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Strategic Networks

NSERC SMART MICROGRID NETWORK
nsmg-net

Annual Report 2013 | 2014 *(Revised October 27, 2014)*

Vision

Smart Microgrids are the building blocks of a new electrical grid that, by 2020, will: provide **reliable, low cost and clean power**; **defer investments** in transmission and distribution systems; **improve power quality** and reduce system losses; **improve energy efficiency** and enable conservation; and help **reduce the carbon footprint** of the energy system.

Objectives

Capacity Building

Train personnel with the skills to transform the Canadian electricity industry, as it embraces new business models, renewable sources of energy and new digital technologies.

Research

Support and conduct multidisciplinary research in electrical engineering, planning and regulatory issues and communication technologies.

Knowledge Transfer

Adapt research activities into constructive forms of information for consumers, manufacturers and policy makers.

Business Development

Translate research into practical products and services for technology companies and electricity utilities.

Support

NSMG-Net is made possible by the NSERC Strategic Network Grants program, with its goal of increasing research and training in targeted areas that could strongly enhance Canada's economy, society and environment in the next ten years.

NSMG-Net host institution is the British Columbia Institute of Technology, whose innovative campus Microgrid provides a near-real test environment for microgrid technologies.

NSERC CRSNG BCIT

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Message from the Network Leader

Hassan Farhangi
Network Leader,
NSMG-Net

NSMG-Net's mid-term review provided the network the opportunity to revisit, scrutinize and update NSMG-Net's research plan, strategies and targets based on current realities of the utility sector and industry as a whole.

We began this important task by asking each Theme leader to review individually and collectively their Theme's and Network's research plan with their industrial partners in terms of its relevancy, scope and focus on industry's priorities and directions. Moreover, each Theme leader was asked to review their Theme's linkages to other themes, including specific discipline requirements, technology needs and collaborative frameworks.

This exercise, carried out in conjunction with, and in parallel to a network review by the Site Visit Committee, proved invaluable.

First of all, it demonstrated that despite all the changes and flux which the utility sector had experienced, NSMG-Net's research strategies and assumptions were still intact and adequately relevant to sector's priorities and plans. Moreover, our partners found our research achievements valuable and in line with their expectations and preferences.

The second half of the Network was thus begun with a sense of pride that our work was endorsed, supported and driven by Canada's utility sector, and thus in line with our country's drive to modernize its critical infrastructure for the benefit of Canada and all Canadians.

I am pleased to report that most projects are on schedule and on target in terms of milestones and deliverables. We also continue to collaborate successfully with the NSMG-Net's industrial partners and our research community at large. Internationally, our researchers have worked closely with ERPI (USA), National Instrument (USA), LSIS (South Korea), North China Electric Power University (China), University of Guadalajara (Mexico), KU Leuven (Belgium), and the University of Campinas (Brazil), just to name a few.

NSMG-Net has hired, funded and supervised a total of 82 students since its inception. The student and research cohort have disseminated their acquired knowledge in the form of 55 journal articles, conference papers and other publications in the past year.

NSMG-Net's researchers have also taken opportunities to meet with other researchers in the network, as well as with those outside, to enrich and promote network's interdisciplinary and collaborative work. For instance, researchers attended the IEEE PES General Meeting in July 2014, resulting in multiple one-to-one discussions related to network's activities and projects.

We have also taken bold steps to boost our international collaborations. One of NSMG-Net's students (Moein Manbachi, Project 3.4) has been attached to RWTH Aachen University in Germany to work with Prof. Antonello Monti (ACS Lab. E.On Energy Center, RWTH Aachen University) to validate a VVO engine developed by NSMG-Net researchers, using ACS Labs' extensive co-simulation infrastructure.

I am also excited to report that we will capture the essence of NSMG-Net's work in the form of a new project (Project 2.5) to develop an all-inclusive microgrid blueprint, the purpose of which is to bring together the technologies developed by all three Themes and design guidelines for islanded or grid connected microgrid solutions required by Canadian utilities and remote communities.

Finally, we are most grateful to our industry partners for their continued support of the Network, both financial and in-kind. Two great in-kind offers this year were a webinar from Manitoba HVDC on their software PSCAD, and discussions with Schneider Electric on programming their inverters with Project 1.1 algorithms. Without their support, our work would literally not be possible.

The Smart Microgrid Puzzle

This section addresses the following Site Visit Committee feedback:

> *The problem of Smart Microgrid is a large puzzle and the Network projects are each solving some pieces of this puzzle. No one expects the Network to solve the whole puzzle. However, more valuable results can be achieved if the team could use its 3+ year experience with the Network* ***to refine the definition of the puzzle****, the pieces of it that each project intends to ultimately solve (****deliverables****) and relationship of those pieces with one another.*

The smart grid or intelligent grid agenda is an effort to transform the electrical grid, from generation though transmission and distribution to end users, and make it more reliable, efficient, effective and flexible. Given that transmission and generation have benefited from continuous improvements over the years, a better part of recent efforts are being expended on the distribution and end-user sides, where grid modernization has so far been limited in scope.

Initiatives are now taking place to integrate, into distribution systems, distributed and dispersed generation, in the form of alternate and renewable energy resources, and distributed storage, collectively known as distributed energy resources (DER). These will add to the generation available locally, reduce reliance on central generation and peak loading on the transmission grid and increase the resiliency of the distribution system. In addition, and in order to further reduce the peak loading on the transmission and distribution grid, demand response or load management is being implemented on a wider scale.

From Smart Grid to Smart Microgrid

The smart grid agenda is a large undertaking, even if only the distribution system in its entirety is considered. Network proponents believe that a more manageable approach is to deploy smart microgrids within the distribution grid, where needed and economically justifiable.

These microgrids are geographically well-defined and delimited distribution networks that incorporate self-generation and load management. These structures allow the deployment and integration of DER and the implementation of the elements of smart grids required to manage the microgrid. These elements include the modern control, information and communication technologies, such as those deployed in other areas of industry, communities and society. They need, however, to be adapted to the operation of distribution systems and more specifically smart distribution grids and microgrids.

Smart microgrids can be considered the building blocks of modern distribution grids. Distribution grids can then be assembled in part by coordinating the operation of a number of microgrids within a geographic area.

What is *Smart* about Smart Microgrids?

Smart microgrids are an evolution from traditional microgrids in the following three ways:

a) **Variable generation (VG)**. Traditional microgrid generation is dispatchable, typically diesel generation. Modern smart microgrids incorporate variable generation such as wind and photovoltaic solar, so that electricity must be either be used or stored.

b) **Islandability (I)**. Traditional microgrids have been built in off-grid areas, or for emergency back-up power, and so are permanently islanded. Smart microgrids may be built in remote, campus and urban areas, and must be able to connect and disconnect from the larger 'macro' grid seamlessly.

c) **Demand response (DR)**. In traditional microgrids, generation follows the load. Modern smart microgrids use forecasting, modern sensing and communication technology to manage demand and more closely match available generation.

These three dimensions cut across the three research Themes of the network, providing channels for inter-disciplinary dialogue and collaborative research.

Research Goals and the Puzzle

The Network research program addresses most of the issues associated with the operation of smart microgrids within distribution systems or as stand-alone grids and referred to in the introductory remarks made above.

The program deals with issues related to the management and control of electric power flow within a microgrid, namely the operation, control and protection of the elements of a microgrid and the microgrid as a whole (Theme 1), the justification, planning and optimization of a microgrid (Theme 2), and the required information and communication technologies to operate the microgrid (Theme 3).

In keeping with its research agenda, initial milestones and deliverables, the Network has developed a greater part of the knowledge required to justify, deploy and operate a microgrid, in the form of technologies, tools and methodologies.

This knowledge, residing in individual projects, and executed by experts with different and complementary backgrounds, can be described as pieces of the microgrid puzzle.

In the coming year, efforts will be made to assemble the pieces of this puzzle into a coherent methodology that will be useful to all stakeholders, Network partners and other Canadian entities. This methodology will involve the planning, justification, deployment and operation of microgrids within distribution systems or as stand-alone distribution grids in remote locations.

To this end, the Network has set up a new project: **Integration Design Guidelines and Performance Metrics (Project 2.5)**. The mandate of this new project is to integrate the relevant knowledge developed under the various projects associated with the three themes into a coherent and structured microgrid design methodology addressing power, control and communication issues. An associated mandate is to coordinate the remaining work in individual projects to help develop the microgrid design methodology and produce a structured compendium of the Network's final deliverables. This will be in the form of maps, blueprints and matrices of information, linking the different components of knowledge required to plan, justify, develop, deploy and operate typical microgrids for Canadian applications and requirements.

Table 1: How each of the NSMG-Net projects relates to Smart Microgrid features Variable Generation (VG), Islandability (I) and Demand response (DR).

Project	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
VG	X			X	X			X	X		X	
I		X	X		X	X		X	X	X		
DR	X		X		X	X	X		X	X	X	X

Project Focus: Microgrids in Remote Communities (1.1)

At the mid-term review, the Site Visit Committee was particularly interested in this Project. This section provides an update on this project and addresses specific questions raised by the Committee .

Project 1.1 is focused on **Microgrids in Remote Communities** and is led by Dr Amir Yazdani, who transferred to Ryerson University from the University of Western Ontario in 2011.

Of particular note is Dr Yazdani's engagement with Network partner Schneider Electric, whose new microgrid lab in Burnaby, BC, and programmable inverters will allow NSMG-Net students to test control strategies and algorithms on industry-level equipment and systems.

Figure 1. Project leader Amir Yazdani *(right)* with Theme 1 colleague Wilsun Xu (Project 1.3)

Apart from publishing papers, what has been achieved in Project 1.1 up to now and what work is remaining to be done?

In terms of deliverables, the goals of Project 1.1 are as follows:

1) To provide robust control and protection strategies, algorithms and specify the required ICT for remote microgrids;
2) To identify strategies to maximize the level of integration of renewables in remote microgrids; and,
3) To validate R&D results based on detailed time-domain simulation studies on study benchmark systems and experimental results in the BCIT Microgrid System.

Papers published by this project to date directly relate to points one and two as they describe control and protection strategies for inverter-based microgrids, and wind-storage systems. The following table indicates how the knowledge developed and reported in these papers can be translated into use by partner utilities and technology companies.

Table 2: Project 1.1 Deliverables

Completed Milestones	Discrete Deliverable for Technology Transfer
Research and development of control strategies and algorithms	Control algorithms for the electronic interfaces of distributed energy resources, such as wind, PV, and battery energy storage.
Research and development of coordinated control, supervisory, and operational strategies	Algorithms for optimal planning and system-level operation of a microgrid with multiple distributed energy resources.
Research and development of protection strategies	Devices and algorithms for the protection of a microgrid with multiple distributed energy resources which can operate in both off-grid and grid-connected modes.
Current Milestone	**Planned Deliverable for Technology Transfer**
Research and development of control strategies and algorithms	Collaborations with Schneider Electric will test, verify, and commercialize the developed control algorithms for electronically interfaced distributed energy resources.

The effect of the move from Western University to Ryerson University caused delays in conducting the research work. What remedial steps have been taken?

The cause of the delays was both the move, and the recruitment of students out of the research program. This is both a happy and unfortunate consequence of the high demand for HQPs in the industry.

Nonetheless, to maintain integration with the Network despite the recruitment issues, the Project has been collaborating with McGill University's Project 1.4 since January 2012. Thus, a McGill PhD student has been working with Project 1.1 on the dynamics and control of islanded microgrids, which directly contributes to the milestone on "control strategies and algorithms".

Further, an adjunct appointment at the University of Toronto has enabled Dr Yazdani to engage in the co-supervision with Dr Iravani of two students, a PhD student and a Masters student, as of September 2013. The PhD student is completing the remaining research on control strategies and algorithms as well as supervisory control and operational strategies, while the Masters student is exploring test cases and evaluation studies.

Dr Yazdani also recruited a PhD student at Ryerson University in January 2013 who will complete the remaining planned research on protection strategies.

How do the collaborations with Network projects contribute to meeting the project goals?

This Project has collaborated with Project 1.4 (Operational Strategies and Storage Technologies to Address Barrier for Very High Penetration of DG Units in Intelligent Microgrids) led by Dr Geza Joos at McGill University since January 2012.

This collaboration contributes to the objectives of Project 1.1 by allowing continued research progress in the face of hiring difficulties, and by bringing expertise on the integration of high penetration variable generation in islanded microgrids.

Thus far, the collaboration has resulted in the production of two journal articles and one conference paper (see p.23 for details), indicating significant progress with respect to control strategies and algorithms and protection strategies.

Feedback from Utility Partners

*…We at **BC Hydro** are very pleased with the evolution of the projects listed in the NSMG-Net themes.*

We are involved with a few projects in particular addressing Wi-Max communication protocols, PLCs, Microgrids, Energy management systems and energy storage systems.

The feedback has been great and it helped us evaluate, asses and ultimately select/adopt technologies that are relevant for our environment.

Besides the direct interest that we have due to our current immediate needs, we are monitoring and participating indirectly in other project and activities by providing input and sharing information.

It was nice to see the work done by students during the last AGM meeting in Vancouver. Again we identified opportunities to follow up with collaboration between Hydro Quebec IREQ and Powertech (subsidiary of BC Hydro) involving students guided by Prof Geza Joos, and Hassan Farhangi…

*…**Hydro One** is very pleased with the progress this Network has made so far. Hydro One as a member of the Scientific Committee, is satisfied and pleased with the content and the leading edge work being undertaken by this Network, and to the fact this work is tuned to the needs of the industry*

We at Hydro One have been actively advising the team as others are doing as well. We are happy to continue to support this effort as outlined in our letter of support at the start of this project.…

Management and Governance

We had three new members join the Board of Directors in Year 4.

Following the retirement of our NSERC representative Shaheer Mikhail, our new representative is Alison Janidlo, who manages the entire NSERC Strategic Networks program. Paul Ohrt at the Department of National Defence was invited to join the board, after Peter Kouri left to work in Europe. Finally, Nat Gosman from the BC Ministry of Environment has replaced Andrew Pape-Salmon, who changed jobs.

For our final year, the Board will also benefit from two additional members. Gilles Jean, Director General of NRCan, has agreed to join the board: his experience with RETScreen will be particularly valuable. (RETScreen is a software tool developed by NSMG-Net partner NRCan and commonly used in many microgrid planning scenarios to evaluate renewable energy options.)

Additionally, a representative from one of our key utility partners has been invited to join the Board and we hope to confirm this person shortly.

We thank all our volunteer board members for their valuable contribution to the network.

Board of Directors

Industry:
Dr John MacDonald (Chair), retired (formerly Day4Energy)
Mr Jack Li, Retired (formerly Enmax Power Corp)
Mr Richard Wunderlich, Siemens
Mr Chuck Filewych, Smart Grid Canada

Academia:
Dr Liuchen Chang, University of New Brunswick
Dr Paul Fortier, University of Laval
Dr Andreas Athienitis, Concordia University
Dr Hassan Farhangi, BCIT

Government:
Mr Nat Gosman, BC Ministry of Energy
Ms Alison Janidlo, NSERC
Dr Gilles Jean, NRCan
Mr Paul Ohrt, Dept of National Defense
Ms Heather Quinn, Government of New Brunswick

Scientific Committee

Industry & Government:
Mr Giuseppe Stanciulescu, BC Hydro
Mr Anand Srinivasan, Eion Wireless
Dr Chad Abbey, Hydro Quebec
Mr Ravi Seethapathy, Hydro One
Dr Lisa Dignard, CanmetENERGY, NRCan
Mr Tony Gray Schneider, Electric Canada

Academia:
Dr Hassan Farhangi, BCIT
Dr Reza Iravani, University of Toronto
Dr Geza Joos, McGill University
Dr Julian Meng, University of New Brunswick

Outreach Committee

Dr Geza Joos, McGill University
Dr Steven Wong, CanmetENERGY, NRCan

Events and Activities

NSMG-Net is about more than just scientific research. Through the network structure and special events, HQPs have opportunities to collaborate and learn from colleagues at other Canadian universities, from Network partners and from international businesses and researchers.

The following section describes some of the events attended by HQPs in Year 4. Details regarding research collaborations can be found in the Theme and Project reports (see pages 18-39 and 50-72, respectively).

NSMG-Net Annual General Meeting 2013

On July 26th, 2013, NSMG-Net researchers, partners and guests gathered in Vancouver, BC, to share research results and plan collaborations.

The first speakers set the scene by describing the modern microgrid context. Mark McGranaghan from EPRI spoke on "The Role of the Microgrid in the Electric Distribution System". Sara Bavarian of Powertech Labs described "Utility Telecommunication Strategic Planning" and Network Leader Hassan Farhangi provided an update on "The BCIT Campus Microgrid".

