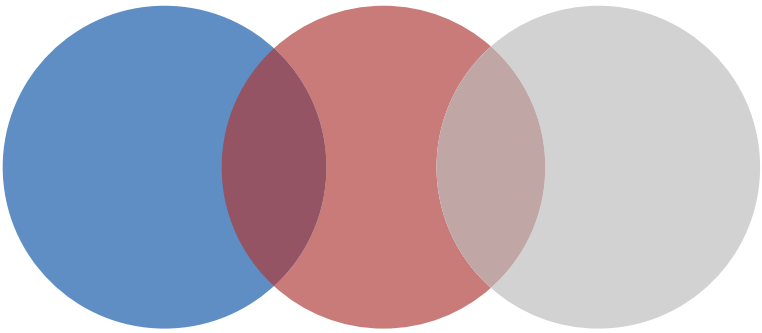


NSERC CRSNG

NSERC SMART MICROGRID NETWORK
nsmg-net

Annual Report 2012 | 2013

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 electrical and communication 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.

NSMG-Net logo

Our logo communicates three autonomous but interconnected microgrid nodes, or the three Theme Groups of our collaborative national research network, in a form that connotes the Canadian maple leaf, the 2010 Olympic flame (held in our founding year and host province) and a figure with arms raised in success.

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/or environment within the next 10 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.

Table of Contents

NSMG-NET
BCIT Technology Centre,
CARI Building, Wing A

Researchers and partners at the 2013 NSMG-Net AGM in Vancouver

Message from the Network Leader

On behalf of the Scientific Committee

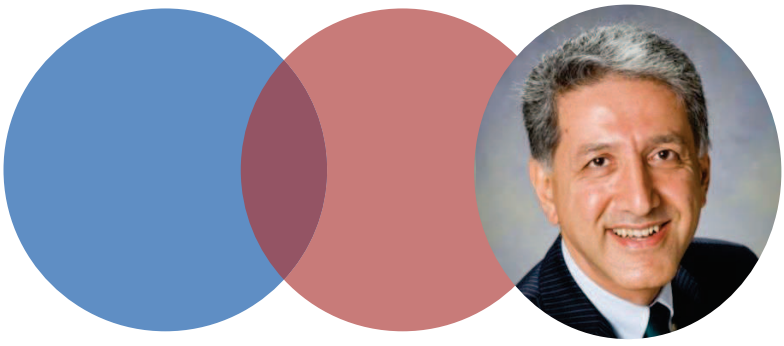
It gives me great pleasure to present you with NSMG-Net's 2013 Annual Report. Looking at the achievements of our HQP and researchers in getting us steps closer to our network's objectives of facilitating the developments of the required technologies, components and solutions for Canada's Next Generation Electricity Grid, makes me confident to report that we are on the right path.

Our Strategic Network was started by recognizing the need to bring together the three constituent disciplines of Electrical Engineering, Information Technologies and Communication engineering to work collaboratively on smart microgrid technology. Only by combining these disciplines can we build the cohesive technologies and strategies required to deliver NSMG-Net's objectives. I am glad to note that three years down the line, the framework for collaborative research among such diverse disciplines has been built and is yielding good results.

There is always room for improvement, however, and while there are many projects producing well beyond their expected milestones, there are others in need of support to keep up. The recent mid-term review was a timely and very worthwhile exercise in self-reflection, and the comments from the Sit Visit Committee will I'm sure help us to build a stronger and ever more united research output.

The rest of this report captures the achievements of our researchers and industrial partners to bring us closer to our network objectives. I invite you to take a look at the rest of this report to see how this is done. I am personally very hopeful that the next two years of will bring nothing but more success to NSMG-Net and our partners.

Hassan Farhangi,
Network Leader



On this page: students from across Canada at this year's collaborative workshop held at BC Hydro.

Year in Review

During this third year of the network, our researchers have continued to make strong progress along the milestones set out in our Network Research Program.

