.
- Implement several droop response characteristics for the control system.
- Represent the hot water tank as a resistive load bank.
- Manipulate the provision or consumption of power to the test network to create variable frequency events and monitor and prove the response of the control system algorithms.
- Implement various representations of the large hot water tank, in terms of limiting the available thermal capacity.
- Test the performance of the proposed solutions when exposed to various power quality phenomena, including harmonics, flicker and variations in voltage.
- Test the ability of the control system to manage and coordinate the potentially conflicting goals of voltage and thermal constraint resolution with frequency response.

In order to perform this testing, a lab with a large enough source of power (1 MVA or greater) and capable of 11 kV or thereabouts is required. The testing will require control of the consumption and provision of power and the ability to create and control variable frequency events on a test network to replicate conditions expected to be encountered in the real-life deployment of the control system. The main monitored parameters will be frequency, voltage and current. The control signals and operation of the control system will be closely monitored and recorded during testing. SGS will provide an interface to perform this function but it is expected that this will be complimentary to extensive logging of all data associated with the trial by the host organisation.

The host installation team are expected to advise on all health and safety aspects of the proposed testing. SGS and SHEPD welcome the involvement of the host organisation in formulating test procedures and identifying appropriate test equipment.

One limitation of the testing is that the large heating element will not be present at the lab for testing. However, insight from the lab testing using a resistive load bank should inform the commissioning test procedure. There is also the risk that the correct conditions and power level will not be available in the lab; this risk can be mitigated through careful lab selection.

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

It is the belief of the project team that the frequency responsive demand side management scheme being proposed would be the first to offer a more analogue form of response, rather than simply turning on or off the heating element. Such systems could play a crucial role in future networks, where carbon reduction is an overarching goal and therefore new and clean means of balancing electricity systems with high penetrations of renewable generators is required. The basic operation of the control system will be tested together with its incorporation within a wider Active Network Management (ANM) solution to resolve network voltage and thermal constraints. It is crucial that extensive testing of the control system is performed prior to it being deployed on SHEPD's network, where it will be tasked with contributing to frequency regulation and therefore have a direct impact on security of supply.

One clear advantage of the proposed system that further enhances the universal appeal of the approach to be tested is the use of off-the-shelf components. In addition, the accompanying analysis techniques and methodologies being developed separately from the testing being proposed here will provide insight and learning to the industry.

Accompanying the control system design, testing and implementation is the exploration of a number of issues that will be of relevance to the wider community. In implementing this control system, SGS and SHEPD will be tackling the following questions:

- How can frequency responsive demand of a large single heating demand be technically and commercially deployed?
- How can the system be designed, considering the technical and economic impact on existing arrangements?
- What is the value of such a demand side management facility to network operators?
- What contribution to network security can be provided by such installations?
- How can such installations facilitate increased renewable energy production and facilitate low carbon networks? And how can this be quantified?
- How can frequency responsive demand also be incorporated within Active Network Management schemes to maximise the use of existing network capacity for renewable generation?
- How can such systems be harnessed to increase the MW capacity of renewable energy connected to existing networks?
- How can the implementation of such demand side management schemes be factored into infrastructure planning decisions?
- What are the impacts on network performance?
- How does the control system perform during network events?

The validation and implementation of the proposed approach will represent a significant step forwards with regard to incorporating demand side management within the operation of low carbon electricity networks. The results being of interest to research and academic institutions and being of relevance to electricity network operators and industrial organisations across Europe and the world.

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

After a review of the publicly available information regarding the various DERri laboratories, it is the opinion of SGS and SHEPD that the Flexible Power Grid Lab (FPGL) in Arnhem is the preferable choice for the trial. This is for the following reasons:

- It is a requirement for the testing to be at realistic power and voltage levels; the FPGL meets these criteria as the lab can provide a flexible supply voltage of up to 24 kV at a power level of 1 MVA.
- The tests will be performed within an environment that replicates the conditions to be found on SHEPD's network; the FPGL can replicate different grid conditions, including significant variations in fundamental frequency and harmonic distortion.
- The control system requires testing beyond bench testing to provide credibility for utilities; FPGL provides both the scale and flexibility to replicate the wide range of conditions expected on utility networks.
- The FPGL laboratory has the required load banks to dissipate waste heat during testing and a wide range of instrumentation to accurately capture the performance of the equipment under test.
- The FPGL is relatively close to Scotland, where both SGS and SHEPD are based.

- KEMA are a long established independent organisation with excellent experience and expertise in performing tests for T&D equipment across a wide range of power, voltage and environmental conditions.
- The project partners consider the FPGL laboratory to be appropriate in terms of pedigree and reputation for providing key testing to permit this control system to progress through to higher technology readiness levels.