This was followed by Theme Leader presentations summarizing research progress to date, and presentations by students on select research highlights. All presentations are available for download from the publications page of the NSGM-Net website.

In the afternoon, students pitched their posters in quick succession, with just four minutes and two slides each. This innovative session was an excellent way to cover a wide range of work, and allowed the audience and poster judges to hear directly from students about their work.

Our judging panel (consisting of Heather Quinn, Dave Michelson, Hassan Farhangi, Geza Joos and Sol Lancashire) scored posters against four criteria and chose the following three winners:

- 1st Place: **Michael Ross, McGill University**, for his poster "Multi-Objective Optimization Dispatch for Microgrids with a High Penetration of Renewable Generation"
- 2nd Place: **Ahda Pionkoski Grilo Pavani, University of Alberta**, for her poster "Microgrid Load Monitoring Using State Estimation Techniques"
- 3rd Place: **Moien Manbachi, Simon Fraser University**, for his poster "Smart Grid Adaptive Solution for Volt/VAR Optimization (VVO) of Distribution Networks Using VAR Dispatch"

Figure 2. AGM speakers (from top) Mark McGranaghan, Sara Bavarian, and Hassan Farhangi

The first prize was the chance to represent NSMG-Net at the Symposium on Microgrids in Santiago, Chile. The second and third prizes were generously donated by NSMG-Net partner Schneider Electric.

Santiago 2013 Symposium on Microgrids

The Santiago Symposium on Microgrids took place in Santiago, Chile, in early September 2013. In total there were 110 in attendance, with various presentations about innovations from around the world in different fields. NSMG-Net partners and researchers had a significant presence at the Symposium through presentations, poster sessions, and discussions.

The Symposium covered diverse topics on microgrids including: remote communities, extreme operating conditions, advanced protection in microgrids, renewable energy in microgrids, energy storage systems, grid-connected microgrids, demand-side management, energy management systems, clusters of microgrids, economic analyses and business cases, demonstration projects and political initiatives, sizing and planning studies, and V2G applications. The final panel session involved many experts from utilities, companies, and academia discussing issues on commercializing microgrid technologies – including standardization, barriers, market space, maturity of technologies, and economics.

Figure 3. Demonstration of the 10kVA MicroHydro generator at the University of Chile

The Symposium ended with a tour of the University of Chile's facilities, which included a tour of the MicroHydro Lab, a 1.2 kW solar racing car, and a low voltage microgrid test laboratory.

PSCAD Webinar

On June 19th, 2014, NSMG-Net students and partners attended an exclusive webinar on PSCAD offered by Farid Mosallat, Engineering Research and Development Manager at NSMG-Net partner Manitoba HVDC, the research division of Manitoba Hydro. Manitoba HVDC's their software for Power Systems Computer Aided Design (PSCAD) is widely used in industry.

Attendees included Ehsan Nasr from the University of Waterloo, Masoud Shabestary from the University of Alberta, Aboutaleb Haddadi, Michael Ross and Mike Quashie from McGill University, Fahimeh Kazempour and Sahar PiroozAzad from the University of Toronto, as well as NSMG-Net partners Steven Wong from NRCan and Song Da from NRC-IFCI.

Feedback from attendees was very positive:

- *Thanks for organizing the Webinar. The material presented in the Webinar was quite relevant to my research.*
- *Thank you to NSMG-Net and Farid so much for your helpful Webinar.*

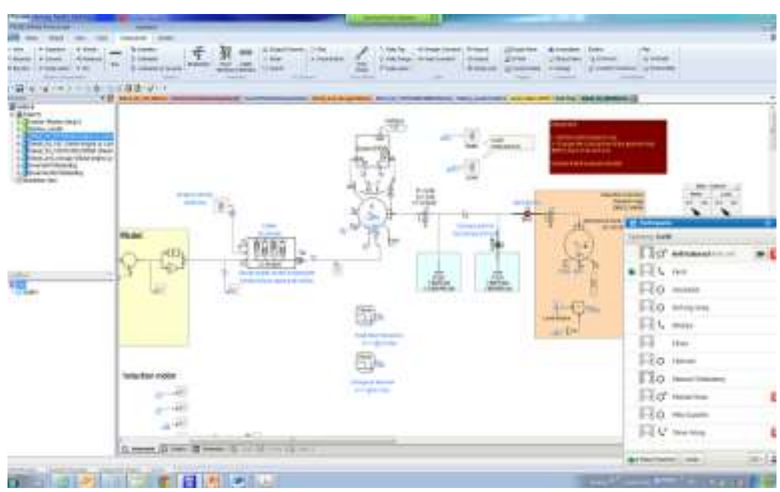

Figure 4. PSCAD Webinar Screenshot

27th Biennial Symposium on Communications at Queen's University

This event is a long-standing Canadian tradition that focuses on developing Canadian expertise in the fields of coding, information theory, telecommunications, and signal processing. It connects Canadian and global leaders both in academia and industry and provides a platform for student professional development.

Figure 5. Rajalingham presenting at the Biennial Symposium in Kingston, ON

At the 2014 conference held June 1-3, 2014, in Kingston, ON, graduate student Gowdemy Rajalingham (Project 3.2) delivered a presentation entitled "Random Linear Network Coding for Converge-cast Smart Grid Wireless Networks". Rajalingham's work is part of a preliminary study on the feasibility of networking coding to improve the data transmission robustness of microgrid communication networks. It is also part of the overall project goal to develop efficient transmission, information processing, and networking techniques and strategies suitable for a robust communications infrastructure that supports the integration of smart microgrids.

Rajalingham's research has determined that utilities and microgrid developers should use network coding that allows for partial decoding operations when designing communication networks:

> *A microgrid Neighborhood Area Network (NAN) poses a communications challenge due to the bottlenecks associated with the converge-cast nature of uplink traffic. This can potentially be addressed through network coding. In this research, Random Linear Network Coding (RLNC) is considered in converge-cast scenarios while both network size and link reliability are varied. This preliminary study suggests that inter-session RLNC does achieve throughput enhancements but at the cost of higher network load. Additionally, performance drops sharply with low link reliabilities due to the lack of partial decoding. Therefore, for large converge-cast networks network coding that allows for partial decoding operations would be more beneficial*. *[abstract from presentation]*

Altaeros Webinar

On Thursday May 1st, 2014, NSMG-Net students attended an exclusive webinar on an innovative wind power technology for remote community microgrids. Chris Vermillion, Lead Engineer for Stability and Control at Altaeros Energies and Professor of Mechanical Engineering at the University of North Carolina, spoke with NSMG-Net students Michael Ross (Project 1.4), Aboutaleb Haddadi (Project 1.1), Mike Quashie (Project 2.1) and representatives from partners BC Hydro and NRCan CanmetENERGY.

Figure 6. Altaeros Wind System

The discussion began with an overview of Airborne Wind Energy technologies including kite designs that generate power on the ground, fixed wing designs like Google's Makani project, and aerostat-based designs like Altaeros' Bouyant Airborne Turbine (BAT). Each have advantages and disadvantages, with a key advantage of Altaeros' BAT being its near-vertical profile, and the ability to raise and lower the device for optimum generation. This controllable wind generation could allow diesel generators and demand-response systems on the ground to run more effectively.

Inter-Theme Network Meeting in Montreal

Theme 3 led a workshop on August 14, 2014, at McGill University in Montreal. Participants included project leaders from Theme 3 (Dr Fabrice Labeau, Dr Tho Le-Ngoc and Dr Julian Meng) as well as from Theme 2 (Dr Geza Joos). Several graduate students representing all three of the Network's themes were also in attendance. A presentations about the overall focus of Theme 3 was given by Dr Julian Meng, and individual presentations on specific Theme 3 projects were delivered by graduate students and researchers.

Numerous cross-theme discussions took place during the meeting and it is anticipated this will lead to additional student-student collaborations between themes (e.g., Fahimeh Kazempour of Projects 1.1 & 1.2 examining microgrid controls and Gowdemy Rajalingham of Project 3.2 investigating QoS and network simulation). Following the presentations, Dr Marthe Kassouf of McGill University led a discussion on the future of intelligent microgrid communication architectures with a specific focus on cyber security. Her connection to industry partners offered a unique perspective on possible security issues as the power grid becomes modernized with communications and various customer information applications over the smart grid network layer.

Figure 7. MSMG-Net members at the Inter-Theme meeting in Montreal

Project Changes

Project 3.1

In late October 2013, Dr Michelson tendered his resignation from NSMG-Net, citing a prohibitive workload. Following a comprehensive search for candidates to take over the remaining milestones, Dr Fabrice Labeau at McGill University was selected to complete the work of Project 3.1 in collaboration with other projects. Dr Labeau began in April 2014. Project 3.1 funds remaining at UBC are in the process of being returned to BCIT.

Project 2.4

As noted in last year's report, Dr Gole's participation in NSMG-Net has been terminated. Although an MSc and PhD student had been funded for two years and some collaboration with Manitoba HVDC took place, no project reports were provided by Dr Gole and no effort was made to engage with other projects or partners. Repeated attempts to re-engage with Dr Gole by the Network Leader, Network Manager, and the Theme II leader were unsuccessful.

As a result, the following actions have been taken:

- Funds remaining at University of Manitoba have been returned to BCIT.
- The 2014 milestone "*Determine the modeling details required to refine microgrid models*" will be taken up in Year 5 by an additional Masters student in Project 1.2 (Dr Iravani).
- The 2015 milestone "*Conduct case studies and their validation for various scenarios as identified through networking with the other Themes*" will be taken up in Year 5 by Project 2.1 (Dr Joos).

Project 2.5 (new)

A new project has been approved for Year 5: "Integration Design Guidelines and Performance Metrics". The overall goal of the project is to present usable unified models and use cases, based on the research carried out across the Network. The project team will consist of one MSc student and one post-doctoral researcher, to be supervised by Dr Geza Joos (Theme 2 leader) and Dr Hassan Farhangi (Network Leader). Details of the project are below.

Challenge

The purpose of this project is to make use of the research carried out in the Network to develop design and performance evaluation tools, in the form of use cases, among others, in either islanded or grid connected modes. The project covers power, control and communication benchmarks for the different types of microgrids, including remote communities and installations, and their interaction with the distribution grid. It addresses the real time operation of the microgrid (voltage and frequency control, protection, islanding and reconnection) as well as the energy management of its components, generation, storage and controllable loads within the microgrid, in islanded and grid connected modes. It will allow the Network to make use of most of the results developed in the different projects carried out by Network researchers and demonstrate the usefulness and contributions of the Network projects to advancing the microgrid business case.

Methodology

- Compile the available microgrid benchmarks for the electric power system, including the models developed for the BCIT microgrid and the benchmarks used in the different Network projects, identifying and providing justification for the approaches used in the study of the different microgrid structures used in the various projects.
- Document the models used for microgrid elements in these benchmarks, including generators, energy sources, loads, and local energy storage options.
- Analyze and provide a critical assessment of the modeling detail and the model detail tradeoffs, and recommend modeling details as appropriate for the type of study to be performed.
- Compile the control systems and approaches implemented in the microgrids used in and meeting the requirements of Theme 1 (Microgrid Operation and Control) and Theme 2 (Microgrid Planning, Optimization and Regulatory Issues).
- Compile the information and communication systems implemented in the microgrids used in and meeting the requirements of Theme 3 (Microgrid Communication and Information Technologies).
- Define a modeling approach that combines the power and communication systems, allowing a complete system study.
- Define typical system studies and requirements associated with the operation of the microgrid, in grid connected and islanded operation, based on the work carried out in other Network projects in all three Themes, identifying the systems required for case studies, including the appropriate benchmark systems and components.
- Determine a set of system sample case studies required for the study of the various microgrid operating scenarios and contingencies, for real time operation (voltage and frequency control, protection, islanding and reconnection), and energy management of the generation, storage and loads within the microgrid, in islanded and grid connected modes.
- Develop use cases for the sample case studies defined above.
- Validate the models with field results from BCIT microgrid and Hydro-Quebec Test-line (as applicable).

Expected Results and Deliverables

The following tools, based to a large extent on work done in other projects, will be produced:

i. Benchmark models for microgrids and microgrid elements, particularly for integrated power system and communication/control infrastructures;
ii. Modeling strategies for making planning and operation case studies for different microgrid structures, with the inclusion of renewable energy sources and storage, and considering the various operating strategies, such as grid connection, islanding and power system restoration (black start);
iii. Case studies and use cases allowing a structured approach to analyzing microgrid operation and specifying appropriate microgrid structures.

This project will make use of previous Network results and interact with projects in all three Themes.

Milestones

- Compile microgrid models, including the power systems and the control and communications systems.
- Define system studies.
- Define case studies and use cases.

Research Sites

University of Toronto, McGill University, BCIT, Hydro-Quebec, NRCan

Theme Research Reports

The next generation Smart Grid is the convergence of Information and Communication Technology with Power System Engineering.

The three research themes of NSGM-Net reflect this interdisciplinary nature.

Theme 1 is led by Dr Reza Iravani at University of Toronto. The four projects in this theme are focused on the electrical engineering issues involved in Canadian urban, rural and remote microgrids.

Theme 2 is led by Dr Geza Joos at McGill University. The four projects in this theme are focused on the overall technical and economic justification of microgrids, and their interactions with the main grid.

Theme 3 is led by Dr Julian Meng at the University of New Brunswick. The four projects in this theme are focused on innovative network architectures to support seamless exchange of data and commands between participants in the smart grid network.

Theme 1: Microgrid Operation and Control

(Dr Reza Iravani, Theme Leader)

The objective of Theme 1 is to address control, protection, energy management, operation, and new technology integration aspects/issues of smart microgrids with focus on developing strategies, algorithms, and technologies:

1) to accommodate dynamic demand response;
2) to operate in the islanded mode and the grid-connected mode, and enable transition between the two modes;
3) to address and accommodate variability of generation, in particular under high depth of penetration of renewable and alternative resources in single and multi-microgrid conditions, and
4) to enable utilization and integration of new and evolving technologies such as energy storage and EV chargers.

The RD&D activities of Theme 1 are conducted under the umbrella of the following four projects.

Project 1.1: ***Control, Operation, and Renewables for Remote Intelligent Microgrids***. This project deals with control, management, and operation of smart remote (islanded) microgrids. The main objective of the project is to displace conventional generation (e.g., diesel-based generation) with renewable (e.g., wind and solar generation), and maximize the depth of penetration renewable generation. The main challenge in this context is to address the impacts of renewable variability and intermittency by (i) robust control strategies, (ii) the use of energy storage devices (e.g., battery storage or fly-wheel storage) to enhance performance and maintain stability, (iii) integration of demand side response to maximize efficiency and asset utilization, and (iv) adopting modified/adaptive protection strategies.

Items (i) and (iii) above relate Project 1.1 to the Project 1.2. Item (ii) above relates Project 1.1 to Project 1.4, and in a broader sense to Theme 2 projects. Item (iv) above relates Project 1.1. to Project 1.3. Since the ICTs are the requirement for the envisioned operational requirements of Project 1.1, it is also directly related to Theme 3 projects.

Project 1.2: ***Distributed Control, Hybrid control and Power Management for Intelligent Microgrids***. This project deals with control, protection, management and operation of mart urban and rural microgrids under both grid-connected and islanded modes of operation. The main objectives of this project are to accommodate high-depth and intermittency of renewable, deal with the uncertainty of the microgrid configuration, load, and variability of generation, and provide secure and seamless transition from grid-connected mode to the islanded mode and inversely. The challenges of Project 1.2 are (i) development of supervisory and local controllers that can provide stable and secure operation during both islanded and grid connected modes of operation, ride-through the transition from one mode to the other, and accommodate distributed demand response, (ii) development of islanding detection methods that can discriminate between accidental islanding scenarios and faults and provide seamless transition, (iii) provision for protection strategies to comply with the control dynamics and adopt itself to the operating condition (islanded or grid-connected), (iv) development of energy management strategies that can provide viable and optimal operation conditions for the controls subsequent to changes in the system and enable optimal use of renewables and legacy assets, and (v) coordinated operation and control of multiple microgrids.

Item (i) above relates Project 1.2 to the objectives of Project 1.1. Items (ii) and (iii) relates Project 1.2 to the objectives of Project 1.3. Objective (iv) above links this project to Project 1.4. The ICTs provide "smartness" to the microgrids of Project 1.2 and relates Project 1.2 to the projects of Theme 3. Objectives of Theme 2 encompass single and multiple microgrid structures and are directly related to those of Project 1.2.

