ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

User-Project Acronym	DISCOSE
User-Project Title	DIStributed demand Control Operating through System Events
Main-scientific field	Power systems operation
Specific-Discipline	Demand side management

Lead User of the Proposing Team:

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Activity type and legal status* of Organization	Public research organization
Position in Organization	Researcher

* 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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(Repeat for all Users)

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DERri
Distributed Energy Resources
Research Infrastructures

Activity type and legal status* of Organization	Public research organization
Position in Organization	Researcher

Date of submission	30 September 2010
Re-submission	YES________ NO___x____
Proposed Host TA Facility	University of Strathclyde
Starting date (proposed)	1 December 2010

Summary of proposed research (about ½ page)

The DISCOSE (DIStributed demand Control Operating through System Events) project proposes the deployment of a novel electricity supply and demand coordination algorithm on an dynamic and flexible laboratory scaled microgrid. The coordination algorithm, called PowerMatcher, provides a real-time coordination of supply and demand for electricity networks with a high penetration of distributed generation. With the increase in distributed generation and renewable energy sources, unpredictability and fluctuation of energy supply increases as well. This may cause significant power imbalances on the grid which in turn causes unacceptable frequency excursions. One way to mitigate this problem is to better match the power supply and demand in real-time. Fundamentally, the proposed coordination algorithm is based on multi-agent technology and electronic markets. It is expected that this coordination algorithm will contribute to the secondary frequency control of the network. Therefore large cascading tripping of generators may be avoided. The proposed research will investigate how this coordination algorithm performs on a hardware microgrid. The expected outcome is that this research will provide invaluable insight and knowledge in this field.

State-of-the-Art (about 1 ½ page)

Distributed coordination of electricity supply and demand

An important prerequisite for reliable and stable operation of electrical power grids is that supply and demand of power are balanced at all times. In traditional, centrally-controlled electrical power networks, real-time balancing is usually implemented by adjusting large-scale generation to fluctuations in demand. However, this load-following strategy is becoming increasingly difficult with the growing degree of integration of renewable and distributed generation (DG-RES), which affects both the forecast ability and controllability of the electrical grid.

A promising solution is to encourage large-scale demand-side and non DG-RES generation participation in real-time balancing mechanisms. In such a setting, modern ICT solutions are provided to producers, consumers and so called prosumers(customers having both consumption and production capability). These are connected to current market mechanisms for exerting grid support functionality. Handling of - potentially - millions of small customers requires organization of consumers in such a way that their overall power usage can be controlled, but individual behavior and comfort is not impeded. Multi- agent technology provides a paradigm for this, since agents can balance cooperation, yet act in self-interest.

The PowerMatcher™ technology, as developed by ECN [1], delivers such a real-time coordination mechanism for coordination of supply and demand of electricity in networks with a high share of distributed generation. Applications so far have been focused on virtual power plant (VPP) operation based on commercial interests, such as balancing of a portfolio of a balance responsible partner, or price/market driven peak load reduction (a.k.a. demand response). Peak load reduction based on capacity restrictions, e.g. on a substation, has been a first grid-critical application [2].

A relatively new application area for the PowerMatcher to prove its potential is the grid-critical area covered by ancillary services [3]. These types of application tend to be more time-critical, such as frequency control. Testing under time-critical conditions it is only feasible in real grid circumstances, which are not available at the current test sites where the PowerMatcher is deployed.

Power-Hardware-In-the-Loop

The laboratory demonstration and validation of enhanced power system control requires interfaces between hardware and software due to the complexities of interaction. To facilitate use on power hardware and represent larger network phenomena, a real-time system with hard calculation limits must be used.

The use of hardware-in-the-loop (HIL) digital simulation for testing of power equipment has increased in popularity over recent years. A key enabler of this is the availability of computing power necessary to simulate power systems in real time, with the fidelity required to simulate transient phenomena in power systems. Traditionally hardware in the loop simulation has been used for testing of secondary power equipment such as protection relays and controllers for machines and converters.