If this proposal is successful, SGS and SHEPD will fund the shipping of the control solution to Arnhem, which will be configured in a manner agreed as being suitable with KEMA. SGS will provide full input/output lists and instructions as required to support the installation of the control solution in the lab. SGS will also provide a test specification and anticipate receiving feedback and involvement from KEMA to refine and establish the testing regime for the trial. SGS anticipate making use of the supplies, load banks and power electronics devices to create a grid with passive and active loads. SGS also anticipate providing a Human Machine Interface (HMI) for the proposed control solution to allow parameters to be monitored and visualised as intended for installation. However, full use will be made of the local control room and instrumentation at the FPGL laboratory.

SGS anticipate the testing taking less than one week to complete, not counting the time spent by KEMA to establish and configure the test components and infrastructure, or to provide feedback and guidance on the test specification and any associated health and safety aspects.

Synergy with ongoing research (about ½ page)

There is a parallel activity regarding the implementation of multiple small-scale frequency responsive heating demand units. In the same manner as for the proposed project, this will be focused on analogue demand side management, rather than the on/off control of individual or coordinated devices. The goal of the concurrent project is to develop the control systems (working with manufacturers) to enable functionality within domestic heaters. The approach to be adopted will be standardised with respect to the subject of this proposal, ensuring platform compliance.

The analytical methods and methodologies developed will be applicable to cope with both the single large heating element and the multiple small electric heating loads. The control systems will be compatible and complimentary, ensuring that the necessary data and control philosophy exists to ensure network security. Again, the integration of such devices within an Active Network Management scheme will be explored, ensuring that such devices can play a part in managing voltage and thermal capacity limits on networks, while also providing frequency response.

Dissemination – Exploitation of results (about ½ page)

The work forms part of the research, development and demonstration (RD&D) activities undertaken by Distribution Network Operators (DNOs) in the UK. As a condition of the funding provided for this work the DNOs must publish information on their activities. This includes an annual report on all RD&D activities and, for work under the new Low Carbon Network Fund (LCNF), an annual conference that will be held in the UK. It is an objective of the LCNF work that the lessons learned by one DNO will be shared with others. Dissemination within the UK DNO community will be supplemented by presentation at conferences, and journal publications where appropriate, over the coming years. The project partners also expect to continue the practice of presenting and disseminating results at European conferences.

Time schedule (about ½ page)

The proposed schedule for this work is as follows (all 2010):

16.08-27.08: Define test environment, test components, simulation and system aspects. Produce short report on overview of test facilities and components including overview of

	recommended test procedures.
30.08-10.09:	Produce detailed test specification.
06.09-01.10:	Detailed laboratory testing of proposed arrangements (one week within this window).
04.10-15.10:	Produce report on outcomes of testing, including recommendation for control system option to be deployed.

Description of the proposing team (as long as needed)

Smarter Grid Solutions (SGS) formed in 2008 to commercialise Active Network Management (ANM) concepts developed at the University of Strathclyde to manage technical constraints on electricity networks associated with the connection and operation of renewable generators. ANM can be used to optimise the use of electricity networks for accommodating more generation or demand than would normally be considered appropriate using conventional network planning standards and operation of a 'passive' distribution network. SGS offer a range of ANM products and services to assist electricity network operators in allowing cheaper and faster connection of low carbon technologies. SGS products are based on distributed real-time control systems. To help electricity network operators to understand how ANM can be applied, and to evaluate the costs and benefits, SGS have developed a suite of analytical tools to undertake appropriate feasibility studies.

The SGS project team is expected to include the following personnel:

- Robert Currie, Operations Director
- Colin Foote, Head of Power Systems
- Neil McNeill, Head of Smart Grid Delivery
- James O'Flaherty, Senior Smart Grid Engineer

SGS personnel have published widely both in international journals and conferences regarding ANM. More information regarding SGS can be found at www.smartergridsolutions.com.

Scottish Hydro Electric Power Distribution's (SHEPD) operating region covers a quarter of the UK landmass, which attracts unique challenges both in terms of distance and location. As well as the major towns and cities of Aberdeen, Dundee, Inverness and Perth, SHEPD connect to most Scottish islands with over 100 subsea cable links, including the Inner and Outer Hebrides, Arran and the Orkney Islands. SHEPD also serve the Shetland Islands, which presently has no interconnection with the mainland and runs as a separate electrical system.

The SHEPD project team is expected to include the following personnel:

- Stewart Reid, Network Services Manager
- David MacLeman, Distribution R&D Manager
- Bob Fordyce, Lead Protection Engineer
- Brian Punton, System Planning

SHEPD are one of the leading DNOs in the UK regarding the connection of renewable generators and the implementation of novel low carbon grid technologies. More information regarding SHEPD can be found at www.ssepd.co.uk.