Project 1.3: ***Status Monitoring, Disturbance Detection, Diagnostics and Protection for Intelligent Microgrids.*** This project deals with the (i) protection strategies and technologies for microgrids under grid-connected and islanded modes, and (ii) islanding detection methods and technologies for "fast" and "seamless" islanding process under both accidental and planned islanding events. Item (i) above directly relates Project 1.3 to Project 1.1, Project 1.2 and Project 1.3. Item (ii) above is a requirement for Project 1.2 and 1.4. The advanced protection and islanding methods are based on ICTs and directly relate Project 1.3 to the projects of Theme 3.

Project 1.4: ***Operational Strategies and Storage Technologies to Address Barrier for Very High Penetration of DG Units in Intelligent Microgrids***. This project deals with the strategies and removal of barriers to enable high-depth of penetration of renewable in islanded and grid-connected microgrids. The main challenge in the context of this project is the degree of variability of generation and its highly unpredictable range and speed of variations. This project not only deals with the technical solutions such integration of demand side management to counteract the variability of generation, but also considers the use of new and evolving technologies such as power and energy storage media to address fast transients and long term generation variations. Due to the high-depth of penetration of renewable, Project 1.4 deals with more challenging microgrid scenarios under both islanded and grid-connected as compared with the other projects in Theme 1, and directly builds on the deliverables of Projects 1.1., Project 1.2 and Project 1.3.

All four projects are on schedule and on the target in terms of milestones. Project 1.1 which was behind schedule in Year 2 and Year 3, due the transition period of the project leader (Dr Yazdani) from Western University to Ryerson University, is currently progressing according to the original plan and provides supervision to three full-time PhD students.

During the past four years, since the beginning of the NSMG-Net, Theme 1 has involved and supervised over 52 undergraduate students, 11 MSc students, and 20 PhD students in the project activities. Sixteen of the MSc and PhD students have graduated within the last four years. The number of graduate students per project is as follows:

- Project 1.1: five students
- Project 1.2: eleven students
- Project 1.3: ten students
- Project 1.4: five students

It should be noted that based on the collaboration with the industrial partners during the last four years, each project's objectives have been well aligned with the needs and encompass the requirements of the industrial partners. The mechanism for involving industrial partners in HQP training in Theme 1 is to inform the partners involved about the details of each project's activities through progress reports and/or technical presentations (i) at pre-specified time intervals, (ii) when a particular milestone is achieved, and/or (iii) when specific problem(s) arise. The comments, feedbacks, and suggestions from the industrial partners are then adopted by the students to address the relevant subjects/problems and the results relayed back to the industrial partner. This process results in face-to-face meetings and conference calls with industrial partner. In each of these events, the designated students are responsible for presentations and questions and answers.

The mechanism for involving different teams in each project and cross training of HQP is through (i) primarily joint supervision of graduate students, (ii) utilization of specialized laboratory infrastructure and expertise at each institution for Theme 1 related work of other projects led by other institutions, and (iii) transfer of results (based on published reports/papers, data files, etc.) and know-how from one project to another project based on direct involvement of graduate students.

During Year 4 of the Network, Theme 1 managed to continue its collaborations with the NSMG-Net industrial partners and also to establish new collaborations with the industrial partners. The industrial partners who are involved in joint collaborative efforts with Theme 1 projects are as follows:

- Project 1.1: Schneider Electric
- Project 1.2: NRCan, CYME, Hydro One, IESO, OCE, Manitoba HVDC Centre
- Project 1.3: Hydro One, PowerTech Labs
- Project 1.3: Hydro Quebec, NRCan

During Year 4 of the Network, Theme 1 established or continued collaborations with additional industry partners within or outside Canada. These partners are as follows:

- Project 1.1: n/a
- Project 1.2: ERPI (USA), National Instrument (USA), LSIS (South Korea)
- Project 1.3: APIC
- Project 1.4: n/a

During Year 4 of the Network, Theme 1 has established research collaboration with universities (outside Canada) in terms of exchange of visitors, graduate students, PDFs, invited lectures, short courses, and joint research projects. These collaborations per project are as follows:

- Project 1.1: n/a
- Project 1.2: North China electric Power University (China), University of Guadalajara (Mexico), KU Leuven (Belgium)
- Project 1.3: University of Campinas (Brazil)
- Project 1.4: n/a

During Year 4 of the Network, Theme 1 has developed has provided technology transfer through patent applications and IP disclosures as follows:

- Project 1.1: n/a
- Project 1.2: two patents awarded (in collaboration with Hatch and Ecamion), one provisional application completed (in collaboration with Opus One), three IPs were disclosed to the University of Toronto
- Project 1.3: one patent awarded
- Project 1.4: n/a

During Year 4 of the Network, Theme 1 has published a set of journal papers and conference papers, offered lectures, presented invited talks, and participated in panel presentations in microgrid related conferences and symposia. These activities per project are as follows:

- Project 1.1: three journal papers and one conference paper
- Project 1.2: two journal papers, one CIGRE Technical Report, five invited lectures
- Project 1.3: two journal papers
- Project 1.4: three conference papers, one technical presentation

Publication of a large number of refereed journal publications, all in the IEEE Transactions and IET Proceedings, and invited lectures in prestigious conferences and universities are clear indications of the high quality, relevance, and interest of the academic community and the industry in the outcome of the work from Theme 1.

Theme 1 project leaders and several of the graduate students attended the IEEE PES General Meeting GM-2014, July 27-31, in Washington DC. The project leaders and the students managed to have multiple one-to-one and bilateral meetings/discussions related to Theme 1 activities and progress.

Which partner is helping students with Dynamic Demand Response and how? What are the students producing?
Hydro One and IESO provide load profiles and students develop the corresponding models in simulation tools to design and tune controllers.

Which partner is helping students with transitions between islanded and grid-connected mode?
Hydro One provides the limits for variation of current, voltage, frequency and any other relevant electrical variable that is needed for an islanding scenario. Then students develop and test islanding strategies and the corresponding algorithms to meet the conditions specified by Hydro One.

Which partner is helping with integration of EV chargers? And are the patents awarded for Dynamic Demand Response, for EV charger integration or something else?
EV chargers are variable loads, but with exhibit different characteristics from the conventional loads. Therefore any discussion that applies to "loads" and "demand response integration" is also applicable to EV chargers.

Table 3: Theme 1 Publications in Year 4

Project	**Citation** *(Click on link to access article where available)*	Refereed Journal Article	Non-refereed Journal Article	Invited Conference Presentation	Non-invited Conference Presentation	Other
1.1	Bhuiyan, F., A. Yazdani, and S.L. Primak, "An optimal sizing approach for an islanded microgrid," IET Renewable Power Generation, RPG-2013-0416 (in press).	x				
1.1	Haddadi, A., A. Yazdani, G. Joos, and B. Boulet, "A gain-scheduled decoupling control strategy for enhanced transient performance and stability of an islanded active distribution network," IEEE Trans. on Power Delivery, vol. 29, no. 2, pp. 560-569, November 2013.	x				
1.1	Haddadi, A., B. Boulet, A. Yazdani, G. Joos, "A μ-based approach to small-signal stability analysis of an interconnected distributed energy resource unit and load," IEEE Trans. on Power Delivery, 8 pages, TPWRD-00282-2014 (in press).	x				
1.1	Syed, I. and A. Yazdani, "A simple mathematical model of photovoltaic modules for simulation in Matlab/Simulink," Canadian Conference on Electrical and Computer Engineering CCECE 2014, Toronto, 6 pp., May 2014.				x	
1.2	Ajaei, F.B. and R. Iravani, "Enhanced equivalent model of the modular multilevel converter," IEEE Trans. on Power Delivery, DOI: 10.1109/TPWRD.2013.2294651, January 2014.	x				
1.2	CIGRE TF-C6.04.02, "Benchmark systems for network integration of renewables and distributed energy resources," CIGRE Report 575, 101 pp., ISBN:978-2-85873-270-8, April 2014.					x
1.2	Etemadi, A. and R. Iravani, "Overcurrent and overload protection of voltage-sourced distributed resources in microgrid," IEEE Trans. On Industry Application, vol. 60, no. 12, pp. 5629-5638, December 2013.	x				
1.2	Iravani, R., "AC-DC microgrids," University of Cardiff, UK, December 2013.					x
1.2	Iravani, R., "Real-time analysis of large grids and microgrids," Washington State University, USA, November 2013.					x
1.2	Iravani, R., "Virtual power plant mode of operation of microgrids - control, protection, and supervisory aspects," Tsinghua University, China, April 2014.					x
1.2	Iravani, R., "Wide-band equivalent of type-3 wind power plants," University of Guadalajara, Mexico, February 2014.					x
1.2	Niaki, A., R. Iravani, H. Kojori, "Robust commutation circuit for reliable single step commutation of MC," Applied Power Electronic Conference, Austin, Texas, March 2014.					x
1.3	Grilo, A.P., P. Gao, W. Xu, and M. C. de Almeida, "Load monitoring using distributed voltage sensors and current estimation algorithms," IEEE Trans. Smart Grid, vol. 5, no. 4, pp. 1920–1928, July 2014.	x				
1.3	Torquato, R., Q. Shi, W. Xu, and W. Freitas, "A Monte Carlo simulation platform for studying low voltage residential networks," IEEE Trans. Smart Grid, pp. 1–11, July 2014.	x				
1.4	Ross, M, "Multi-objective optimization dispatch for microgrids with a high penetration of renewable generation," Santiago 2013 Symposium on Microgrids, Santiago, Chile, September 2013.				x	
1.4	Ross, M, "Optimisation de ressources d'énergie distribuées dans un micro-réseau," Journée Scientifique 2013 : Stagiaires-Étudiants à l'IREQ, Hydro-Québec Research Institute, November 2013. (Received award for best presentation).					x
1.4	Ross, R., C. Abbey, Y. Brissette and G. Joós, "A novel isochronous control strategy for coordination of distributed energy resources in an islanded microgrid," CIGRÉ Canada Conference, September 2014.				x	
1.4	Ross, R., C. Abbey, Y. Brissette and G. Joós, "Real-time microgrid control validation on the Hydro- Québec distribution test line," CIGRÉ 2014 Paris Session, August 2014.			x		

Table 4: Highly Qualified Personnel in Theme 1 since Inception (listed by Project #)

Project	Name	Program	Start	End	Employer (if graduated)
1.1	Akbari, K.	PhD	January 1, 2014	ongoing	
1.1	El-Tayb, M.	MSc	September 1, 2011	October 1, 2012	
1.1	Kaler, S.	UG	May 1, 2014	September 1, 2014	
1.1	Kazempour, F.	PhD	April 1, 2014	ongoing	
1.1	Lin, H.	UG	May 1, 2013	September 1, 2013	
1.1	Oliveira, R.	PhD	September 1, 2013	ongoing	
1.1	Syed, I.	PhD	January 1, 2013	February 1, 2014	
1.2	Badrkhani, F.	PhD	September 1, 2011	March 1, 2015	
1.2	Helmy, S.	PhD	September 1, 2013	August 1, 2016	
1.2	Hernandez, G	PhD	September 1, 2008	November 1, 2011	Assistant Professor - Mexico Polytechnique University
1.2	Huzayin, A.	PhD	September 8, 2014	December 1, 2011	Assistant Professor - Cairo University
1.2	Kazempour, F.	PhD	September 1, 2012	December 1, 2015	
1.2	Kobravi, A.	PhD	August 1, 2009	December 1, 2012	Design Engineer - US Hybrid - CA
1.2	Mehrizi-Sani, A.	PhD	August 1, 2008	September 1, 2011	Assistant Professor - Washington State University
1.2	Mirzahosseini, M.	PhD	January 1, 2012	December 1, 2015	
1.2	Paradis, D.	MASc	September 1, 2011	December 1, 2013	US Hybrid
1.2	Ramadan, M.	PhD	January 1, 2012	December 1, 2015	
1.2	Samarakera, K.	MASc	September 1, 2013	August 1, 2015	
1.3	Gao, P.	PhD	September 1, 2010	December 1, 2014	
1.3	Jiang, C.	MSc	September 1, 2009	December 1, 2012	
1.3	Polzl, A.	PhD	September 1, 2011	Left program	
1.3	Salles, D.	PhD	September 1, 2011	May 1, 2012	
1.3	Shabestary, M.	MSc	January 1, 2013	December 1, 2015	
1.3	Shi, Q.	MSc	September 1, 2011	March 1, 2014	
1.3	Tian, Y.	MSc	September 1, 2011	September 1, 2013	
1.3	Torquato, R.	MSc	May 1, 2013	April 1, 2014	
1.3	Yazdanpanahi, H.	PhD	September 1, 2009	December 1, 2013	
1.3	Zhou, Y. (Peter)	MSc	September 1, 2013	September 1, 2015	
1.4	Elkasrawy, A.	PhD	September 1, 2011	January 1, 2013	
1.4	Haddadi, A.	PhD	April 1, 2011	Ongoing	
1.4	Milicevich, M.I	UG	May 1, 2013	August 1, 2013	
1.4	Ross, M.	PhD	October 1, 2010	Ongoing	
1.4	Saadeh, O.	MSc	January 1, 2012	December 1, 2013	Greentech Media
1.4	Wang, M.	MSc	January 1, 2011	December 1, 2012	GE Energy

Table 5: Intra-Network Collaborations Led by Theme 1 in Year 4

Projects		Milestone Collaborated on, Specific Research Tasks Performed
1.2	1.1	We are working with Dr. Yazdani's Group at Ryerson and also supervising one PhD student (F. Kazempour).
1.2	1.3	We receive information regarding Project 1.3 from Dr Xu.
1.2	1.4	Dr Yazdani is conduit between us and Team 1.2 through his joint supervision of one student from Team 1.4.
1.2	2.1	Our primary collaboration on this project is through project 2.2.
1.2	2.3	We have close collaboration with team 2.3 though a Hydro One-NRCAn project on application of microgrids for remote communities in Canada.
1.2	3.1	We have provided microgrid system simulation test cases and benchmark configurations to Team 3.1.
1.2	3.3	Our main interactions with Team 3.3 is through the use of test cases and simulation results in our microgrid test cases, based on the published papers from Team 3.3.
1.3	1.2	At PES General Meeting 2014, Powerlab researcher and PhD student have interacted and discussed key research topics related to microgrid islanding detections and strategies.
1.3	1.3	Researched and developed fault ride through strategies and Protection Coordination for DG inverter based microgrid.
1.3	1.4	At PES General Meeting 2014, Powerlab researcher and PhD student have interacted and discussed key research topics with current researchers from University of McGill related to microgrid fault/type location and ride through methods.

Table 6: Collaborations with Partners Led by Theme 1 in Year 4

Project	Partner	Milestone Collaborated on & Description of Activity	Partner Personnel	Name of NSMG-NET Student Involved
1.1	Schneider Electric	Collaborations have been planned and are to take place in regards to the implementation, verification, and commercialization of the control algorithms for electronically interfaced distributed energy resources. Thus, Schneider Electric will provide PV solar inverters and engineering personnel, to complement the experimental set-up that is being developed at Ryerson University.	P. Revuru	R. Oliveira (PhD) and S. Kaler (UG)
1.2	CYME Internatio nal	This include utilization of CYME tools for a wide array of studies and data transfer between Hydro One Toronto Hydro and U of T team, and development of unbalance component modes.		A group of 4 students are involved
1.2	Hydro One	This includes modeling weak a feeder and operation of the feeder as microgrid under VPP mode of operation, and investigation the impact of unbalanced operation conditions on the Hydro One protection system.	C. Essendal, V. Maksimovich	S. Helmy (PhD student)
1.2	IESO	This involves development of microgrid model to incorporated in the large transmission system model to investigate impact of intermittency of microgrid generation on the voltage profile and power flow of transmission system.		F. Kazempour (PhD Candidate)
1.2	Manitoba HVDC	This involves development of converter models for transient studies.		F. Badrkhani
1.2	NRCan	Large scale integration of PV in microgrids and distribution systems.	J. Hiscock	5 students and 2 research associates
1.2	OCE	This project involves evaluation of distributed communication-based monitoring system for integration of local distribution systems as semi-independent microgrids.	I. Vera-Perez	M. Graovac (RA) and a group of 3 students
1.3	Hydro One	Industrial Partner		
1.3	Powertech Labs	Industrial Partner		
1.4	Hydro Quebec	Microgrid energy management system implementation and testing.	C. Abbey	M. Ross
1.4	NRCan	Data and models for microgrid implementation and testing.	S. Wong	M. Ross

Table 7: International Collaborations Led by Theme 1 in Year 4

Project	Partner	Milestone Collaborated On & Description of Activity	Partner Personnel	Name of NSMG-Net Student Involved
1.2	EPRI	This involves in application of EPRI DSS software and measurement system for Hydro One selected feeders.	J. Smith	S. Helmy
1.2	North China Electric Power University	This project involves studies and experimental evaluation of integrated battery storage and hydrogen storage in microgrids.	H. Zhao	F Badrkhani
1.2	University of Guadalajara	Development of underground cable models for PSCAD.	A. Ramirez	F. Badrkhani
1.2	National Instrument	Real-time control-hardware-in-the-loop model development of distributed resources for microgrids.	B. Black	M. Graovac (RA) and R. Mirzahosseini (PhD candidate)
1.2	LSIS South Korea	Performance evaluation of Juji Island smart microgrid.	J. Kim	A group of 3 research associates and 4 students are involved in the project
1.3	University of Campinas, Brazil	Research and collaborated on Anti-islanding passive protection of synchronous generators.	W. Freitas	C. Jiang

Theme 2: Microgrid Planning, Optimization and Regulatory Issues

(Dr Geza Joos, Theme Leader)

Theme 2 deals with the operation of the microgrid from the point of view of its insertion into the main grid. It covers issues related to the economic and technical justification of the creation of a microgrid (Project 2.1), the interaction with the main grid, including the utility regulatory requirements for connecting to the main grid, the energy and supply security considerations related to the loads served by the microgrid, including energy management (Project 2.2), and demand response and metering requirements (Project 2.3). In order to provide tools for the justification and the deployment of microgrids and facilitate their implementation, metrics are developed for microgrid assessment and study cases assembled (Projects 2.4 and 2.5).