A key aspiration, however, is to couple entire electrical networks in hardware to digital models of other electrical networks running in real-time. The hardware network might contain many generators, loads, cables, transmission lines and transformers. The simulated network might be even more complex, or might be a very simple network such as an infinite bus or large single generator. The construction of such a system allows sections of power systems to be constructed in hardware, and coupled to simulations of larger power networks that cannot be implemented in hardware due to constraints of time, cost, and space. The results from experiments performed on such a system have high credibility due to the use of actual hardware and control systems wherever possible. The proposed hardware network can be subjected to simulations of grid perturbations and faults, etc., and the desired response verified. Such a step represents a sensible final test of a prototype power system before deployment in the real world.

To achieve such a goal requires a specialized interface to "transfer" power and maintain the conservation of energy between the simulated network and the hardware network. This interface must emulate the simulated model at the point where the hardware is connected. Generally a controllable power supply is needed where the current and voltage output can be set. This is known as Power-Hardware-in-the-Loop (PHIL) simulation [4].

References

[1] K. Kok, C. Warmer, and R. Kamphuis. PowerMatcher: multi-agent control in the electricity infrastructure. In AAMAS '05: Proceedings of the 4th int. joint conf. on Autonomous Agents and Multi-agent Systems, volume industry track, pages 75, 2005. ACM Press.

[2] Warmer, C.J., Hommelberg, M.P.F., Roossien, B., Kok, J.K., Turkstra, J.W. 2007. A field test using agents for coordination of residential micro-CHP. ISAP conference, November 4-8, Taiwan.

[3] C.J. Warmer, I.G. Kamphuis, R.M. Hermans, J. Frunt, A. Jokić, P.P.J. van den Bosch Balancing Services in Smart Electricity Grids Enabled by Market-Driven Software Agents.

[4] A. J. Roscoe, A. Mackay, G.M. Burt, and J.R.McDonald, "Architecture of a network-in-the-

loop environment for characterizing AC power system behaviour," IEEE Transactions on Industrial Electronics, vol. 57, no. 4, April 2010

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

Objectives

- Appraisal of the effectiveness of coordinated demand side measures in providing graduated secondary frequency support through pricing.
- Demonstration of PowerMatcher distributed control on a dynamic and flexible power hardware platform emulating grid emergency state conditions and pre-emergency conditions.

Expected Outcome

An experimentally based understanding of the operation of a market based demand side dispatching system in a hardware environment with challenging system operational scenarios. Given the critical contribution that demand side measures have to make to the smart grid paradigm, it is expected that this experimental validation will attract strong industrial interest and provide excellent dissemination potential.

Fundamental Scientific and Technical Value and Interest

With the increasing penetration of distributed generation (DG) into the distribution networks there is decreased operator visibility of the total of generation online or available. It has been seen in recent events[1] that DG is now at the level to cause significant and unexpected changes in frequency. If a system of distributed demand/DG control (such as PowerMatcher) was in place, then its coordinated action when presented with frequency events such as those in the UK of May 2008 would limit the frequency excursion and provide valuable frequency support. Of significant interest is the ability of PowerMatcher to provide continuous reaction to frequency variations, so with the anticipated growth of controllable demand (e.g. electric vehicle charging), the contribution may be equally significant to the maintenance of operational frequency ranges as it is to statutory frequency limits.

The PowerMatcher software requires a change in frequency to be defined as a step change in power the Microgrid control system will need to provide this data. Testing within the Strathclyde laboratory will permit issues of measurement accuracy, refresh rates, and potentially predictive control to be appraised.

Plan for the experimental setup

The main setup for this test is given in the information flow diagram in Figure 1. ECN will be responsible for the components on the PowerMatcher platform, that will run on a PC under Microsoft Windows. The team will work with the University of Strathclyde to establish the Δ-power signalling and integration of load bank controllers. The interfaces between the platforms have to be developed by both parties.