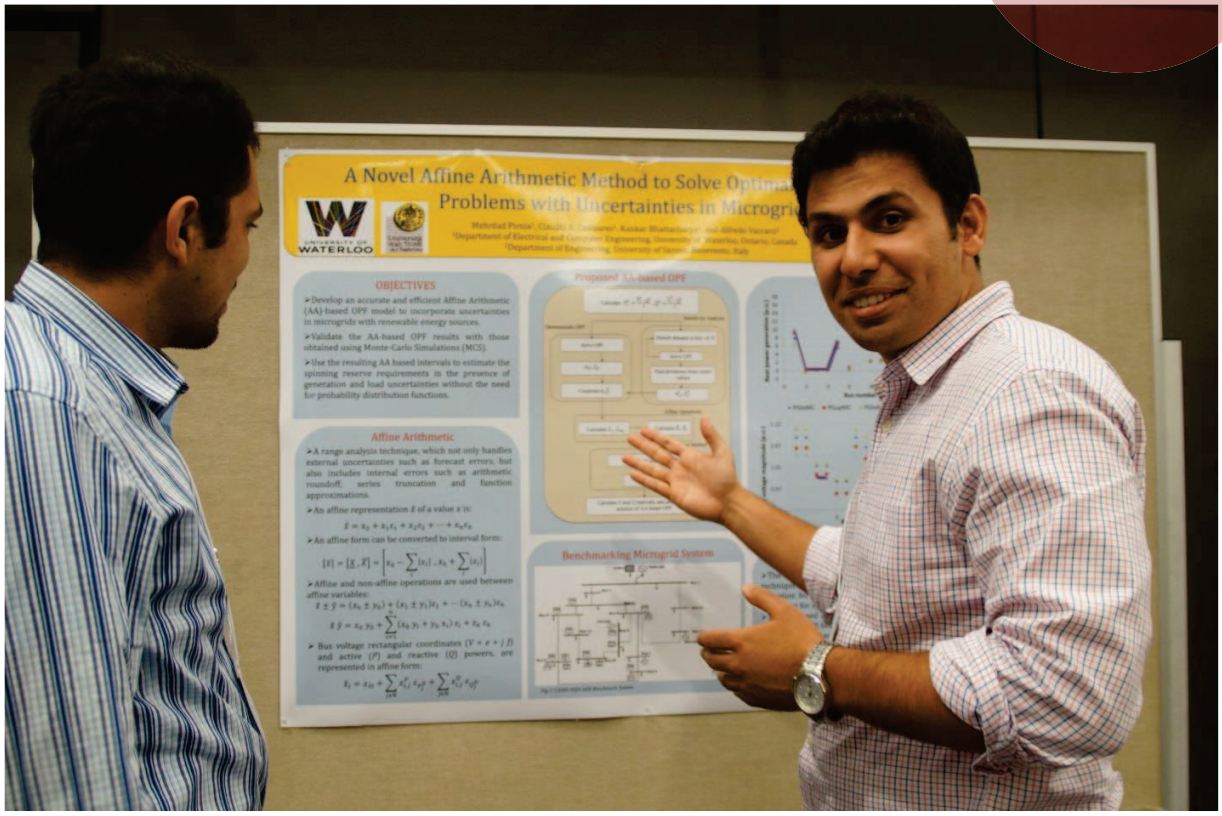
In **Theme One** students are defining the most suitable control strategies for an electronically interfaced off-grid PV-wind-storage-diesel microgrid. One project has specified the required ICT for microgrid models developed in prior years, and another has completed an investigation into self-excitation conditions when induction generators operate in an islanded microgrid. Finally a review of energy storage system technologies has been completed.

In **Theme Two**, students developed a methodology to optimize the benefits of a microgrid, and a framework for the economic assessment of remote PV-diesel microgrids. Also a unique mathematical model has been developed to assess the uncertainty from intermittent generation: test results from this model formed the basis of an IEEE transactions paper. Elsewhere in the theme, students are developing decentralized robust control strategies for local controls, applicable to grid-connected mode under grid-supported and virtual power plant conditions.