Direct benefits to Canada of this theme are in providing tools to quantify the benefits of implementing microgrids, not only to the operator of the microgrid, but also to the operator of the distribution grid to which it is connected. Utilities will be given tools to assess the impact of the deployment of microgrids, particularly if done on a large scale, on their distribution grid, in particular the positive impacts on energy security and power quality (system voltage profiles and voltage regulation).

Three out of the four projects are on track. The start of the last project, Project 2.4, was initially delayed and subsequently very little progress has been made towards meeting milestones and deliverables. This is despite the efforts done to obtain a response from and to help the Project Leader to meet milestones and deliverables. Because of the lack of progress on this project, a new Project 2.5 was initiated that would address some of the more important deliverables of Project 2.4.

Highlights

Project 2.1*: Cost-Benefits Framework - Secondary Benefits and Ancillary Services*
Project Leader: Dr Geza Joos (McGill University)

- Milestones and deliverables: according to original schedule
- Transferable technology: software programs that can evaluate the benefits and help develop a business case for building microgrids, with a focus remote microgrids, including mining installations
- Students and researchers: according to availability of funding, 3 students (1 PhD, 2 MEng)
- Industrial collaborations: within Network - Hydro-Quebec, NRCan; outside Network - Lawrence Berkeley National Laboratory (internship, DERCAM software training and use)
- Research collaborations and interactions within the Network: interaction with Project 1.4
- Dissemination of results and publications: one thesis (MEng)

Project 2.2: *Energy and Supply Security Considerations*
Project Leader: Dr Reza Iravani (University of Toronto)

- Milestones and deliverables: according to original schedule, with extensions
- Transferable technology: guidelines to assist power utilities to evaluate the impact of large number of microgrids on legacy asset, maintenance planning, and asset utilization; microgrid models

Project 2.3*: Demand Response Technologies and Strategies - Energy Management and Metering*
Project Leader: Dr Kankar Bhattacharya (University of Waterloo)

- Milestones and deliverables: according to original schedule, with adjustments
- Transferable technology: not yet applicable; several mathematical models have been developed and and are being analyzed/tested
- Students and researchers: six MSc and 3 PhD students since inception
- Dissemination of results and publications: three journal articles, three conference presentations and three theses

Project 2.4: ***Integration Design Guidelines and Performance Metrics - Study Cases***
Project Leader: Dr Ani Gole (University of Manitoba)

No report has been received to date regarding this project and it has been terminated. The more important deliverables are being covered by other projects as well as by the newly initiated Project 2.5.

Project 2.5 (new): ***Microgrid Design Guidelines and Use Cases***
Project Leaders: Dr Geza Joos (McGill University), Dr Hassan Farhangi (BCIT)

The purpose of this project is to make use of the research carried out in the Network in all three themes to develop design and performance evaluation tools, in the form of use cases, among others, for either islanded or grid connected microgrid operating modes. The project covers all research areas of the Network, including power, control and communication technologies and benchmarks for the different types of microgrids, including remote communities and grid connected installations, and their interaction with the distribution grid. Preliminary work has begun on this project and a researcher has been recruited to coordinate this project beginning October 1, 2014.

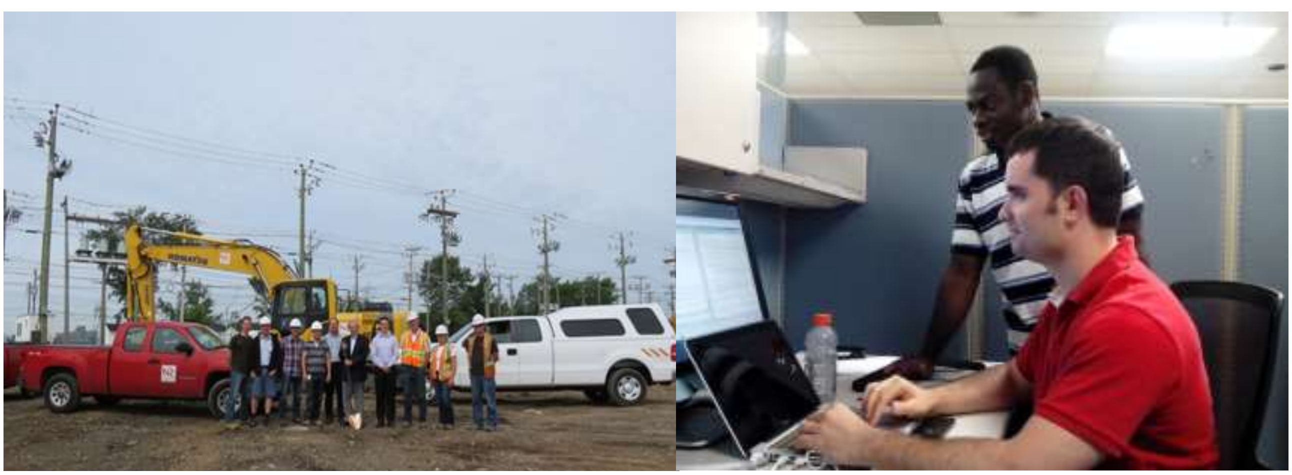

Figure 8. Theme 2 Students on site with Hydro Quebec (*left*); Theme 1 & 2 students collaborating on models (*right*)

Table 8: Publications by Theme 2 Projects in Year 4

Project	Citation *(Click on link to access article where available)*	Refereed Journal Article	Non-refereed Journal Article	Invited Conference Presentation	Non-invited Conference Presentation	Other
2.2	CIGRE TF-C6.04.02, "Benchmark systems for network integration of renewables and distributed energy rersources," Electra, no. 273, pp.84-89, April 2014 CIGRE Report 575, 101 pages, ISBN:978-2-85873-270-8, April 2014.	x				
2.2	Etemadi, A. and R. Iravani, "Overcurrent and overload protection of voltage-sourced distributed resources in a microgrid," IEEE Trans. On Industry Application, vol. 60, no. 12, pp. 5629-5638, December 2013.	x				
2.2	Iravani, R., "An iterative power flow and transient stability analysis frame work for security analysis and impact evaluation of microgrids of interconnected power systems", North China Electric Power University, Beijing, China, April 2014.					x
2.2	Iravani, R., "Impact of multiple microgrids and renewable power plants on transient stability and security", Tsinghua University, China, April 2014.					x
2.2	Iravani, R., "Power flow models of wind power plant and solar power plant models for security analysis of interconenected systems", University of Guadalajara, Mexico, February 2014.					x
2.2	Mao, A. and R. Iravani, "Trend-oriented power system security analysis based on load-generation profile," IEEE Transactions on Power System, vol. 3, no. 29, pp. 1279-1286, November 2013.	x				
2.3	Gaete, F.R., C. Canizares and K. Bhattacharya, "Effect of price responsive demand on the operation of microgrids," 18th Power Systems Computation Conference, Wroclao, Poland, August 2014.			x		
2.3	Kundu, R., C. Canizares and K. Bhattacharya, "Smart operation of centralized temperature control system in multi-unit residential buildings," CIGRE Canada Conference, Toronto, Canada, September 2014.			x		
2.3	Nasr-Azadani, E., "Modeling, Stability Analysis, and Control of Distributed Generation in the Context of Microgrids", University of Waterloo, May 2014 (thesis).					x
2.3	Nasr-Azadani, E., C. Cañizares, D. Olivares and K. Bhattacharya, "Stability analysis of unbalanced distribution systems with synchronous Machine and DFIG-based distributed generators," IEEE Transactions on Smart Grid, vol. 5, no. 5., pp. 2326 – 2338, July 2014.	x				
2.3	Pirnia, M., "Stochastic Modelling and Analysis of Power Systems with Intermittent Energy Sources", University of Waterloo, January 2014 (thesis).					x
2.3	Pirnia, M., C. Cañizares and K. Bhattacharya, "Revisiting the power flow problem based on a mixed complementarity formulation approach," IET Proceedings on Generation, Transmission and Distribution, vol.7, no. 11, pp.1194-1201, November 2013.	x				
2.3	Pirnia, M., C. Canizares and K. Bhattacharya, A. Vaccaro, "An affine arithmetic approach for dispatch in microgrids with intermittent resources," 18th Power Systems Computation Conference, Wroclaw, Poland, August 2014.			x		
2.3	Pirnia, M., C. Cañizares, K. Bhattacharya and A. Vaccaro, "A novel affine arithmetic method to solve optimal power flow problems with uncertainties," IEEE Transactions on Power Systems, in press.	x				
2.3	Raghurajan, A., "Optimal Demand Response of Controllable Loads in Isolated Microgrids", University of Waterloo, July 2014 (thesis).					x

Table 9: Highly Qualified Personnel in Theme 2 since Inception (listed by Project #)

Project	Name	Program	Start	End	Employer (if graduated)
2.1	Clavier, J.	MSc	January 1, 2012	December 1, 2013	GE Energy (CA)
2.1	Elkasrawy, A. (partial, scholarship)	PhD	September 1, 2011	January 1, 2013	
2.1	Morris, G. (partial)	MSc	September 1, 2011	May 1, 2012	
2.1	Qin, S.	PhD	September 1, 2012	Ongoing	
2.1	Quashie, M.	PhD	September 1, 2011	Ongoing	
2.1	Rifkin, D.	UG	May 1, 2012	August 1, 2012	
2.1	Ross, M. (partial)	PhD	October 1, 2010	ongoing	
2.2	Akbari, K.	PhD	September 1, 2013	December 1, 2016	
2.2	Annakkage, M.	MASc	September 1, 2013	December 1, 2013	
2.2	Azad, S.	PhD	September 1, 2009	November 1, 2013	PDF - KU Leuven - Belgium
2.2	Etemadi, A.	PhD	September 8, 2014	August 1, 2012	Assistant Professor - George Washington University - USA
2.2	Gumusteking, G.	MASc	September 1, 2013	August 1, 2015	
2.2	Hayhoe, S.	MASc	May 1, 2014	April 1, 2016	
2.2	Jedrzejczok, J.	PhD	September 1, 2013	December 1, 2016	
2.2	Kamh, M.	PhD	January 1, 2008	October 1, 2011	Senior Engineer - Atlanta Power - Calgary
2.2	Mohamed, A.	PhD	September 1, 2010	August 1, 2015	
2.2	Wang, S.	MASc	September 1, 2011	November 1, 2013	Engineer - Siemens Canada
2.3	Gaete, F. R.	MSc	September 1, 2011	Sept 17, 2013	
2.3	Jain, R.	MSc	September 1, 2011	December 1, 2012	METSCO Energy Solutions
2.3	Kundu, R.	MSc	September 1, 2011	May 5, 2013	
2.3	Le, B.	MSc	September 1, 2011	April 1, 2012	IESO
2.3	Madhavan, A.	MSc	May 1, 2011	April 1, 2012	Robertson and Associates
2.3	Nasr-Azadani□E.	PhD	September 1, 2011	May 13, 2014	
2.3	Pirnia, M.	PhD	May 1, 2011	February 10, 2014	California ISO
2.3	Raghurajan, A.	MSc	May 1, 2013	April 1, 2014	GM Canada
2.3	Solanki, B.	PhD	January 1, 2014	August 1, 2015	

Table 10: Intra-Network Collaborations Led by Theme 2 in Year 4

Projects		Milestone Collaborated On, Specific Research Tasks Performed
2.2	1.1	We are working with Dr Yazdani's Group at Ryerson and also supervising one PhD student (K. Akbari).
2.2	1.3	We receive information regarding the projects of Project 1.3 from Professor W. Xu.
2.2	1.4	Dr Yazdani is conduit between us and Project 1.2 through his joint supervision of one student from Team 1.4.
2.2	2.1	Our primary collaboration on this project is through project 2.2.
2.2	2.3	We are in close collaboration with Project 2.3 though a Hydro One-NRCan project on application of microgrids for remote communities in Canada.
2.2	3.1	We have provided microgrid system simulation test cases and benchmark configurations to Project 3.1.
2.2	3.3	Our main interactions with Project 3.3 are through the use of test cases and simulation results in our microgrid test cases, based on the published papers from Project 3.3.

Table 11: Collaborations with Partners Led by Theme 2 in Year 4

Project	Partner	Milestone Collaborated on & Description of Activity	Partner Personnel	Name of NSMG-Net Student Involved
2.1	NRCan	Data and models for microgrid operation and cost benefit analysis	S. Wong	M. Quashie
2.2	BCIT	Data and consumption information for the BCIT microgrid	M. Manbachi	M. Quashie
2.2	NRCan	Large scale integration of PV in microgrids and distribution systems	J. Hiscock	Group of 3 students, 1 PDF, and two research associates are involved in this project
2.2	CYME International	This includes utilization of CYME tools for power flow analysis of multiple microgrid under balanced and unbalanced conditions and evaluation of their mutual impacts. The main focus is translation of geographical data intro circuit data for large scale system analysis.		A group of 3 students and one research associate are involved in this process
2.2	Hydro One	This includes dontaing circuit configuration, short-term and long-term load and generation patterns and maintenance scheduling and translation of information for security analysis.	B. Singh and C. Essendal	A. Mohamed (PhD student), J. Jedrzejczok(PhD student)
2.2	IESO	This investigates impact of intermittency of multiple microgrids, wind and solar power plants on optimal generation portfolio and strategies for optimal demand-response strategies.	F. Gao	A. Ahmed (PhD student), M. Ramadan (PhD student), K. Akbari (Ph.D student)
2.2	OCE	This involves evaluation of real-time communication for OPF-based dispatch.	I. Vera-Perez	M. Graovac (RA) and a group of 3 students
2.2	Manitoba HVDC	This involves development of converter models for transient studies.		G. Gumussteking (MASc student)
2.3	NRCan	Visits by Dr Steve Wong to discuss research and progress in the project. Dr Wong has interacted with the project research students and provided inputs to their works. Exchange of research documents and emails.	A. Bowers	M.Manbachi
2.3	Hydro One	A research presentation to Hydro One will soon be made to receive their inputs and seek their comments. Communications are underway to set up this event.	D. Nechay	Q. Dung Ho

Table 12: International Collaborations Led by Theme 2 in Year 4

Project	Partner	Milestone Collaborated on & Description of Activity	Name of Collaborator	Name of NSMG-Net Student Involved
2.2	EPRI	This involves in application of EPRI through NRCan for case studies on Hydro One system.	J. Smith	A. Mohamed (PhD student) and M. Ramadan (PhD student)
2.2	Tsinghua University, Beijing, China	This project involves development of efficient power flow studies for real-time analysis and security evaluation. Currently we have one PDF for Tsinghua University in our group and from January 2015 we will have two visiting PhD students in group.	C. Chen	K. Akbari (PhD student)
2.2	North China Electric Power University	This project involves development of real-time security analysis software engine based on iterative power flow and transient stability analyses	C. Guo	A. Mohamed (PhD student) and S. Chungphisit (PhD student)
2.2	National Instrument	Real-time dedicated-hardware simulation platform for transient stability and security analysis. This project also encompasses objectives of Project 1.2 and conducted jointly with the activities of Project 1.2.	B. Black	M. Graovac (RA), R. Mirzahosseini (PhD candidate), and S. Chunagpishit (PhD student)

Theme 3: Microgrid Communication and Information Technologies

(Dr Julian Meng, Theme Leader)

Project 3.1: *Universal Communication Infrastructure*
Project Leader: Dr Fabrice Labeau (McGill University)

This project has focused on the utilization of LTE wireless communications technologies for smart and microgrid applications. Industry liasons include Quebec Hydro and IREQ.