[1] See for example the National Grid Presentation on the May 2008 Frequency excursion event *www.cigre.org/fr/events/download/3-%20UK%20Frequency%20Excursion.pdf*

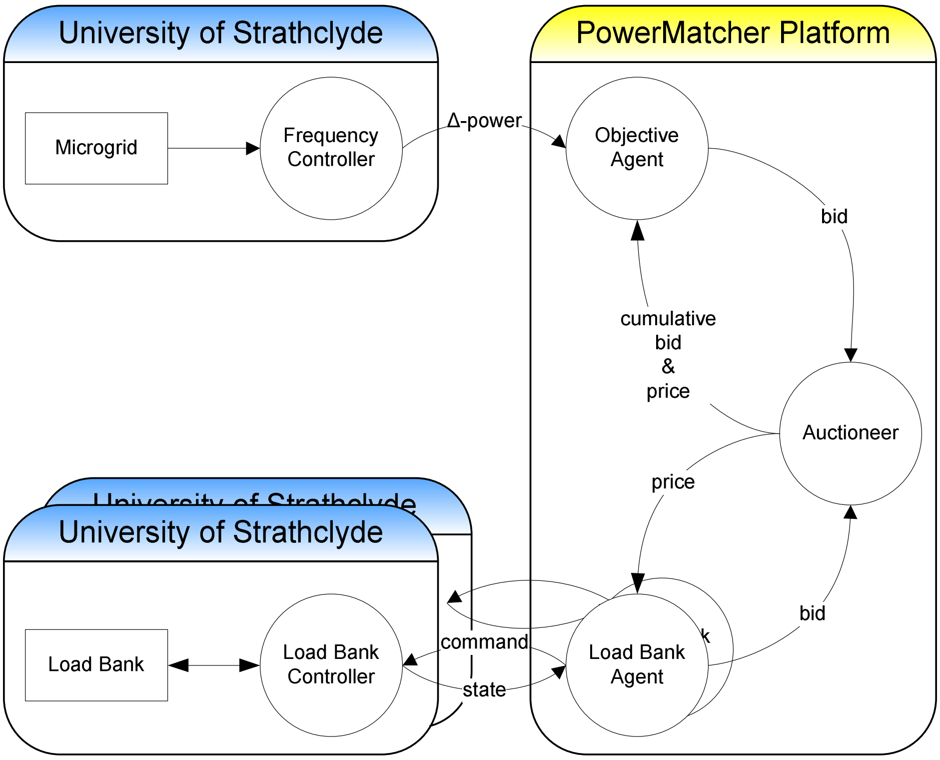


Figure 1: Information flow diagram

At the University of Strathclyde D-NAP facility a frequency disturbance scenario can be fed into the microgrid. A challenge for the lab is to emulate the frequency disturbance by load and generation switching such that they mimic the time response delays of a large network. The load bank agents then can change the settings of the load banks such that the shortage (or surplus) of supply is countered. Therefore the load bank agents take part in a PowerMatcher organized market in order to switch the most profitable flexible loads or generators. Since secondary control is a time-critical service, a main criterion for success is whether the PowerMatcher can organize a timely response from the load banks.

The main components in the test are defined in Table 1.

Table 1: Key processes defined for the PowerMatcher enabled frequency support.

Microgrid Frequency Controller	This serves to integrate the microgrid monitoring with the power imbalance based PowerMatcher Objective Agent.
Objective Agent	Transforms the Δ-power to a PowerMatcher bid function, using the current cumulative bid function and price from the auctioneer
Load Bank Agent	Sends a bid function to the PowerMatcher Auctioneer, based on the current state of its Load Bank. Interprets the price (change) from the Auctioneer and transforms this to a load command for the Load Bank Controller. In the experiment there will be two or more load banks, each reacting at different price levels.
Auctioneer	Receives bid functions from its agents (both load bank agents and the objective agent) and determines the equilibrium price. This price is sent to all agents
Load Bank Controller	Retrieves the 'state' of the Load Bank and sends it to its Load bank Agent. The definition of this state will be formalised in the early stages of the project.

	Receives commands from its Load Bank Agent with respect to the new set point for power level of the Load Bank and implements this set point.

