DERri
Distributed Energy Resources
Research Infrastructures

ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	ROSEDN
User-Project Title	Robust State Estimation using Smart Meters for Distribution Networks with a Large Penetration of Distributed Energy Resources
Main-scientific field	Electrical Engineering – Power System Analysis
Specific-Discipline	Distribution State Estimation for Smart Grids

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Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	Lecturer

* 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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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)

(Repeat for all Users)

Date of submission	31/05/2011
Re-submission	YES_____ NO__X_____
Proposed Host TA Facility	RSE, Italy
Starting date (proposed)	30 January 2012

Summary of proposed research

Smart meters, with the associated ICT infrastructure, can greatly improve observability of distribution networks with high penetrations of distributed energy resources (DER). Improved observability will allow the networks, and the DER, to be controlled more effectively and utilization of the assets improved. State estimation is a technique to clean up errors in measurements and estimate the system state. Smart meter measurements may contain a large number of errors and bad data with non-normal distribution coming from meter/communication delays and interruptions. Moreover, the measurement configuration (type, location, accuracy of measurements) has a large impact on the estimate quality. Based on the test facility (DER-TF) provided by RSE, a robust state estimation method developed in Cardiff will be tested and improved to provide robustness in both measurement space (considering the error distribution) and factor space (considering the measurement configurations). Various test systems will be set up based on the DER-TF considering the network topology (radial or meshed), DER penetration, two operation mode (grid-connected or islanded) to implement four operation scenarios which will be investigated in the proposed project. The test systems will be operated for a short time period (e.g. 1 day per operation scenario) and all operating information will be collected (e.g. measurements every 5 minutes). Disturbances will also be added manually to capture the system behaviour under abnormal conditions. Then detailed analysis will be carried out in Cardiff to investigate the technical feasibility and key technologies of using robust state estimation to increase the observability of the distribution system, especially with smart meters and large DER penetration. The proposed research work will be carried out based on the close collaboration between the investigators from Cardiff and the experts in RSE. A technical report for the DERri project describing the research work and the output will be submitted. The research output will be summarised in papers collaborating with RSE. The link between Cardiff University and the DERri consortium will be further strengthened by the proposed research, and will contribute to an integrated European research capability.

State-of-the-Art

Real-time monitoring and control is very limited in present day distribution networks due to the lack of sensors and insufficient communication infrastructure. A large number of pseudo measurements from load estimation and load forecasting can be used for distribution state estimation but this remains difficult as the measurements are often polluted by outliers and bad data [1].

With the large-scale roll out of smart meters the ICT infrastructure of distribution networks will be enhanced. Distribution networks will then change from being in an under-determined to an over-determined condition. However, there is limited agreement on the role of smart metering in distribution network operation. The information obtained through heterogeneous sensors and communication networks of smart metering, whose main purposes currently are automatic meter reading and instigating a change in the behaviour of energy consumers, may contain severe time

delays, which introduces errors in the real-time measurements. Moreover, temporary communication network failures may interrupt the measurements and thus disable the state estimator. Measurements from DER have a large impact on the quality of state estimation, e.g. inaccurate measurements will deteriorate or even disable the state estimator.

Robustness is a common requirement of state estimators for distribution networks. For the under-determined network, a number of approximate load estimation techniques have been applied to obtain the required pseudo measurements based on transformer capacity (kVA ratings), peak demand, or customer billing information. Existing methods include state-estimation based methods [2-3], probabilistic modeling methods [4], computational-intelligence-based methods [5-6], and hybrid methods [7]. Gross errors among pseudo measurements can disable the conventional state estimators, e.g. Weighted Least Square (WLS) estimators, and hence jeopardize system operation. Robust estimation methods were developed to identify, remove or reduce the impact of outliers and bad data. These include modified WLS methods such as Iteratively Re-weighted Least Square (IRLS) estimation [8]; and methods based on non-quadratic criteria such as the Weighted Least Absolute (WLAV) Value estimation [9], Quadratic-linear (QL) and Quadratic-constant (QC) estimators [10]. For the over-determined problem, some distribution state estimators using metering information have also been developed [11-12].