Project Highlights:

- Use of existing measurements taken in the framework of another project within Hydro-Quebec substations as a starting point. These measurements concerns wideband data, and we have started the operation of digitally filtering these measurements to give them a narrowband characteristic around 1800 MHz. The next step will be to determine what existing model (if any) is suitable to represent this data.
- A new measurement campaign around the 700 MHz (LTE) band has been started. At this time, the necessary equipment to modify our measurement setup to accommodate this new frequency band is being procured. Measurements will then be made with the help of Hydro –Quebec collaborators.
- Construction of measurement setup for substation noise in the 700 Mhz band and corresponding measurement campaign (in collaboration with Hydro Quebec)
- Development of simplified version of existing impulsive channel model for narrow band, and design of a corresponding optimal receiver.
- Integration of impulsive noise model in sensor network simulator and explored the design of optimal receivers for the most recently developed substation electromagnetic noise model, i.e. a multi-state partitioned Markov chain.

Project 3.2: *Grid Integration Requirements, Standards, Codes and Regulatory Considerations*
Project Leader: Dr Tho Le-Ngoc (McGill University)

This project has focused on the assessment of PLC and the IEC 61850 standard and their applicability to communication requirements for an intelligent microgrid. Also, various routing protocols were assessed to determine the best performance for wireless mesh networks applied to a smart grid.

Project Highlights:

- An investigation on the role and applicability of the IEC 61850 standard and Power Line Communications (PLC) in microgrids has been completed. Our study suggests that, due to vital requirements on interoperability and scalability, communications for monitoring and control applications in microgrid needs to employ the IEC 61850 standard.
- The simulation of a Greedy Perimeter Stateless Routing (GPSR) and the Routing Protocol for Low Power and Lossy Networks (RPL) using the OMNET simulation tool has been performed. Various studies on the performance of these two candidate protocols in microgrid communication networks have been conducted and recommendations made.
- A preliminary study on the usability of networking coding to improve the data transmission robustness of microgrid communication networks has been done. Specifically, various types of

network coding schemes and selecting the candidate schemes that can be used jointly with routing protocols in microgrid scenarios have been investigated.

- A comprehensive overview study was completed for the communications networks and technologies for microgrids and smart-grid applications. The focus of this study was the investigation of network architectures, communications standards, and quality-of-service (QoS) requirements for microgrids. This includes the design of a proactive parent switching scheme in RPL in order to enhance the resilience to smart meter failures.

Project 3.3: *Distribution Automation Communications: Sensors, Condition Monitoring and Fault Detection*

Project Leader: Dr Julian Meng (University of New Brunswick)

This project's main goals are the development of smart, remotely re-configurable wireless sensors that can operate in harsh RF environments (e.g. electrical sub-stations) and the associated software application to allow for sensor configurability. Also, efficient database structures will be developed to allow fast access for real-time data storage and retrieval of sensor data. Utility partners will be called upon for sensor network deployment and testing.

Project Highlights:

- Continued development of sensor nodes: 14 constructed nodes is the target production number. A/D inputs on the sensor is now working and will provide the flexibility needed to allow the sensor node to acquire numerous types of measured quantities such as current, voltage, power etc.
- A gateway node has been designed and is in development. This will be used as an Internet access point.
- A ZigBee Noise Profiling measurement study has been completed and it has been found that the ZigBee sensor is sensitive to noise levels generated by low voltage machines.
- ZigBee sensor software applications have been completed to allow the sensors to acquire multi-faceted telemetry data.
- A higher layer software application has been developed that allows for a simple wireless sensor network to be configured and deployed.
- A database mechanism has been designed, completed and tested in a node-router-server-test-bed architecture bridging between ZigBee-Ethernet protocols.

Figure 9. Sensor node developed by Project 3.3

Project 3.4: Integrated Data Management and Portals

Project Leader: Dr Hassan Farhangi (BCIT/SFU)

The main objective of Project 3.4 is to investigate system level issues associated with microgrid applications which require access to real-time or quasi real-time data. To study this, Project 3.4 has chosen a typical microgrid function such as Volt-VAR Optimization (VVO), as a vehicle to find an optimal system topology, capable of improving the functionality of an existing microgrid/smart-grid function using new data streams. This project works closely with industry partners such as ABB, Siemens and Schneider Electric.

Project Highlights:

- Developed a new predictive VVO algorithm, capable of using real-time AMI data captured from termination points, and accurately predicting the feeder's load profile.
- Studied the impact of a Community Storage System on the VVO engine.
- Extended the VVO algorithm to include optimal maintenance scheduling of VVO assets during system operation.
- Extended the ability of the Predictive VVO Engine to perform its optimization task based on global (e.g., DMS/SCADA), as well as local attributes (e.g., AMI) in real-time.
- Improved the VVO Engine by enabling it to accept specific requirements (i.e,. VVO objectives) from network operators.
- Studied different optimization techniques suitable for the VVO Engine (80% complete)
- Worked on the impact of different loads and load profile variations on the VVO engine (completed). Here, different load profiles were modeled in terms of their impact on the performance of the VVO.
- Developed VVO algorithm with new objective functions and constraint (completed), such as maximizing energy conservation, minimizing distribution network losses and minimizing distribution network operating costs.
- Studied transformer losses (completed), and evaluated the impact of transformer loading on transformer loss and how it would be possible to estimate transformer losses in distribution network in quasi real-time.

Figure 10. Eight racks of RTDS in ACS-Lab RWTH Aachen University where P3.4 student Moein Manbachi is on exchange. Each rack supports around 22 electrical nodes.

Table 13: Publications by Theme 3 in Year 4

Project	Citation *(Click on link to access article where available)*	Refereed Journal Article	Non-refereed Journal Article	Invited Conference Presentation	Non-invited Conference Presentation	Other
3.2	Gao, Y. "Performance and Applicability of Candidate Routing Protocols for Smart Grid's Wireless Mesh Neighbor-Area Networks," MEng Thesis, McGill University, April 2014 (thesis).					x
3.2	Ghosh, S. T.-N. Tran and T. Le-Ngoc, "Dual-Layer EBG Based Miniaturized Multi-Element Antenna for MIMO Systems," IEEE Transactions on Antennas & Propagation, vol. 62, no. 8, pp. 3985-3997, August 2014.	x				
3.2	Ho, Q.-D., C.-W. Chao, M. Derakhshani and T. Le-Ngoc, "An analysis on throughput and feasibility of narrow-band power line communications in advanced distribution automation scenarios," 2014 IEEE International Conference on Communications (ICC 2014), DOI: 10.1109/ICC.2014.6883985, June 2014.		x			
3.2	Ho, Q.-D., Y. Gao, G. Rajalingham and T. Le-Ngoc, "Performance and applicability of candidate routing protocols for smart grid's wireless mesh neighbor area networks," 2014 IEEE International Conference on Communications (ICC 2014), DOI: 10.1109/ICC.2014.6883894, June 2014.		x			
3.2	Ho, Q.-D, Y. Gao, G. Rajalingham and T. Le-Ngoc, "Wireless Communications Networks for Smart Grid," Springer Briefs in Wireless Communications, Springer, 2014.					x
3.2	Ho, Q.-D., G. Rajalingham and T. Le-Ngoc, "Performance and applicability of geographic-based routing in smart grid's neighbor area networks," IEEE International Conference on Advanced Technologies for Communications (ATC 2013), Hochiminh, Vietnam, October 2013.		x			
3.2	Ho, Q.-D., Y. Gao, G. Rajalingham and T. Le-Ngoc, "Robust RPL Routing Protocol in Microgrid Scenarios", Technical Report, McGill, May 2014.					x
3.2	Rajalingham, G., Q.-D. Ho, and T. Le-Ngoc, "Evaluation of an efficient smart grid Communication system at the neighbor area level", Proc. of the 11th Annual IEEE Consumer Communications & Networking Conference (CCNC 2014), January 2014.		x			
3.2	Rajalingham, G., Q.-D. Ho and T. Le-Ngoc, "Random linear network coding for converge-cast smart grid wireless networks", Queens Biennial Symposium on Communications (QBSC 2014), Kingston, ON, 1-4 June 2014.		x			
3.2	Rajalingham, G., Y. Gao, Q.-D. Ho and T. Le-Ngoc, "Quality of Service Differentiation for Smart Grid Neighbor Area Networks through Multiple RPL Instances", The 10th ACM International Symposium on QoS and Security for Wireless and Mobile Networks (Q2SWinet 2014), Montreal, QC, September 21-26, 2014.		x			
3.3	Jia, J. and J. Meng, "Partial discharge impulsive noise in electricity substations and the impact on 2.4 GHz and 915 MHz ZigBee communications", in Proc. IEEE PES General Meeting, Vancouver, Canada, July 2013.			x		
3.3	Jia, J. and J. Meng, "A dual protection scheme for impulsive noise suppression in OFDM systems," AEU International Journal of Electronics and Communications, vol. 68, pp. 51-58, January 2014.	x				
3.3	Saleh, S.A., A.S. Aljankawey, R. Meng, J. Meng, C.P. Diduch and L. Chang, "Anti-islanding protection based on signatures extracted from the instantaneous apparent power", IEEE Trans. on Power Electronics, vol. 29, no. 11, pp. 5872 – 5891, November 2014.	x				
3.3	Saleh, S.A., A.S. Aljankawey, R. Meng and J. Meng, "Impacts of grounding configurations on responses of ground protective relays for DFIG-based WECSs", IEEE IAS Industrial & Commercial Power Systems (ICPS) Conference, Fort Worth, TX, May 2014.			x		
3.3	Saleh, S.A., D.M. Arbolaez, E.C. Guerra and J. Meng, "Real-time testing of Newton-Phaselet method for calculating the power factor of single phase loads," In Proc. of the 48th IEEE IAS'13			x		

	Annual Meeting Conference, Orlando, FL, October 2013.		
3.4	Manbachi,M., M. Nasri, B. Shahabi, H. Farhangi, A. Palizban, S. Arzanpour, M. Moallem, and D. Lee, "Real-time adaptive VVO/CVR topology using multi agent system and IEC 61850-Based communication protocol," Proc. Of the IEEE Transactions on Sustainable Energy, vol. 5, no. 2, pp. 587-597, April 2014.	x	
3.4	Manbachi, M., H. Farhangi, A. Palizban and S. Arzanpour, "A novel Volt-VAR optimization engine for smart distribution networks utilizing vehicle to grid dispatch", International Journal of Electrical Power and Energy, (submitted).	x	
3.4	Manbachi, M., H. Farhangi, A. Palizban and S. Arzanpour, "Predictive algorithm for Volt/VAR optimization of distribution networks using neural networks," in Proc. IEEE Canadian Conference on Electrical and Computer Engineering (CCECE2014), May 2014		x
3.4	Manbachi, M., H. Farhangi, A. Palizban and S. Arzanpour, "A novel predictive Volt/VAR optimization engine for smart distribution systems," CIGRE Canada Conference, Toronto, ON, September 2014.		x

Table 14: Highly Qualified Personnel in Theme 3 Since Inception (listed by Project #)

Project	Name	Program	Start	End	Employer (if graduated)
3.1	Monier, E.	UG	May 1, 2014	August 1, 2014	
3.1	Sacuto, F.	PhD	May 1, 2014	Dec. 2014 (est)	
3.2	Chao, C.-W.	UG	May 1, 2011	August 1, 2011	
3.2	Gao, Y.	MEng	October 1, 2010	May 1, 2014	
3.2	Ghosh, S.	MEng	October 1, 2010	August 1, 2012	
3.2	Herath, S.	PhD	October 1, 2010	ongoing	
3.2	Leung, C.r	PhD	January 1, 2011	August 1, 2012	
3.2	Rajalingham, G.	MEng	January 1, 2012	Ongoing	
3.2	Santorelli, J.	UG	May 1, 2011	August 1, 2011	
3.3	Harrington, M.	UG	2014	2014	
3.3	Jia, J.	PhD	2012	Ongoing	
3.3	Kar, A.	MSc	2010	2013	
3.3	Khammash, T.	UG	2011	2011	
3.3	Losier, T.	MSc	2010	Ongoing	
3.3	MacDonald, R.	UG	2013	2014	
3.3	MacNearney, D.	UG	2012	2012	
3.3	Morales, D.	PhD	2012	Ongoing	
3.3	Owhuo, G.	MSc	2014	Ongoing	
3.4	Manbachi, M.	PhD	Sept. 2011	Ongoing	
3.4	Nasri, M.	PhD	Aug. 2011	Ongoing	
3.4	Shahabi, B.	MSc	Aug. 2011	Apr. 2013	Alpha Tech.
3.4	Zhang, G.	MSc	Oct. 2013	Ongoing	

Table 15: Intra-Network Collaborations Led by Theme 3 in Year 4

Projects		Milestone Collaborated on, Specific Research Tasks Performed
3.2	1.4	Control systems for microgrids; wind farms and their effects on nature and animals
3.2	2.1	Business modelling of renewable energy in microgrid
3.2	2.4	Co-simulation for the integration of power grid and communications networks
3.2	3.1	Intelligent micro grid communications networks
3.2	3.3	Sensor networks for detecting power component failures
3.2	3.4	Volt-Var optimization & demand response; communications network architectures, standards and requirements for microgrids
3.4	3.2	Project 3.2 research on PLC was of value to Project 3.4. The two teams collaborated from 2012- 2014 on NB-PLC characteristics and applications.

Table 16: Collaborations with Partners led by Theme 3 in Year 4

Project	Partner	Milestone Collaborated on and Description of Activity	Partner Personnel	Name of NSMG-Net Student Involved
3.1	Hydro Quebec	Milestone 1 -measurements are carried out in Hydro-Quebec substation, in collaboration with Hydro-Quebec staff	B. Agba, J. Beland, M. Kassouf, S. Morin	F. Sacuto
3.2	BC Hydro	Technical discussions on power line monitoring, fault detection and restoration	Various researchers at BCIT	C.-W. Chao, G. Rajalingham
3.2	BCIT	Technical discussions on renewable energy generation, control system and communications networks for the microgrid & smart homes experimented in the BCIT campus , as well as emergency power failure responses and their communications requirements (following a visit on July 26/2014)	A. Palizban M. Manbachi	C.-W. Chao, G. Rajalingham
3.2	Corinex	Technical discussions on Broadband Power Line Communications (BB-PLC) for AMI networks	D. Nechay	Q. Dung Ho
3.2	Hydro Quebec	Technical discussions and e-mail exchanges on research results on applications of PLC, wireless networking for NAN segments	M. Kassouf	G. Rajalingham & Q.g Dung Ho
3.2	NRCan	Technical discussions on Power Line Communications (PLC) technology and bandwidth requirements for microgrids	S. Wong	C.-W. Chao
3.3	NB Power/Saint John Energy	Meeting to deploy sensor network in substation and other strategic locations.	D. Lamont/Saint John Energy	G. Owhuo
3.4	BCIT	Microgrid data, Smart Metering technology info, Load profile data	H. Farhangi	M. Manbachi
3.4	BC Hydro	VVO Requirements and Features	G. Stanciulescu	M. Manbachi
3.4	CYME International	VVO and Distribution Network Simulation/ Analysis	J.-S. Lacroix	M. Manbachi
3.4	Schneider Electric	Issues related to smart metering	A. Bowers	M. Manbachi

Table 17: International Collaborations Led by Theme 3 in Year 4

Project	International Partner	Milestone Collaborated on and Description of Activity	Name of Collaborator	Name of Student
3.2	Curtin University	Reliability and availability of IEC 61850 in substation	N. Das	C.-W. Chao
3.2	University of Tennessee	Co-simulation & wireless communication in smart grids	R. Mao	C.-W. Chao
3.4	RWTH Aachen University	In a recent visit by Project Leader to ACS Lab (E.On Energy Research Center), RWTH Aachen University, Germany, Project 3.4 was identified as an area of interest for joint research collaboration. This collaboration could enhance the knowledge of students and researchers from both sides. Common research topics such as distribution automation and NB-PLC for VVO application have been under study by both teams. The decision was therefore taken to attach Project 3.4's student to the University of Aachen for a period of time, enabling the validation of the developed VVO engine on ACS Labs's extensive co-simulation infrastructure.	A. Monti (ACS Lab. E.On Energy Center, RWTH Aachen University)	M. Manbachi

Financial Statement Year 4

Balance at start of Year 4 (October 1, 2013)	**361,202**
REVENUE	
NSERC transfers	739,500
Partner Contributions	184,500
Total funds available in Y4	**1,285,202**
EXPENDITURES	
Disbursements to universities	-634,001
Travel	-14,360
Network Manager	-80,000
Administration	-1,231
Outreach assistance	-3,372
Total expenditures in Y4	**-732,964**
Balance at end of Year 4 (September 30, 2014)	**552,240**
Outstanding Year 4 transfers to universities	*-286,826*
Unbilled Year 4 travel costs (AGM)	*-21,539*
Surplus available for Year 5	**243,873**

Partners

Our partnerships between industry, government and academia help us translate research into practical real-world applications. As well as providing funding support for network expenses and training Highly Qualified People, our partners offer in-kind support in the form of donated software licenses, access to professional equipment, and the time of their technical staff.