Main work breakdown

Preparatory work

1. Agreement of one or more frequency disturbance scenarios to be implemented at the Strathclyde D-NAP facility
2. Definition of information to be exchanged at the interface between the Frequency Controller and the Objective Agent and the interface between the Load Bank Agent and the Load bank Controller
3. Definition of the interfaces between software systems
4. Refinement of the Objective Agent algorithm & interface, and Load Bank Agent algorithm & interface
5. Tailoring of Frequency Controller and Load bank Controller, including the interfaces
6. Collaborative testing of the interfaces, initially using Web services between laboratories, but including one day site visit.

Intensive on-site laboratory testing

7. On site testing of separate components, module testing and system testing
8. Experimental investigation of the agreed scenarios using the PowerMatcher-driven load control within the microgrid laboratory. Initial analysis of results

Dissemination activity

9. Analysis of results, leading to dissemination by papers and presentations

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

Near real-time control of load and generation is traditionally limited to large scale generation (e.g. for reserve capacity) and load shedding. The huge potential of a large number of small devices with flexible demand or supply cannot be reached through current, top-down, control mechanisms. Replacing reserve capacity with flexible demand and supply delivers large potential for efficiency with respect to energy and capital. The PowerMatcher technology also provides a market mechanism that allows development of a profitable business case, e.g. by linking the flexible demand and supply to the current balance market.

So far the PowerMatcher software has been demonstrated in field trials, but has not been exposed to abnormal power system events such as frequency excursions due to large and sudden power imbalance. It is believed that other agent-based pricing systems have similarly yet to be demonstrated on real-world system events within a dynamic and flexible microgrid laboratory.

The demonstration of this system is of interest to UK utilities, and is similarly likely to attract interest from European operators. This application offers near term support to operators with weak electrical links at the extremities of their networks, wherein demand side management offers operational support. There is furthermore potential for such a system to be applied on physical islands around Europe. This could provide an elegant solution to supporting the greater penetration of intermittent generation within such communities, providing rapid response to varying wind patterns for example. Also, such a scheme could support more rapid recovery after loss of any submarine interconnector to the mainland.

The proposed work also fits very well into the Strategic Energy and Technology plan (SET-Plan) as presented by the EU Commission: demonstration of automating distribution network control and operation, combined with activation of the customer site and development of innovative markets. http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm. Also one UK DNO license holder has already expressed an interest in this research, and the team will establish an industry interest group to demonstrate experimental findings.

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

ECN believe the University of Strathclyde uniquely has the facilities to host this project and support it to completion. The proposed hardware infrastructure is Strathclyde's microgrid laboratory linked to their RTDS system (D-NAP facility). Strathclyde have already begun the process of allowing 3rd party access to their software control system and it is not envisaged that there will be any problems in them implementing this in the near future; tests of a data-read capability through OPC have already taken place. To maximize time whilst in-situ ECN and Strathclyde propose to perform a remote web based link-up of the PowerMatcher software with the OPC database held on site at Strathclyde. This will allow problems to be identified before the ECN team arrives at Strathclyde, as well as providing an interesting evaluation of a web-services link-up of two laboratories.

Several load banks will be used as substitution for devices with flexible demand and supply (e.g.

electric heating or cooling processes). The distributed control of these load banks will take up the role of secondary control, replacing (partly) secondary reserve capacity. The D-NAP laboratory has been previously used to emulate grid events such as that of May 2008. It is capable of providing electrical frequency in the range of 45-55Hz and can be cycled through this range in realistic time periods. The May 2008 event will therefore be used as a test case for proposed experimental setup of the microgrid and the PowerMatcher.

Strathclyde have experience in the laboratory demonstration of software algorithms interacting with hardware, e.g. the AuraNMS project. Further they are one of the few facilities to have successful demonstration of linking an RTDS real time system to a microgrid laboratory, and have already overcome many of the timing issues associated with such work. Furthermore, the team have strong industrial connections that will provide for good engagement with relevant stakeholders.

Synergy with ongoing research (about ½ page)

The following lists some current research projects with which this project has synergy.