Finally **Theme Three**, with a focus on communications, researchers have completed the development of robust transmission techniques suitable for information exchange in intelligent Microgrids. In Project 3.2, basic components and operation mechanisms of RPL have been implemented in OMNET network simulator. Project 3.3 has begun testing its sensor node in harsh RF conditions and in Project 3.4, the focus is on verifying the suitability of NB-PLC for IEC61850 and distributed command and control Volt/VAr Optimization.

NSMG-Net HQPs presenting their research.

Left: Gowdemy Rajalingham, McGill
Below: Mehrdad Pirnia, U. Waterloo



Training Highly Qualified People

This year NSMG-Net funded 43 students at undergraduate, masters and PhD level. Five PhD and three masters students graduated and entered the workplace: for example one former PhD student has joined ATCO Electric in Alberta, and another has joined SaskPower. Over the course of the network, 120 students will receive funding through the network, preparing them with the skills needed by Canadian electrical utilities and technology companies.

Students have prepared papers and posters for presentation at events such as the Canadian Conference on Electrical and Computer Engineering (CCECE 2013) in Regina, the Electrical Power and Energy Conference (EPEC 2013) in Halifax, IEE Power and Energy Systems 2013 in Vancouver and even the 2013 IEEE Wireless Communications and Networking Conference (WCNC 2013) in Shanghai-China

Management and Governance

Our Scientific Committee (SC) is comprised of the three Theme Leaders and interested representatives from our government and industrial supporting partners. The SC met by teleconference three times this year, to discuss research progress, opportunities for student collaborative workshops, possible new network partners and planning for the AGM.