There is a need to investigate the technical feasibility and key technologies of using robust state estimation to increase the observability of distribution systems. The impact from measurements of smart meters and DER needs to be investigated. Although the state estimation research in Cardiff University has made a theoretical contribution to this topic, further study using high-quality test facilities to validate and improve the proposed method and identify new problems is necessary. The DERri project provides an excellent opportunity for our research to use the high-profile test facilities in Europe.

References

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Detailed Description of proposed project : Objectives – Expected Outcome – Fundamental Scientific and Technical value and interest

This project will address the following challenge based on the RSE test facility (DER-TF).

Research Challenge:

Smart meter measurements may contain a large number of small errors and bad data with non-normal distribution. Moreover, the measurement configuration (type, location, accuracy of measurements) also has a large impact on the estimate quality. Low-redundancy measurement configurations will lead to the presence of leverage measurements, which can be identified based on the measurement Jacobian H, and thus the factor space can be defined based on the rows of H which correspond to individual measurements. The grip-connection points of DER usually provide some extra real-time measurements, which have large impact on the quality of state estimation. A big challenge is how a state estimator deals with various kinds of errors and influence from the measurement configuration effectively and provides accurate estimation of the system state.

Objective:

Based on the test facility (DER-TF) provided by RSE, a robust state estimation method developed in Cardiff will be tested and improved to provide robustness in both measurement space (considering the error distribution) and factor space (considering the leverage measurements).

Research Programme:

The test facility DER-TF provided by RSE will be used. The research will be carried out in three tasks. The first two tasks will be carried out through close collaboration with RSE staff. The third task will be mainly carried out in Cardiff but regular meetings will be scheduled to inform RSE of the progress and receive suggestions/comments from RSE staff.

Task 1: Set up the test systems (2 weeks)

(1.1) Two test systems will be set up, one is with radial structure and the other one is a meshed network.

(1.2) A set of selected distributed generation will be connected to the test systems (intermittent renewable generation will be given priority).

(1.3) Two operation modes of the Microgrid will be investigated in the study, i.e. grid-connected mode and islanded mode. This research will not develop new DG control methods and existing control will be used directly.

(1.4) Four operation scenarios will be designed and investigated, i.e. grid-connected & radial network, islanded & radial network, grid-connected & meshed network, and islanded & meshed network.

(1.5) All system and equipment parameters needed by the research will be collected, e.g. line parameters and settings of DER.

Task 2: Run the test systems and obtain comprehensive operating data (1 weeks)

Each scenario designed in Task 1 will be operated for a short time period (e.g. 1 day) and all operating information will be collected (e.g. measurements every 5 minutes). Disturbances will be added to the system manually (based on discussions with experts in RSE) to capture the system behaviour under abnormal conditions.

Task 3: Data analysis and robust state estimation study (7 weeks)

(3.1) The data that has been obtained will be analysed using the power flow tool, and the

information will be used as the real system state.

(3.2) Real-time measurements will be added to the test system manually to specify which quantities are visible. Various metering schemes will be investigated.

(3.3) Errors will be added to the measurements which follow specified probabilistic distributions.

(3.4) The information will be fed into the state estimator developed in Cardiff to get the estimated system states. Detailed analysis will be carried out to investigate the aforementioned challenge and the state estimator will be improved based on the test study.

(3.5) Conclusions will be drawn from this study on the technical feasibility and key technologies of using robust state estimation to increase the observability of the distribution system, especially under the conditions of a large smart meter and DER penetration. A final report will be provided.

Methodology:

Task 1 and 2 will be carried out based on DER-TF in RSE. The research will not design new control strategies for the DER, but just use existing facilities to simulate several possible operating conditions of various future distribution networks for further analysis using state estimation. Preparation stage of Task 1 and the whole Task 3 can be carried out in Cardiff. The work will base on existing research [1][2] and will be undertaken within the context of other energy infrastructure and Smart Grid studies.

Deliverable:

A technical report to the DERri project describing the research work and the output will be submitted. The research output will be summarised in papers collaborating with RSE.