- ECN is taking part in the EERA Joint Program on Smart Grids. Especially in Sub-Program 1 where frequency control is a main area of interest.
- SUPERGEN HiDEF (Highly Distributed Energy Futures) and SUPERGEN FlexNet; these projects concern the design and control of the future grid encompassing many different generators and customer types. The PowerMatcher experiments will give these research teams insight of the issues associated with providing market based control of such resources, and of integration challenges with existing control systems.
- ECN is participating in several projects in the area of ancillary services. The RegelDuurzaam project is formed by a Dutch consortium, including TenneT, the Dutch TSO, and APX Group (Amsterdam Power eXchange). In the project innovative markets are being developed for ancillary services. One of them focuses on participation of flexible distributed energy resources in primary and secondary control
- Rolls-Royce Distributed Generation control project has provided flexible controls of distributed generators; this DERRI TA project will provide a framework in which such flexibility could be exercised and coordinated to provide significant system support:
- DERRI JRA 1 is relevant as the first step in this project will be to set up an international link into the Strathclyde IT Network and allow limited remote control of power devices on the Strathclyde Microgrid.
- DERRI JRA 3 is relevant as this contains a part about extending the use of Real-Time simulation systems. By attaching the power matcher system to that in-situ then further understanding of RT interactions may result.
- Scottish Power Advanced Research Centre and the Scottish and Southern Energy Research Partnership; both of these centres of excellence at Strathclyde have interests in the impact of DER and how to control such resources and operate the market. The demonstration at Strathclyde will inform power sector stakeholders through these channels.
- Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response, Roscoe, A.J.1; Ault, G.1 Source: IET Renewable Power Generation, v 4, n 4, p 369-382, July 2010

Some of the above listed projects will be described in a bit more detail.

Due to the development of the electricity market and the further integration of DG there is uncertainty about maintaining the balance between supply and demand in the electricity system. In the Dutch project 'Regelduurzaam' funded from the Long Term Energy Research Program (EOS), of the Dutch Ministry of Economical Affairs, required agreements and measures are studied to secure a reliable electrical energy supply in the future. This project aims at an electrical energy supply that functions with the both the lowest possible costs and environmental impact. Beside this boundary condition, no insight on a central level in the available production capacity and the expected load for the next period of time, is taken into account. The research work conducted in RegelDuurzaam is rather theoretical in nature.

In electricity grids the frequency of the voltage is stabilized by a combination of the rotational inertia (rotating mass) of synchronous power generators in the grid and a control algorithm acting on the rotational speed of a number of major synchronous power generators. When in future small non-synchronous generation units replace a significant part of the synchronous power generation capacity, the total rotational inertia of the synchronous generators is decreased significantly. As a consequence the variation in the rotational speed of generators due to changes in their net load will become much higher than at present. This causes large frequency variations that can end up in an unstable grid. A way to stabilize the grid frequency is to add virtual rotational inertia to the distributed generators. A virtual inertia can be attained for any generator by adding a short-term energy store to it, combined with a suitable control mechanism for the storage its power electronics converter. In this way a generator can behave like a "Virtual Synchronous Generator" (VSG) during short time intervals, and contribute to stabilization of the grid frequency. ECN is leading an European project on VSGs, called VSYNC. The aim of VSYNC is to demonstrate the VSG concept in a number of field trials across Europe.

In the "European Energy Research Alliance (EERA) SmartGrids, Sub Program 1 (ECN is contributing to this)- Network Operation" project, funded by the EERA joint research program on Smart Grids of the European Commission, is mentioned that in future grids it is expected that huge quantities of power are generated by variable renewable electricity energy sources such as wind, wave power and photovoltaic devices. This raises stability issues, identifiable as frequency and voltage fluctuations. The variability of the decentralized sources can be compensated for, either by a combination of fast reserve generation and controllable loads, or by deployment of energy stores and controlling these in such a way that the power system is stabilized in the short and medium time frame. The desired result is that, in the longer time frame, system operators and balancing algorithms have ample time to restore potentially unstable states to normal operation. In order to achieve stabilization of the future grid, research is needed on control and optimization on short time scales ranging from seconds to minutes. In this EERA Sub Program 1 a combination of emerging control algorithms and techniques acting on complementary time scales is sought to provide a primary smart grid control structure.