Appendix:

Individual Project Reports

Project 1.1: *Control, Operation, and Renewables for Remote Intelligent Microgrids*

Electrification of remote areas and islands remains a challenge in Canada and across the world. To date, remote areas are either not electrified at all, or are electrified through unreliable and weak connections to provincial or national electric grids, or are off-grid and energized by diesel engine-generator sets. However, there typically is a great potential for electric power generation through the renewable energy resources with which many remote areas are blessed. Integration of renewable energy resources, which are typically scattered in geography and intermittent in nature, is believed to be most effectively enabled through the concept of microgrids. Thus, Project 1.1 concentrates on the modeling, control, operation, and protection of microgrids for electrification of remote areas.

One major challenge associated with the realization of a remote microgrid is the lack of sufficient control and protection strategies. Utilization of renewable energy resources is almost invariably enabled through electronic power processors which, presently, are optimized for grid-connected applications. Thus, islanded (off-grid) operation is not supported by the current lines of product, while a worldwide market is quickly developing for off-grid applications. The research in Project 1.1, therefore, attempts to develop and test control, operation, and protection strategies that also enable off-grid operation of multiple electronically interfaced renewable energy resources and energy storage units. The results are expected to benefit both the Canadian manufacturers and utility companies. The results are expected to be modeling and analysis knowhow (for both utilities and manufacturers), product level control algorithms (for manufacturers), and system level implementation and operation techniques (for utilities).

To date, the project has developed and published on the specific topics of control and protection, and significant progress has been made on the topic of operation. Modeling and analysis techniques have also been developed as integrated steps towards the aforementioned developments. Further, in collaboration with Schneider Electric, an experimental set-up is under development for laboratory tests at Ryerson University of the developed algorithms, and their subsequent campus-wide tests at BCIT campus. Project 1.1 also collaborates with Projects 1.2 and 2.2, as well as with Theme 3 on the topic of communications for control and operation of microgrids.

Amirnaser Yazdani (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Research and development of control strategies and algorithms	Control algorithms for the electronic interfaces of distributed energy resources, such as wind, PV, and battery energy storage.
Research and development of coordinated control, supervisiory, and operational strategies	Algorithms for optimal planning and system-level operation of a microgrid with multiple distributed energy resources.
Research and development of protection strategies	Devices and algorithms for the protection of a microgrid with multiple distributed energy resources which can operate in both off-grid and grid-connected modes.
Development of simulation test cases and benchmark models	n/a
Performing test cases and evaluation studies and identification of the beta site and specification of requirements and test cases	n/a
Performing beta test cases	n/a

Current Milestone	Planned deliverable for Technology Transfer
Research and development of control strategies and algorithms	Collaborations with Schneider Electric will to test, verify, and commercialize the developed control algorithms for electronically interfaced distributed energy resources.

Project 1.2: *Distributed Control, Hybrid Control and Power Management for Intelligent Microgrids*

The main activities of Year 4 of Project 1.2 included: i) modeling and inclusion of ICTs in the control of the microgrid; ii) develop of performance evaluation criteria for investigating the impact of ICTs on the control, protection, energy management, and operation of microgrids, and iii) evaluation the impact of ICTs on the control and operation of microgrid test cases based on simulation and experimental test-beds (in hardware-in-the-loop environment).

Successful realization of the microgrid concepts and technologies is based on in-depth analysis and understanding of i) economical aspects of microgrids and ii) technical issues/requirements of the microgrid. Project 1.2 primarily concentrates on the latter item and covers "system" aspects associate with Themes 1 and 3 of the NSMG-Net.

The outcome of this project is intended for the manufacturing industry and the electric power utilities to provide the required microgird components/apparatus and operate the microgrid, respectively. Project 1.2 i) is conducted in collaboration with NSMG-Net partners, i.e., Hydro One, IESO, NRCan, OCE, (ii) extensively uses software infrastructure from the NSMG-Net partners CYME and Manitoba HVDC, (iii) collaborates with NSMG-Net research teams from University of Waterloo (through a project with Hydro One and Hatch) and Ryerson University (through supervision of PHD students), and (iv) has established industrial collaborations with multiple industries in Canada and USA, (e.g., Hatch Associates, Opus One, Prolucid, Ecamion, Eaton, Ecamion, CMC, National Instrument and EPRI).

Related to the activities of Project 1.2, we have now filed three patent applications with Ecamion, Hatch, and Opus One, and in Year 4 disclosed 4 IPs to the University of Toronto (one of them is being evaluated for patent application and initial discussions are underway to evaluate viability of a start-up). Currently three lines of products has been developed based on the activities of Project 1.2: (i) a microgrid controller, called CPPM has been marketed by Ecamion; (ii) a microgrid Energy Management System is being developed and tested and Hatch has the mandate for marketing this product, and (iii) a microgrid Supervisory System is being developed which will be marketed by Opus One.

Currently a group of 6 graduate students, 5 undergraduate students, 1 post-doctoral fellow, 3 research associates, and 4 visiting scientists are either full-time or part-time are involved in various aspects of Project 1.2.

Reza Iravani (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Year 1 Milestones: • We developed a robust control strategy for a single electronically-interface DER unit for both grid-connected and islanded modes of operation of the urban-type and the rural-type microgrids. • We developed and mathematically formalized the overall microgrid and the control system models, in the state-space form, and systematically deduced the corresponding linear models to design and optimize the control systems parameters. • We developed all algorithms of the control strategies in s-domain and verified based on time-domain simulation studies, using the PSCAD/EMTDC simulation platform. • We developed digital control form the S-domain controllers from digitization of their analog forms. The digital algorithms will be implemented in an NI-CRIO control platform and their performances, in a hardware-in-the-loop environment based on the RTDS system.	**Deliverables of Project for 2010-2011**: • Pieces of software for measurement, signal conditioning, and signal decomposition for control and protection applications. These pieces of software, depending on the platform for implementation, are developed in different languages and implemented on various processors such DSPs, FPGAs, or general purpose processors. • Pieces of custom-made hardware for interfacing control/protection hardware based on the required speed/protocol/IO-limits. The developed control/protection algorithms are digitally implemented in production-grade utility-standard hardware

• We initiated the process of integrating and evaluating performance of the designed control systems, as the slave controllers, of a centralized microgrid control structure.	platforms such as NI-cRIO, NI-PXI, and Ruggedcome Communication Interface platforms.
Year 2 Milestones in Continuation of Year 1 Milestones: • We developed a robust, centralized control strategy and corresponding algorithms for the control and operation of a microgrid that includes multiple distributed resource units. • We selected the LabView as the medium to develop the digitized controllers of the first year for integration the algorithms for integration in the hardware platform. • We developed digital form of all controller algorithms of the first year in the Lab view environment. • We integrated all the digital algorithms in the NI-CRIO hardware platform for testing. • We developed software modules (in FORTRAN and C languages) in the off-line digital time-domain simulation package PSCAD/EMTDC for evaluation of the developed algorithms and their refinements in the PSCAD/EMTDC. It should be needed that the conventional capabilities of the PSCAD/EMTDC (as well as other software tools, e.g., EMTP-RV) only permits analog form of controls and do not permit representation of digital control algorithms. • We developed the models of power circuitries of the selected microgrid systems with multiple distributed resource units in the real-time simulator environment RTDS. • We interfaced some of the developed NI-CRIO hardware controllers with the RTDS and currently are in the process of finalizing all the interface issues and optimization of the software-CRIO-RTDS interface requirements. • We investigated and developed the communication and the computational requirements/specifications for ICT based control and power management of microgrids.	**Deliverables of Project for 2011-2012:** • Pieces of software for measurement, signal conditioning, and signal decomposition for control and protection applications. These pieces of software, depending on the platform for implementation are developed in different languages and implemented on various processors such DSPs, FPGAs, or general purpose processors, depending on the final platform that makes of the software • FPGA-based hardware platforms the implements software modules and control/protection algorithms and tailored for integration in HIL test beds and integration in digital coltrol/protection modules of off-the-shelf platform from specific vendors.
Year 3 Milestones in Continuation of Year 1 & 2 Milestones: • We investigated various communication media, communication protocols, market available communication hardware/software applicable/acceptable to the power utility industry. • We selected a hybrid communication medium composed of any combination of microwave, fiber optics and power line for as the medium. • We identified interface communication "boxes" from Ruggedcom, based on the widely acceptability in the power utility industry. • We started modeling utility system cyber layer, including sensory and communications, for representation in the overall system cyber-physical layer of the utility grid, based on representation of the cyber layer (i) as a fixed delay, (ii) as a multiple of fixed delays, (iii) as a delay within a pre-specified limits, (iv) multiple delays, each within specific limits, and (v) a random delay. Based on the results, we would determine if there is a need for more detailed representation of the cyber layer in the context of our project objectives. • We integrated models (i), (ii) and (iii) as user developed models in the PSCAD/EMTDC environment for time-domain simulation studies of the distribution utility control/protection and energy management studies. The studies are conducted on multiple microgrids, representing urban, rural and perpetual islanded micorgrids.	**Deliverables of Project for 2012-2013:** • Pieces of software for measurement, signal conditioning, and signal decomposition for control and protection applications. These pieces of software, depending on the platform for implementation are developed in different languages and implemented on various processors such DSPs, FPGAs, or general purpose processors, depending on the final platform that makes of the software • Pieces of custom-made hardware for interfacing control/protection hardware based on the required speed/protocol/IO-limits. The developed control/protection algorithms are digitally implemented in production-grade utility-standard hardware platforms such as NI-cRIO, NI-PXI, and Ruggedcome Communication Interface platforms.
Year 4 Milestones in Continuation of Years 1,2 & 3: • Investigate the impact of cyber layer on the microgrid controllers developed in the year-2 and the year-3 of the program. (*In progress - 90% complete)* • Research, identify and formulate hierarchical robust control	**Deliverables of Project for 2013-2014:** these form the basis for 3 patents by Hatch, Opus One, and Ecamion, and 3 IP disclosures that are being evaluated for patent applications.

approaches for urban and rural microgrids based on various communication media and bandwidth. (*In progress - 90% complete)*
• Develop linear dynamic models for the design of centralized and distributed controls for benchmark microgrid systems. *(100% complete)*
• Research, develop strategies and algorithms for the control of multiple intelligent microgrids, and specify the required ICT. *(100% complete)*
• Develop performance criteria for control strategies including ICT. *In progress (90% complete)*
• Develop HIL-RTDS environment for real-time testing realization and performance evaluation of the control systems. (*In progress - 85% complete).*
• Identify beta site test cases for selected scenarios to validate the R&D results (2015). (*In progress - 40% completed)*
• Research, select and evaluate communication media for microgrid applications. (*In progress - 75% completed).* This item has extensively extended beyond the original project objectives due to significant technological changes and new concepts/approaches in this field within the last 3-4 years).
• Comparison of various standards, guidelines and utility specific requirements for communication systems *(100% complete)*

Current Milestone	Planned Deliverable for Technology Transfer
• Investigate the impact of cyber layer on the microgrid controllers developed in the Year 2 and the Year 3 of the program(*In progress – 90% complete)* • Research, identify and formulate hierarchical robust control approaches for urban and rural microgrids based on various communication media and bandwidth. (*In progress – 90% complete)* • Develop performance criteria for control strategies including ICT. (*In progress – 90% complete)* • Develop HIL-RTDS environment for real-time testing realization and performance evaluation of the control systems. (*In progress – 85% complete)* • Identify beta site test cases for selected scenarios to validate the R&D results (2015). (*In progress – 40% complete)* • Research, develop strategies and algorithms for the control of multiple Intelligent microgrids, and specify the required ICT (2013). (*In progress – 85% complete)* • Research, select and evaluate communication media for multi-microgrid applications. (*In progress – 75% complete).* This item has extensively extended beyond the original project objectives due to significant technological changes and new concepts/approaches in this field within the last 3-4 years.	The technology transfer is through patent applications and potentially other patents that have been disclosed.

Project 1.3: *Status Monitoring, Disturbance Detection, Diagnostics and Protection for Intelligent Microgrids*

The milestone of Project 1.3 for the 4th year of the program was to develop islanding detection, synchronization strategies, fault type/location identification.

In this context, we have investigated various islanding detection techniques. A power line signaling based islanding detection technique proposed some years ago by the author has been found as a superior method. As a result, we did not research new methods. Instead a method to design the islanding detection scheme was developed. The technique helps to select the component values and signal levels.

Much of our research efforts were spent in the area of synchronization. We proposed a novel, open-loop synchronization method for microgrids. This method is based on the idea of reducing switching transients associated synchronization, such as impedance insertion and point-on-wave closing. Research results have shown that the impedance insertion is the best candidate. An open-loop synchronization scheme can be developed using this idea.

In the area of fault type/location identification, we found that much progress hasbeen made in this area by other researchers, especially the use of power disturbance signatures for fault location. As a result, we started to investigate methods that can anticipate faults before it occurs. Since fault is closely related to the fault-ride through issue of DGs, we are developing an improved fault-ride-through control scheme for converter-based DGs. The graduate student allocated for this research has surveyed the existing fault-ride-through control algorithms and standards.

Two journal papers have been accepted for publications on IEEE Trans. On Smart Grid. Project 1.3 students also made poster presentations at the IEEE PES General Meeting and other conferences.

In terms of student training, one PhD student and one MSc students have graduated.

Wilsun Xu (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Identify benchmark system and worse case scenarios, and research and develop protection strategies and algorithms of adaptive protection for Microgrids	Project 1.3 started
Research and develop strategies, algorithms and identify ICT technologies for protection and monitoring of microgrids	1. Yazdanpanahi, H., Y. Li, W. Xu, "A New Control Strategy to Mitigate the Impact of Inverter-based DGs on Protection System", IEEE Transaction on Smart Grid, vol. 3., no. 3, pp. 1427 – 1436, September 2012. 2. Lin,S., D. Salles, W. Freitas, and W. Xu, "An Intelligent Control Strategy for Power Factor Compensation on Distorted Low Voltage Power Systems," IEEE Transactions on Smart Grid, vol. 3, no. 3, pp. 1562-1570, September 2012. 3. Dong, M., P.C.M. Meira, W Xu, and C.Y. Chung,"Non-Intrusive Signature Extraction for Major Residential Loads," Smart Grid, IEEE Transactions on , vol.4, no.3, pp.1421,1430, Sept. 2013.

Project 1.3

Research and develop strategies and algorithms for detection, discrimination and 48iagnostic functions	1. Grilo, A.P., P. Gao, W. Xu, and M. C. de Almeida "Micro-grid load monitoring using state estimation techniques," submitted to IEEE Trans. Smart Grid, Jun. 2013. 2. Yazdanpanahi, H., W. Xu, and Y. Li, "A novel fault current control scheme to reduce synchronous DG's impact on protection coordination," IEEE Trans. Power Delivery, vol. 29, no. 2, 542-551, April 2014.
Develop islanding detection, Load monitoring estimation algorithm and simulation platform for studying low voltage residential network	1. Patented and licensed through www.dx3ltd.com/anti-islanding. 2. Grilo, A.P., P. Gao, W. Xu, and M. C. de Almeida, "Load Monitoring Using Distributed Voltage Sensors and Current Estimation Algorithms," IEEE Trans. Smart Grid, vol. 5, no. 4, pp. 1920–1928, Jul. 2014. 3. Torquato, R., Q. Shi, W. Xu, and W. Freitas, "A Monte Carlo Simulation Platform for Studying Low Voltage Residential Networks," IEEE Trans. Smart Grid, vol.5, no. 6, pp. 2766-2776, November 2014.
Current Milestone	**Planned Deliverable for Technology Transfer**
Research and develop synchronization strategies, impedance selection criteria for protection of DGs of microgrids.	https://www.dropbox.com/s/5b73vh3rjkow99u/Research%20Description.pdf
Research and develop low voltage fault ride through technology in converter based DG units in microgrids.	https://www.dropbox.com/s/6bwqnny2v4q64in/Project%20description%20for%20NSERC%20SMG%20Network.pdf

Project 1.4: *Operational Strategies and Storage Technologies to Address Barriers for Very High Penetration of DG Units in Intelligent Microgrids*

This project deals with issues related to a high penetration of distributed energy resources based on mostly renewable. Such resources are intermittent and variable and cannot be dispatched in the same manner as conventional generation. Solutions to managing variability include storage (electrical, among others), and load management (curtailment and demand response). Other issues are related to the reliability and security of the energy supply. This project proposes controllers and energy management systems to ensure reliable operation of the microgrid in islanded and grid connected modes.