Contributions to Science and Technology:

This research will be carried out based on physical test facility provided by RSE. Various aspects of robust state estimation method will be addressed and the robust state estimation method will be improved from the test study, which will provide theoretical contributions to the topic. Because various future distribution systems under different operation conditions will be investigated based on physical systems, the results will be able to inform the manufacture, DNOs and decision makers regarding the technical feasibility and key technologies of using robust state estimation to increase the observability of the distribution system.

Reference:

1. J Wu, and N Jenkins, Self-adaptive and robust method for distribution network load and state estimation, 16th Power Systems Computation Conference (PSCC), Glasgow, 2008
2. K Samarakoon, J Wu, J Ekanayake, and N Jenkins, Use of delayed smart meter measurements for distribution state estimation, IEEE PES General Meeting, Detroit, July, 2011.

Originality and Innovation of proposed research – Broader Impact

State estimation, first introduced to power systems by Fred Schweppe in 1968, is used to clean up errors in measurements and estimate the system state. State estimation techniques are widely used in transmission systems where redundant measurements are available (i.e. the system is over-determined). For under-determined distribution systems, a large number of pseudo measurements from load estimates and load forecasting have to be used as input to the distribution state estimator. However previous work has shown that such a state estimator is poorly able to support system operation due to the magnitude of estimation errors. The robust distribution state estimator developed in Cardiff will be tested and improved in the proposed research to provide robustness in both measurement space (considering the error distribution) and factor space (considering the measurement configurations). This research will contribute to the scientific development of robust estimation techniques and fill the gap between the pure theoretical research and practical application. The test systems will be implemented based on physical test facilities reflecting various possible future distribution networks with a large penetration of smart meters and DER, and under different operation conditions. Therefore the research output will be able to inform the technical feasibility and key technologies of using

robust state estimation to increase the observability of the future distribution systems, and thus facilitate the accommodation of future large penetration of DER.

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

The test facility DER-TF provided by RSE is proposed to be used for this project. DER-TF is constituted by several generators with different technologies (renewables and conventional), controllable loads and storage systems. All these DERs are connected to the Microgrid by means of a configuration and interconnection board that allows the system operator to change the system topology, radial or meshed configurations, and the DER interconnections. All the above features provide the capability of simulate various future distribution networks with different DG penetration. Modelling of smart meter errors will be carried out in the analysis stage (Task 3).

The interconnection board and all DERs are provided with electrical measure equipments, constituting a high-speed Data Acquisition System (DAS), that has been set up to collect and analyze the experimental data derived from the field results. This feature is critical which will capture and record all system information for the robust state estimation study.

Technical requirements on the test facility are explained in the section of Detailed Description of Proposed Project.

Synergy with ongoing research

The research team will work closely with industrial partners and other research consortium which the investigators are involved in, i.e. EU FP7 project MERGE; EPRSR projects ITRC, SUPERGEN HiDEF, UKERC, Grand Challenge and HubNet.

The PI is a co-investigator of the European Framework 7 project Mobile Energy Resources in Grids of Electricity (MERGE). The proposed research will provide a good opportunity to validate MERGE findings through the utilization of the DERri TA infrastructure.

The aim of ITRC (the UK Infrastructure Transitions Research Consortium) is to develop and demonstrate a new generation of system simulation models and tools to inform analysis, planning and design of national infrastructures (NI). The research deals with energy, transport, water, waste and ICT systems at a national scale, developing new methods for analysing their performance, risks and interdependencies. Cardiff is collaborating with Oxford University working on the Energy Infrastructure. ITRC will provide theoretical guidance regarding the interactions between the energy and ICT infrastructures to the proposed ROSEDN project.

SUPERGEN HiDEF project aims to design the "future power system that delivers sustainability and security through the widespread deployment of distributed energy resources and thus contributes to national and international ambition for a low carbon future." Cardiff is leading Work Stream 2 on decentralised control, which will provide strong support for the design of test systems in ROSEDN.

Cardiff is leading the Energy Supply theme in the UK Energy Research Centre (UKERC). One of the current research projects is on “Smart metering and demand side participation”. The ROSEDN project will be informed by the research undertaken in the UKERC project.

Grand Challenge and HubNet are two new large research programmes funded by EPSRC which will start in the second half of this year. Cardiff is member of both consortium. These two projects both have significant efforts on smart distribution networks.