Synergy with the proposed DERRI project.

All these projects contribute to a better overall control for electricity grids thereby taking into account all relevant time scales. The proposed DERRI project takes elements from the above listed projects. Both the primary and secondary control elements will be investigated in DERRI.

Dissemination – Exploitation of results (about ½ page)

A coauthored paper for journal publication will be written. This paper has an outline title of 'Demonstration of an agent based power/price negotiating platform within a microgrid laboratory'

The experiment and results will also be presented at national meetings and international conferences such as the Smart Grid Research Symposium and/or IEEE PES. These will be joint authored contributions from both ECN and Strathclyde staff.

Dissemination to utility centres of excellence; engagement with UK and Dutch utilities who are monitoring progress and others who could be interested. This will take the form of direct discussion with relevant persons within the identified organizations. In addition results will be reported within the EERA Joint Program on Smart Grids and several earlier mentioned projects including RegelDuurzaam and VSYNC.

Time schedule (about ½ page)

According to the time-schedule below the following visits to the facility are planned:

- the first visit (ID 2) is to see and discuss the lab facilities and the set-up in detail and take two days (one overnight stay) for two ECN persons,
- the second visit (ID 8) is for testing the interfaces between the user equipment and the lab facilities and take two days (two overnight stays) for one ECN person,
- the third visit (ID 9) is for the actual laboratory tests and take five days, 2 overnight stays for 2 ECN persons and 3 more for one ECN person.

This brings the transport total to:

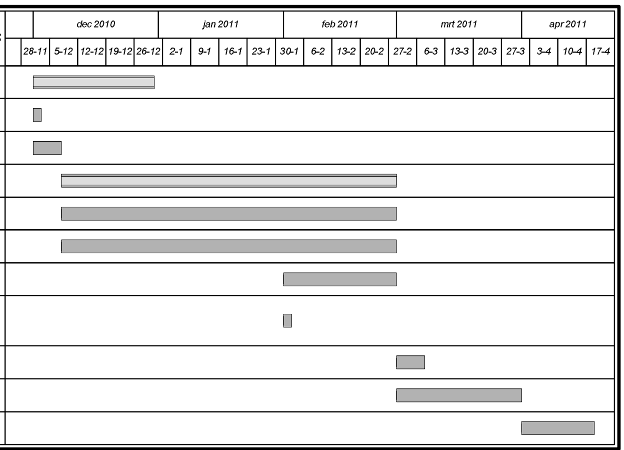
- 5 return journeys (non-stop flights) from Petten the Netherlands to Glasgow UK.

This brings the subsistence total to:

- 11 hotel overnight stays in Glasgow.

The use of the laboratory facility will be 2 + 5 = 7 days.

ID	Task	Task Name	Start	Finish	Hours ECN	Hours UoS
1	1	**Preparations**	1-12-2010	30/12/2010	**40**	
2	1.1	Visit to UoS lab (introduction lab and discussions) 2 persons	01/12/2010	02/12/2010	32	
3	1.2	Defining interface hardware and software algorithm	01/12/2010	07/12/2010	8	
4	2	**Refinement of interfaces**	08/12/2010	28/02/2011	**100**	
5	2.1	Hardware	08/12/2010	28/02/2011		
6	2.2	Software: algorithms & interfaces	08/12/2010	28/02/2011	50	
7	2.3	Defining tests for experiments	01/02/2011	28/02/2011	18	
8	2.4	Visit to UoS lab (testing interfaces and controllers hardware) 2 persons	01/02/2011	02/02/2011	32	
9	3	**Experiments at UoS lab, 2 persons**	01/03/2011	07/03/2011	**100**	
10	4	**Analysis**	01/03/2011	31/03/2011	**30**	
11	5	**Dissimination**	01/04/2011	18/04/2011	**30**	