Fit with the overall Network research program: This project provides solutions to managing microgrids in the context of a high penetration of distributed energy resources. It aims to develop controllers and energy management systems using expertise available in Project 1.1 (controller design, A Yazdani), Project 1.2 (benchmarking, R Iravani), Project 1,3 (power quality management, W Xu) and Project 2.1 (cost-benefit analysis, G. Joos). Students are interacting directly with two of the Network Partners, Hydro-Quebec IREQ (one student, Michael Ross, is receiving a scholarship from the partner and spending at least 50% of his time on the partner premises working on the microgrid related projects of the partner) and NRCan/CanmetENERGY. More specifically, the student was involved in the specification of microgrid controllers for use on the Hydro-Quebec Distribution Test Line incorporating a microgrid.

Benefits to Canada: The research work will help define a specification and an implementation of microgrid controllers and energy management systems and will directly benefit industry (equipment manufacturers) and utilities (distribution system operators) developing and implementing microgrids; controllers and energy management systems are key to making microgrid operational and cost effective, and provide benefits to all stakeholders, including the microgrid operators (independent or other) and the distribution system operator.

Geza Joos (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Research and develop energy management strategies and identify barriers associated for large number of renewable DGs	n/a
Establish performance merits considering cost optimization and provide evaluation based on simulation test cases	n/a
Evaluate storage technologies, modes of operations, ancillary service functions and values	n/a
Research and develop strategies and algorithms to address barriers for penetration of large number of renewable based on storage technologies and ICT	n/a
Evaluate performance of the strategies based computer simulation test cases, and validate the storage and the ICT performance in the BCIT beta site	n/a
Current Milestones	**Planned Deliverable for Technology Transfer**
Research and develop strategies and algorithms to address barriers for penetration of large number of renewable based on storage technologies and ICT	Specification of a microgrid energy management - implementation recommendation - design of microgrid controllers
Validate the results based on simulation test studies and provide verification based on beta site tests	Testing and validation on software platforms - real time testing - testing on Hydro-Quebec distribution test line
Evaluate performance of the strategies based computer simulation test cases, and validate the storage and the ICT performance in the BCIT beta site	Development of simulation test cases (use cases)

Project 2.1: *Cost-benefits framework: secondary benefits and ancillary services*

This project deals with the cost-benefit framework for microgrids and their feasibility as a new component of distribution system technology. Elements of this project include defining the framework for a cost-benefit analysis, establishing the various stakeholders involved in the operation of microgrids, and a list of benefits, independently of the beneficiary. An approach to monetizing the benefits and costs, and allocating benefits, is developed. The methodology is applied to representative microgrids, including remote community and mining installations and dedicated grid connected installations. Key benefits include: reliability improvement, ancillary service provision, investment deferral resulting from peak load reduction and ancillary service provision, and emissions reduction.

Fit with the overall Network research program: This project provides economic justification for the deployment and implementation of microgrids. It draws on expertise available in Project 1.1 (remote microgrid design, A Yazdani), Project 1.2 (microgrid power management, R Iravani), Project 1.4 (strategies for a high penetration of distributed energy resources, G. Joos), Project 2.2 (energy security, R Iravani) and Project 2.3 (demand response, K. Battacharya). PhD student Mike Quashie is interacting directly with two of the Network Partners, NRCan and BCIT.

Benefits to Canada: The research work develops the tools for the preliminary assessment of the economic feasibility of microgrids, taking into account and quantifying their direct and indirect benefits for the different stakeholders, including the microgrid owner and operator, and the operator of the distribution grid to which it is connected. It directly benefits entities interested in implementing microgrids (independent operators) and utilities (distribution system operators) having to operate microgrids along side the conventional distribution systems and loads, by providing the necessary assessment tools.

Technology transfer: This project will deliver among others the requisite spreadsheets to carry out the economic assessments. Providing a structured approach to a cost-benefit analysis can be used as an input to the drafting of policy recommendations.

Geza Joos (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Establish the list of benefits and the framework for quantifying direct, energy supply benefits, taking into account utility interconnection requirements	
Develop the methodology for quantifying the monetary value of the direct benefits	
Develop a framework for implementing and quantifying ancillary services	
Planning and optimization approaches to maximize Microgrid benefits	
Application of the methodology to Microgrid demonstrations in commercial, industrial and remote community settings	
Current Milestone	**Planned Deliverable for Technology Transfer**
Planning and optimization approaches to maximize Microgrid benefits	Testing and validation on software platforms - real time testing - testing on the DERCAM platform
Application of the methodology to Microgrid demonstrations in commercial, industrial and remote community settings	Applying and adapting the methodology to different types of microgrids (remote communities and mining installations, community and military microgrids)

Project 2.2: *Energy and Supply Security Considerations*

The main activities of Project 2.2 in Year 4 included:

- Modeling and evaluation of the impact of multiple microgrids on overall system legacy asset, in switched devices such as tap-changes and switched capacitors;
- Modeling and evaluation of the impact of intermittency of the microgrid DG units and controlled loads on the microgrid components (e.g., transformers) in terms of thermal stresses, increased number of switching events (e.g., tap changers, switched capacitors), and number of operational cycles of continuous controllers (e.g., governor and excitation systems and storage systems);
- Quantification of such impacts on the tear and wear and life-time of apparatus;
- Development of operational strategies, maintenance schedule, and demand-side management, to minimize apparatus loss of life.

Each of above items to be carried out with respect to:

a) The components within a microgrid;
b) The microgrid impact of the apparatus of its host transmission/sub-transmission system

The item (b) also is extended to represent and evaluate the impact of multiple microgrids on each other and on the host power grid.

Successful conduction of required studies necessitates:

- Development of single microgrid model(s), control/protection/energy-management strategies and the corresponding algorithms. This has been the objective of Projects 1.2, 1.3, 1.4 and 2.3 within the last three years.
- Development of models, and control/operation/supervisory control of multi-microgrids as part of a large interconnected host grid. This has been the objective of Project 2.2 during the first three years of the project.
- Collection of actual data from the power utility in terms of failures, maintenance schedules, cost associated with tear-and-wear, legacy remedial methods and short- to long-term (e.g., hourly to yearly), load and generation variation patterns.
- Development of data analytic techniques and dedicated processing engines to handle and process massive data and simulation results to develop comprehensible results.

The main deliverables of this project include:

- Steady-state and dynamic models of microgrids for large-scale power systems that imbeds multiple microgrids.
- A software tool that automates the simulation process, data collection from each simulation study, and tabulation of results according to the user requirements. Considering that evaluation of each scenario requires a large number of case studies, where each case study requires thousands of simulation runs to achieve the results, the automation process is the main challenge of the project.
- Set of guidelines to assist power utilities to evaluate the impact of large number of microgrids and the corresponding intermittent generation on legacy asset, maintenance planning, and asset utilization.

The outcome of this project is intended for:

i. Power utilities for load/generation planning, maintenance scheduling, and development of operational strategies for renewable and demand-side management,

ii. Power apparatus manufactures to accommodate emerging requirements in the apparatus design, manufacturing, and warranties, and
iii. Regulatory and policy-making bodies to define/modify guidelines and/or standards for emerging grid scenarios that necessarily do not comply with the legacy guidelines/standards/practices.

Reza Iravani (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Year 1 Milestones: • Quantify the effects of high-depth of conventional Microgrid penetration on the steady-state, dynamic, and transient phenomena of interconnected power systems (2011). • Determine the potential violations and/or infringements of the regulations, standards and guideline requirements from high penetration of conventional Microgrids (2011). • Develop models to investigate the requirements, intelligence and technologies to mitigate the adverse impact of multiple Microgrids on the host power system. (50% complete) • Develop supervisory control and power management strategies and algorithms to enable inter-Microgrid partial and/or full autonomy and minimize intra-Microgrid adverse impacts. (40% complete) • Develop benchmark systems and operational scenarios to investigate and verify the envisioned strategies. In progress (20% complete) • Investigate and quantify the impacts of the various strategies and, in particular, their associated ICT and the market signals, on the security of supply. (15% complete) • Develop specifications for improvements and the required technologies to mitigate the identified impacts. (20% complete) • Select test cases and beta site(s) to experimentally (even with a limited scope) verify the results of the previous milestones. (10% completed) • Perform beta site tests and computer simulation results to verify/modify the proposed strategies and the corresponding algorithms. (not started)	**Deliverables of Project for 2010-2011 include:** • Pieces of software for measurement, signal conditioning, and signal decomposition for control and protection applications. These pieces of software, depending on the platform for implementation are developed in different languages and implemented on various Software tools such as PSCAD, PSS/E, Matlab. • Development of hardware based data storage to accommodate massive data from measurement and projected operational scenarios.
Year 2 Milestones in Continuation of Year 1: • We developed utility type (communication based), and active islanding detection methods (without communication requirements) and re-synchronization techniques that can accommodate both conventional and electronically- interfaced DER units within a microgrid. • We extended the active islanding detection method also to be isolated sound part of the microgrid from faulted part, during islanding mode of operation to increase reliability and continuity of supply for sensitive/preferential loads of the microgrid. • We developed off-line PSCAD/EMTDC models of the microgrid benchmark systems and tested the proposed islanding synchronization techniques. • We are in the process of adopting the models for real-	**Deliverables of Project for 2011-2012 include:** • Pieces of software for measurement, signal conditioning, and signal decomposition for control and protection applications. These pieces of software, depending on the platform for implementation are developed in different languages and implemented on various Software tools such as PSCAD, PSS/E, Matlab. • Adopting NI-PXI hardware platform for development of hardware based data storage to accommodate massive data from measurement and recorded processing and events.

time- RTDS based real-time simulator.
• We are in the process of implementing the islanding detection and re-synchronization algorithms, in conjunction with a power management strategy (PMS), in an NI-PXI platform for testing and evaluation with The RTDS platform in a Hardware-in-the-loop environment.
• We developed secondary control strategy, mainly for voltage regulation, for a coordinated operation of microgrid and its host utility system.
• We developed the secondary control algorithms as part of a fast PMS.
• We tested the secondary control algorithms based on digital time-domain simulation studies in the PSCAD/EMTDC environment.
• We are in the process of evaluating the interactions of multiple distributed resources with different time response to the developed secondary controller, in conjunction with the detailed behavior of the units in response to their local controllers.
• We are investigating different types of control strategies, e.g., optimization based, with full or partial communication requirements, in terms of robustness, implementation issues, computational resources, ease of design, number and availability of monitoring and feedback signals, for virtual power plant mode of operation of microgrids.

Year 3 Milestones in continuation of Years 1&2:
• We developed and adopted the control/protection models of year-two in real-time- RTDS based simulator environment. This process is still under development and has tailored and extended for three different microgrids, i.e., urban microgrid, rural microgrid and remote microgrid.
• We developed and implemented the islanding detection and re-synchronization algorithms for grid-interface configurations in an NI-PXI platform for testing and evaluation with The RTDS platform in a Hardware-in-the-loop environment.
• We developed secondary control strategy, mainly for voltage regulation, for a coordinated operation of microgrid and its host utility system.
• We developed the secondary control algorithms as part of a fast EMS.
• We tested the secondary control algorithms based on digital time-domain simulation studies in the PSCAD/EMTDC environment.
• In continuation of the year-two activities, we are in the process of evaluating the interactions of multiple distributed resources with different time response to the developed secondary controller, in conjunction with the detailed behavior of the units in response to their local controllers.
• We are developing a decentralized robust control strategies for local controls, applicable to grid-connected mode under grid-supported and virtual power plant conditions.
• In continuation of year-two We are investigating different types of communication requirements, in terms

Deliverables of Project for 2012-2013 include:
• Pieces of software associated with the steady-state, transient stability and electromagnetic transient models of various components, apparatus, and subsystems microgrids and transmission system for system studies.
• Three preliminary reports on the case studies dealing with the impact of high penetration of intermittent DG units and demand-response control action. These reports are provided to the collaborating industries and not publically available.

of robustness, implementation issues, computational resources, ease of design, number and availability of monitoring and feedback signals, for optimal power plant operation of both grid-supported and virtual power plant mode of operation of microgrids.

• We started research for utilization of microgrid EMS computational resources for feeder specific feeder automation functions in the grid-supported urban and rural microgrid configurations for automated fault and outage management.

• We started feasibility studies of data analytics resource integration in the microgrid EMS for asset heath evaluation and market signal integration in optima operation of the microgrid.

• We started (i) integration of applicable concepts, strategies and the corresponding algorithms and (ii) continuous monitoring, data logging and data analysis in one distribution feeder (grid supported microgrid).

Year 4 Milestones in Continuation of Years 1-3:

• Development of positive-sequence, urban and rural microgrid models in the PSS/E platform for power flow and transient stability studies of microgrids (microgrid transients models for PSCAD and equivalent type of tools have already been developed). *(100% complete)*

• Expansion of the above models to unbalanced conditions and 4-wire configurations. *(In progress - 80% complete)*

• Development of "equivalent models" of urban and rural microgrid models (balanced and unbalanced scenarios) for incorporation in the PSS/E for large power system studies. *(In progress - 40% complete)*

• Selection of interconnected power system to accommodate (i) large number of equivalent microgrid models (up to 4000), wind power plants, and solar power plants (up to 35% of the total generation capacity of the interconnected system). *(100% complete).*

• Development of the positive sequence PSS/E-based model of the above system for power flow and transient stability studies. *(100% completed).*

• Augmentation of the above model to accommodate unbalanced conditions. *(In progress - 25% completed)*

• Obtaining short-term and long-term load and generation profiles for the past 25-35 years from the NSMG-Net industrial partners and other industrial partners. *(In progress - 60% completed)*

• Obtaining demand-side management data from recent field measurements. *(In progress - 70% completed)*

• Development of processing algorithms and storage of the above data for use in both real-time and off-line (PSS/E) simulation tools. *(In progress - 50% completed).*

• Obtaining maintenance schedule, apparatus failure data, cause of failure data for tap-changing transformers, switched capacitors, DG units and energy storage systems for distribution class components. *(In progress - 60% complete)*

• Obtaining maintenance schedule, apparatus failure data, cause of failure data for transmission and sub-transmission class on-load tap-changers, switched capacitors, static VAr compensators, HVDC converters,

Deliverables of Project in Year 4 include:

Five technical reports based on the study cases that have been submitted to IESO (3 reports) and Quanta Technology (1 report), and Toronto Hydro (1 report), on IP disclosure to the University of Toronto Innovation Foundation which is currently the basis for a patent application development in conjunction with Prolucid, and a set of scholarly papers as presented on p.29.

excitation system of generators, governor system of steam, gas and hydro turbine-generator units, ride-through capability of wind and solar power plants. *(In progress - 35% complete).*

• Development of a PYTHON-based software tool to automate case studies. It should be noted that for each scenario, tens of thousands of case studies based on load changes and possible variation of generation portfolio has to be conducted and the massive output results processed and automatically evaluated and logically presented. Such software tools are not available and need to be developed. *(In progress - 60% completed).*

• Identify (in consultation with the collaborating partners) case studies and the corresponding operational scenarios to be conducted for a single microgrid (both grid connected and islanded conditions). *(100% complete)*

• Identify (in consultation with the collaborating partners) case studies and the corresponding operational scenarios to be conducted for multiple microgrids within a large interconnected system in terms of impact of microgrids on the apparatus of the large system. *(In progress - 75% complete)*

• Identify (in consultation with the collaborating partners) case studies and the corresponding operational scenarios to be conducted for multiple microgrids within a large interconnected system in terms of impact of microgrids on each other. *(In progress - 60% completed)*

• Translate the study results into
(i) cost of operation and revenue loss/gain,
(ii) recommended operational conditions,
(iii) preferred generation mix,
(iv) desired control time response and function,
(v) static and dynamic operational limits of sensitive apparatus,
(vi) control strategies (and demand-side management strategies).
(In progress- 20% completed).