Although there are common interests between the proposed ROSEDN project and other research projects mentioned above. No other projects address the key research question that the ROSEDN is trying to answer. Thus the ROSEDN project will fill the gap and the research outcomes will be fed into other related energy programmes in order to share best practice, conduct research that complements/enhances the knowledge base and to encourage knowledge

transfer.

Furthermore, based on the preliminary discussions with RSE, the proposed research fits well with the research activities on the state estimation that RSE is carrying out in a FP7 project. Therefore RSE and Cardiff can take this opportunity to jointly develop the initiative and make contribution to this research topic.

The Cardiff team has contributed to a number of research initiatives funded by the European Commission (e.g. SEESGEN-ICT, MERGE, FENIX, MicroGrid, More MicroGrids, Smart A, etc) The link between Cardiff University and the DERri consortium will be further strengthened by the proposed research, and will contribute to an integrated European research capability. The proposed research will also attempt to develop further collaboration with RSE for the new FP7 Call for Proposal in Smart Grid area which will be published in this July.

Dissemination – Exploitation of results

The research output from the ROSEDN project will be published in peer-reviewed journals/conferences, and will be disseminated in the project meetings of other research consortium mentioned above. The investigators will disseminate the ROSEDN findings in several EU centered international conferences, e.g. CIRED and IEEE PES ISGT Europe.

Time schedule

The time schedule is shown in the figure below. The first three weeks will be spent in RSE and the following 7 weeks will be spent in Cardiff.

Week No. - from 30/01/12	1	2	3	4	5	6	7	8	9	10
Task 1										
1.1										
1.2										
1.3										
1.4										
1.5										
Task 2										
Task 3										
3.1										
3.2										
3.3										
3.4										
3.5										

Description of the proposing team

Both team members are from Institute of Energy, School of Engineering, Cardiff University. Following a Science and Innovation award from EPSRC in 2008, Cardiff extended its work in energy networks to include both electrical systems (particularly Distributed Generation and Smart Grids) as well as gas and heat networks. The research team of 6 academics, 18 PhD

students and 10 research associates, has current projects in smart metering and smart grids, infrastructure for electric vehicles, interaction between gas/electricity/heat systems and offshore wind farm transmission. The team is led by Prof. Nick Jenkins.

The proposed research will be led by Dr. Jianzhong Wu, who joined Cardiff University as a lecturer in June 2008. From 2006 to 2008, he was a research fellow in the University of Manchester. He received his PhD in 2004 from Tianjin University, China and then worked there from 2004 to 2006. His final position in Tianjin University was Associate Professor.

He researches on power system analysis and control, Smart Grid and energy infrastructure. He has experience in the development of Distribution Management and Energy Management Systems. He was involved in more than 10 national projects in China. A set of theories, models and methods for the analysis, optimisation and management of urban distribution systems were developed from these projects. The resulting integrated software package was utilised successfully in a number of projects in China. He also led the research and development of a software system for carrying out real-time security monitoring and assessment as well as optimisation for a provincial electric power utility. He has contributed to a number of EU and UK funded projects: EU projects MERGE (Co-I), SEESGEN-ICT (Co-I), FENIX, Smart-A and More-Microgrids; EPSRC projects ITRC, HiDEF, Aura-NMS, FlexNet, and HDPS. He has published 11 journal papers, 25 conference papers and co-authored 2 books. Currently he co-supervises 7 PhD students. Mr. George O'Malley joined Cardiff as a PhD student from National Grid in 2009, and his research area is in Smart Distribution Networks. He is currently developing a Smart Grid test rig based on RTDS and a Cell controller.

Journal Papers:

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2. Zhaoxia Xiao, **Jianzhong Wu**, Nick Jenkins, An Overview of MicroGrid Control, Intelligent Automation and Soft Computing , 16 (2) (2010) 1079-8587
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Conference Papers

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14. Marouf Pirouti, **Jianzhong Wu**, Janaka Ekanayake, and Nick Jenkins, Dynamic modelling and control of a direct-combustion biomass CHP unit, Proceedings of the Universities Power Engineering Conference, Cardiff, September, 2010
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Books

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2. Co-author, "Smart Grid: Technology and Applications", Wiley-Blackwell, 2012