Description of the proposing team (as long as needed)

C.J. Warmer

He graduated as a mathematical statistician from the University of Amsterdam. He joined ECN in 1981 as a mathematics and statistics consultant in a scientific mainframe environment. In this role he also supported the use of mathematical and statistical software. He was later involved in a large number of projects for data and object modeling. In this role he designed and implemented a distributed database for a large radiation-monitoring network in the Netherlands and worked on the design of production and logistics software. He also was involved in life-cycle assessment studies of materials in a number of EU-projects. His current research includes process optimization of large energy consuming systems and optimization of power demand and supply flows in the distribution network using market-based agent algorithms. He recently worked in the EU-projects CRISP and Integral, developing and testing agent technology for bottom-up coordination of demand and supply of electricity, resulting a.o. in the PowerMatcher technology, and in SmartHouse/SmartGrid, developing a novel smart grid ICT architecture, enabling the aggregation of houses as intelligent networked collaborations, instead of seeing them as isolated passive units in the energy grid. He has also been working on Dutch government funded projects FLEXIBEL, on enabling integration of small distributed generation in the power network, 1st TRIAL, demonstrating the ability of a cluster of micro-CHPs to be operated in a virtual power plant, and RegelDuurzaam, researching new energy markets for ancillary services.

J.D. Schuddebeurs

He is a Researcher in the group of Power Systems and Information Technology at the Energy research Centre of the Netherlands (ECN). He received his BSc in Maritime Operations from the Hogeschool Zeeland (The Netherlands) and his MSc in Marine Electrical Power Technology from the University of Newcastle upon Tyne in 2002 and 2005 respectively. From 2005 till 2009 he was with the Electronics and Electrical Engineering department at the University of Strathclyde where he worked as a Research Assistant. Currently, he is finishing a PhD in Electronics and Electrical Engineering from the same university. His research interests include modelling and simulation of more-electric marine power systems and the integration of renewable energy into electricity networks. He is a member of the IEEE and an associate Member of the IMarEST.

P.J.M. Heskes

He received the Electronic Engineer degree from the HTS, The Hague, The Netherlands, in 1980. From 1980 to 1999, he was with a large Dutch electronic-product manufacturer for the military and professional market. He started there as a Product Designer and became a Product Manager of the power-electronic department. His work was related to power electronic converters. In 2000, he started as a Project Co-ordinator with Intelligent Energy Management at the Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands. His current work is related to power electronic converter technology in grid connected distributed energy systems. Today he combines his work at ECN with a position as a Ph.D. student at the Electrical Engineering group of the Eindhoven University of Technology. His research interests are power quality issues with the integration of power electronics in electricity distribution systems.

Grid related journal articles:

[1] P.J.M. Heskes (ECN, The Netherlands), J.M.A. Myrzik, W.L. Kling (TU/e, The Netherlands), "Impact of Distribution System’s Non-Linear Loads with Constant Power on Grid Voltage", in-Press, John Wiley ETEP PQ Journal.

[2] P.J.M. Heskes (ECN, The Netherlands), J.M.A. Myrzik, W.L. Kling (TU/e, The Netherlands), "A Harmonic Impedance Measurement System for Reduction of Harmonics in the Electricity Grid" International Journal of Distributed Energy Resources, vol. 5, no. 4, , pp. 315-331, Oct./Dec. 2009.

[3] P.J.M. Heskes (ECN, The Netherlands), J.F.G. Cobben (TU/e, The Netherlands), H.H.C. de Moor (ECN, The Netherlands), "Harmonic distortion in residential areas due to large scale PV implementation is predictable" International Journal of Distributed Energy Resources, vol. 1, no. 1, pp. 17-32, Jan./Mar., 2005.

[4] J.H.R. Enslin (KEMA, The Netherlands), P.J.M. Heskes (ECN, The Netherlands), "Harmonic Interaction Between Large Numbers of Photovoltaic Inverters and the Distribution Grid," IEEE Transactions on Power Electronics, vol. 19, no. 6, pp. 1586-1593, Nov. 2004.