Current Milestones

On-going work to Reach Year 4 Milestones in Continuation of Years 1-3 Milestones:

• Expansion of the above models to unbalanced conditions and 4-wire configurations. *(In progress - 80% complete)*

• Development of "equivalent models" of urban and rural microgrid models (balanced and unbalanced scenarios) for incorporation in the PSS/E for large power system studies. *(In progress - 40% complete)*

• Augmentation of the above model to accommodate unbalanced conditions. *(In progress 25% complete)*

• Obtaining short-term and long-term load and generation profiles for the past 25-35 years from the NSMG-Net industrial partners and other industrial partners. *(In progress - 60% complete)*

• Obtaining demand-side management data from recent field measurements. *(In progress - 70% completed)*

Planned Deliverable for Technology Transfer

The technology transfer for Project is based on:

• A set of comprehensive technical reposts on the developed models, case studies, and developed software tool to collect, process and introduce data to the main software engine (in this case PSS/E), and developed software tools to process the data from tens of thousands of case studies and translate them in the required pieces of information. As of now five comprehensive reports have been prepared and submitted to industrial partners. A condensed version of these reports will be made publically available.

• Our investigations indicate that processing legacy data and on-lined monitored data based on the use of general purpose computer architecture is neither computationally efficient nor flexible to retrieve pieces of information. In this regard we are working with Prolucid to develop a dedicated hardware/software platform for utility data

• Development of processing algorithms and storage of the above data for use in both real-time and off-line (PSS/E) simulation tools. *(In progress - 50% completed).*
• Obtaining maintenance schedule, apparatus failure data, cause of failure data for tap-changing transformers, switched capacitors, DG units and energy storage systems for distribution class components. *(In progress - 60% completed)*
• Obtaining maintenance schedule, apparatus failure data, cause of failure data for transmission and sub-transmission class on-load tap-changers, switched capacitors, static VAr compensators, HVDC converters, excitation system of generators, governor system of steam, gas and hydro turbine-generator units, ride-through capability of wind and solar power plants. *(In progress - 35% completed)*
• Development of a PYTHON-based software tool to automate case studies. It should be noted that for each scenario, tens of thousands of case studies based on load changes and possible variation of generation portfolio has to be conducted and the massive output results processed and automatically evaluated and logically presented. Such software tools are not available and need to be developed. *(In progress - 60% complete)*
• Identify (in consultation with the collaborating partners) case studies and the corresponding operational scenarios to be conducted for multiple microgrids within a large interconnected system in terms of impact of microgrids on the apparatus of the large system*. (In progress - 75% complete)*
• Identify (in consultation with the collaborating partners) case studies and the corresponding operational scenarios to be conducted for multiple microgrids within a large interconnected system in terms of impact of microgrids on each other. *(In progress - 60% complete)*
• Translate the study results into
(i) cost of operation and revenue loss/gain,
(ii) recommended operational conditions,
(iii) preferred generation mix,
(iv) desired control time response and function,
(v) static and dynamic operational limits of sensitive apparatus,
(vi) control strategies (and demand-side management strategies).
(In progress - 20% completed)

processing. We have disclosed an IP to the University of Toronto which currently is being evaluated for joint patent application with Prolucid and future marking by Prolucid.

Project 2.3: *Demand Response Technologies and Strategies - Technologies and Metering*

During the current year the main research focus was on the following three research topics as elaborated below. Mathematical models have been completed and various analytical studies have been carried out during this period. All the modelling tasks are being supported with various scenario studies and analysis of the performances. The models are being tuned with some realistic data.

Research Topic C: Systems level operational model of a microgrid has been developed taking into account the price-responsive behaviour of loads, and how the system marginal prices and dispatch are dynamically affected by them. To this effect, a load model has been developed using neural networks that is based on realistic data from residential customers. This load model is integrated within the microgrid energy optimization framework to bring about significant benefits.

The effect of load price-elasticity in market prices and dispatch has been studied, based on a linear price-elasticity demand model. Matrix price-elastic models of the EHMS residential model were developed. Matrix models of price-elastic loads were then incorporated into the microgrid model to determine the impact on microgrid operations.

Research Topic D: Mathematical modelling of uncertainty arising from the presence of intermittent generation resources and uncertainty in demand has been considered in microgrids. A novel affine arithmetic based method has been proposed to adequately model such uncertainties in an affine arithmetic based OPF model. The proposed method has been tested on the CIGRE microgrid test system, and very useful findings have been made.

Research Topic E: In this research detailed dynamic models for an unbalanced distribution systems (microgrids) have been developed, with consideration of synchronous machine based distributed generators. Some very important findings have been obtained.

In Year 4, three journal articles based on Project 2.3 research were published, and three presentations were made at conferences. Three theses have also been published.

Kankar Bhattacharya (Project Leader)

Current Milestones	Discrete Deliverable for Technology Transfer
A: Sustainability consequences (environmental, economic and social impacts) of increased use of microgrids. Research on this was delayed because the microgrid model development work had to be completed first. The new start and completion dates for this milestone are: 2014-05-01 to 2015-12-31.	
B: Modeling and scenario analyses, data collection. Significant work has carried out on this milestone. Data collection work has not been undertaken, but we are using data from another source to develop the microgrid load estimation models for demand response studies.	
C: Determining cost and benefits. Significant work has been carried out.	
D: Energy-aware scheduling algorithms - proposing an algorithm for internal microgrid load balancing capability (Some work has been carried out, and this milestone continues to be addressed)	Novel method of modeling uncertainties to solve the optimal power flow problem with uncertain generation sources (Pirnia et al, A novel affine arithmetic method to solve optimal power flow problems with uncertainties, IEEE Trans. Power Systems, in press)
E: Formulation of the optimization problem with constraints on reliability and network capacity. (This milestone has been taken up earlier than proposed. Significant amount of work on microgrid modeling and optimization, as well as network modeling, has been carried out.)	

Project 3.1: *Distribution Automation Communication*

Work has started at a slow pace, midway through the year. We were hoping to jump start the work based on existing measurements from taken earlier on in the network operations, but it has been difficult up to now to procure the measurement results from the previous project leader.

Without this data in hand, we have started to follow two avenues:

(1) Use existing measurements taken in the framework of another project within Hydro-Quebec substations as a starting point. These measurements concerns wideband data, and we have started the operation of digitally filtering these measurements to give them a narrowband characteristic around 1800 MHz. The next step will be to determine what existing model (if any) is suitable to represent this data.

(2) Start a new measurement campaign around the 700 MHz (LTE) band. At the time of writing, we are procuring the necessary equipment to modify our measurement setup to accommodate this new frequency band. Measurements will then be made with the help of Hydro–Quebec collaborators.

In the meantime, we have explored the design of optimal receivers for the most recently developed substation electromagnetic noise model, i.e. a multi-state partitioned Markov chain.

Fabrice Labeau (Project Leader)

Current Milestone	Planned Deliverable for Technology Transfer
(1) Modeling of the substation noise from measurements made in years 1 and 2 in the project. The measurements should allow to characterize the WiMAX 1.8GHz band. As needed, links with hydro-Quebec will be used to complement these measurements with others taken in larger bands, and in particular to lead to models in the new 700MHz LTE band	Measurements and models report to partner

Project 3.2: *Grid Integration Requirements, Standards, Code and Regulatory Considerations*

Project 3.2 deals with the issues of grid integration requirements, standards, codes and regulatory considerations in intelligent microgrids. Specifically, it aims to study and to develop efficient transmission, information processing, and networking techniques and strategies suitable for a robust communications infrastructure that supports the integration of intelligent microgrids.

The milestone set for the fourth year (2013-2014) is "Development of jointly reconfigurable transmission and intelligent information processing schemes of heterogeneous wirelesss/wireline communications networks for integration of Microgrids".

The milestone of this year is mainly to develop a reliable and robust communications network for intelligent micro-grids. Specifically, it involves the selections of relevant communications technologies, associated network architectures, communications standards, and the developments of efficient network routing and coding protocols. Firstly, we completed our investigations on the network architecture, required quality of services (QoS) and candidate wireless communication technologies (including both wireline and wireless technologies applicable to each segment of the power grid) that could be used for micro-grids. These investigations allow system and network engineers in the power and telecom industries to grasp the big picture as well as detailed characteristics of the smart grid/micro-grid communications networks. Secondly, the impacts of the IEC 61850 standard that is expected to be widely accepted for data modeling and communications in numerous intelligent electric devices and equipment manufactured by different vendors are also studied. Furthermore, we have studied the strengths/weaknesses and applicability of promising wireless mesh routing protocols, network coding, and adaptive network re-configuration schemes that could be used to implement the micro-grid communications networks. Packet transmission reliability, latency and robustness of these protocols and schemes are evaluated and compared by simulations in various practical micro-grid scenarios. The findings presented in this work provide micro-grid communications network architects and engineers with valuable proven suggestions to successfully implement a reliable and robust communications architecture capable of supporting current and future intelligent micro-grid applications.

Tho Le-Ngoc (Project Leader)

Milestone	Discrete Deliverable for Technology Transfer
Preliminary studies to characterize different information types in intelligent microgrids to establish their QoS parameters and to classify their dynamic QoS requirements	n/a
Investigation of issues of grid integration requirements, and standards, codes and regulatory issues of emerging communications systems in supporting intelligent microgrids	n/a
Development of robust transmission techniques suitable for information exchange in intelligent microgrids	n/a
Development of jointly reconfigurable transmission and intelligent information processing schemes of heterogeneous wireless/wireline communications networks for integration of microgrids	n/a

Project 3.2

Milestone	Planned Deliverable for Technology Transfer
Development of jointly reconfigurable transmission and intelligent information processing schemes of heterogeneous wireless/wireline communications networks for integration of Microgrids	n/a
Development and evaluation of integration strategies for transmission, information processing and networking architectures, based on available and emerging communications technologies	n/a

Project 3.3: *Distribution Automation: Sensors and Condition Monitoring*

The focus of this project is two-fold:

1. The development of smart, remotely re-configurable wireless sensors that can operate in harsh RF environments e.g. electrical sub-stations and the associated software application to allow for sensor configurability. This work is needed to develop multi-faceted self-healing sensor networks that can monitor the overall status of the microgrid and the individual nodes will be over-the-air configurable. This work will interface with other projects in Theme 3 focussed on communications infrastructure and other Themes that require the acquisition of sensor data from microgrid components.
2. The development of efficient database structures will be developed to allow fast access for real-time data storage and retrieval of sensor data. The objective of this project is to develop use cases for intelligent agents, design the database structure for capturing their data, and developing portals for customer and utility use.

Progress:

- Continued development of sensor nodes: 14 constructed nodes is the target production number. A/D inputs on the sensor is now working and will provide the flexiblity needed to allow the sensor node to acquire numerous types of measured quantities such as current, voltage, power etc.
- A gateway node has been designed and is in development. This will be used as an Internet access point.
- A ZigBee Noise Profiling measurement study has been completed and it has been found that the ZigBee sensor is sensitive to noise levels generated by low voltage machines. Substation deployment will allow the sensor to acquire both telemetry data and noise measurements to assess RF noise in the vicinity of the sensor.
- ZigBee sensor software applications have been completed to allow the sensors to acquire multi-faceted telemetry data.
- A higher layer software application has been developed that allows for a simple wireless sensor network to be configured and deployed.
- A database mechanism has been designed, completed and tested in a node-router- server test-bed architecture bridging between ZigBee-Ethernet protocols. We are looking now at bridging between ZigBee-Cellular-Ethernet protocols so that any data collected in any place where there is cellular cover, could be channelled to a computer anywhere.
- One MSc, two PhD and one undergraduate student(s) are currently working on the project.

Julian Meng (Project Leader)

Completed Milestones	Discrete Deliverable for Technology Transfer
Design and Development of Zigbee sensor prototype	Sensor prototype
Design and Development of sensor network configuration software	Sensor software
Modelling on impulsive noise in high voltage substations and the impact on Zigbee communications	
Assessment of Zigbee sensor sensitivity to noise	
Initial practical testing of sensor node data acquisition system	

Project 3.3

Initial design and testing of the database connection software with UNB nodes and multiple hardware platforms	
Current Milestone	**Planned Deliverable for Technology Transfer**
Gateway Access Node development	Access node
Sensor network deployment and test in substation	
Sensor Network Database Development; storage and mining techniques for relevant sensor data	
Development noise rejection techniques for ZigBee physical layer	
Novel sensor data signal processing and detection applications	

Project 3.4: *Integrated Data Management and Portals*

The main objective of Project 3.4 is to investigate system level issues associated with microgrid applications which require access to real-time or quasi real-time data. To study this, Project 3.4 has chosen a typical Microgrid function such as Volt-VAR Optimization (VVO), as a vehicle to find an optimal system topology, capable of improving the functionality of an existing Microgrid/Smart-Grid function using new data streams.

In line with Project 3.4's planned milestones, the following deliverables have been achieved:

1. Developed a new predictive VVO algorithm, capable of using real-time AMI data captured from termination points, and accurately predicting the feeder's load profile. The algorithm then attempts to optimize system loss cost in quasi-real time through Particle Swarm Optimization Technique and through fuzzified factors.
2. Studied the impact of a Community Storage System on the VVO engine.
3. Extended the VVO algorithm to include optimal maintenance scheduling of VVO assets during system operation.
4. Extended the ability of the Predictive VVO Engine to perform its optimization task based on global (e.g., DMS/SCADA), as well as local attributes (e.g., AMI) in real-time.
5. Improved the VVO Engine by enabling it to accept specific requirements (i.e., VVO objectives) from network operators.
6. Studied different optimization techniques suitable for the VVO Engine (80% complete)
7. Worked on the impact of different loads and load profile variations on the VVO engine (completed). Here, different load profiles were modeled in terms of their impact on the performance of the VVO.
8. Developed VVO algorithm with new objective functions and constraint (completed), such as maximizing energy conservation, minimizing distribution network losses and minimizing distribution network operating costs.
9. Studied transformer losses (completed), and evaluated the impact of transformer loading on transformer loss and how it would be possible to estimate transformer losses in distribution network in quasi real-time.

Our findings so far demonstrates that it is feasible to design a smarter VVO engine, capable of achieving higher levels of optimization based on global attributes of the system, while taking into account real-time variations of the load characteristics it has to serve. The main outcome of this project is to demonstrate the feasibility of designing a reliable engine for distribution grids, capable of minimizing system losses, while increasing feeder efficiency at minimal incremental cost.

This project has been developed in close collaboration with BC Hydro. The researchers have also received advice and inputs from ABB, Siemens and Schneider Electric.

Hassan Farhangi (Project Leader)

Milestone	Discrete Deliverable for Technology Transfer
Integrated Data Management and Portals	Literature review, basics of VVO design
Universal Communication Infrastructure	First generation VVO engine, using objectives functions in three operating steps. Checked the impact of Distributed Generation (DG) on VVO algorithm. Modeled an optimized command and control architecture based on Multi-Agent System (MAS). Validated the suitability of NB-PLC as the medium for data/command transactions for this application.
Smart Grid-based Volt/VAr Optimization of Distribution Networks	Second generation VVO Engine with Genetic Algorithm. Modeled different objective functions in MATHLAB. Validated the designed VVO algorithm for the following applications: 1. VVO confined to the medium voltage (MV) substation 2. VVO within the substation and along distribution feeder to the end user 3. Quasi Real-time adaptive VVO using microgrid distributed energy resources (DER) 4. Studied V2G impact on quasi real-time adaptive VVO 5. Employed IEEE 34 Node Test Feeder 6. BCIT Distribution Network 7. IEEE 37 Node Test Feeder
Smart Grid-based Volt/VAr Optimization of Distribution Networks	Improved second generation VVO engine with different optimization techniques, capable of handling: 1. Different loads and load profile variations 2. Optimal maintenance scheduling of VVO assets 3. New objective functions and constraint 4. Transformer losses
Milestone	**Planned Deliverable for Technology Transfer**
Smart Grid-based Volt/VAr Optimization of Distribution Networks	Third generation VVO engine with improved optimization techniques, capable of incorporating: 1. Community Storage Systems 2. Predictive VVO Engine 3. Quasi-real-time sliding window for the optimization process Currently working towards designing a Selective VVO Engine and checking its performance in different operational conditions, troubleshooting and validating the relevant algorithms using an RTDS.
Load Disaggregation in Smart Distribution Grids	The main deliverable for this master level project is to provide the VVO engine with better visibility of the nature of loads which reside beyond the smart meters and in customers' premises. This will be done through disaggregation of AMI data, with the view to better characterize different loads in terms of their active and reactive components, and their proportional impacts on the accuracy and resolution of the VVO engine.

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