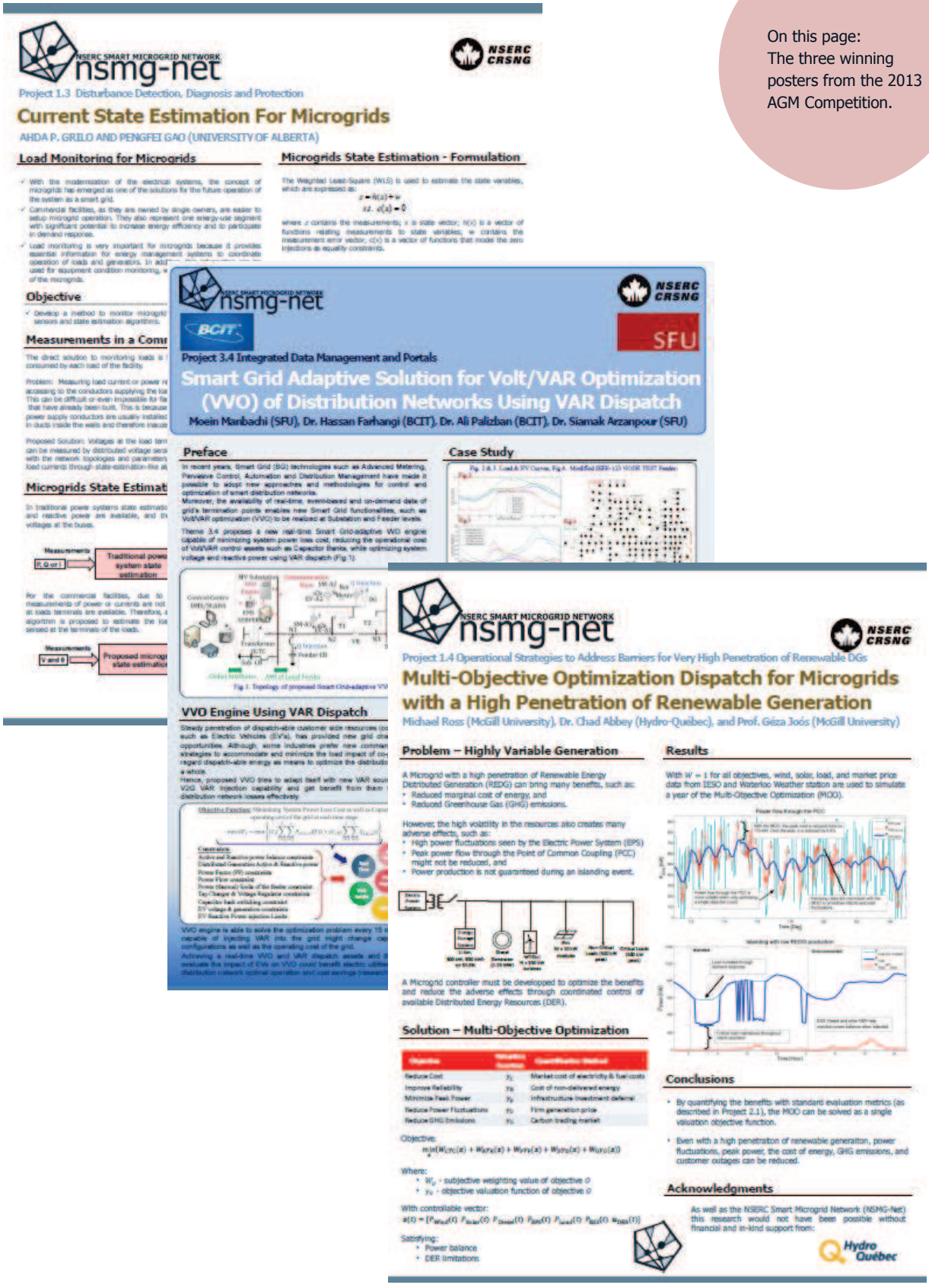
Our Board of Directors comprises twelve arms-length parties, equally representing academia, industry and government. We have seen four changes to the board this year: Richard Marceau and Andrew Pape-Salmon have stepped down, having changed jobs. A new representative from BC Ministry of Environment was sought to replace Andrew, and Nat Gosman will most likely join the board this year. Paul Ohrt at the Ministry of Defense was approached to join the board, after Peter Kouri left to work in Europe. And finally our NSERC representative Shaheer Mikhail has retired: our new representative will be Alison Jandilo. We welcome the new Board members, and wish Shaheer all the best in his retirement!

Outreach and Workshops

In May, BC Hydro hosted a select group of NSMG-Net students from across the country for a one day workshop on Microgrid Emergencies. Students met Ted Borer, who managed the campus microgrid at Princeton during Hurricane Sandy, and BC Hydro staff, who manage the province's grid and plan for future microgrid installations.

Our AGM this year was held in July in Vancouver. Guest speakers, from EPRI in the US and BC Hydro, as well as Network Leader Hassan Farhangi, opened the day, before Theme Leaders provided a summary of research progress this year. In the afternoon over a dozen students presented very short introductions to their research, in rapid succession, and invited the audience to visit their posters for more information.

On this page:
The three winning posters from the 2013 AGM Competition.



Research

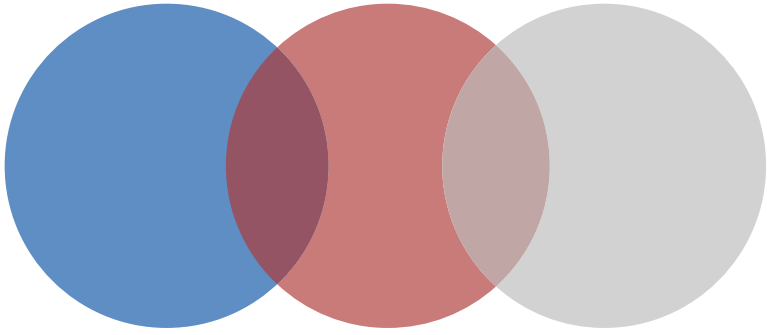
The next generation Smart Grid is the convergence of Information and Communication Technology with Power System Engineering.

The three research themes of NSMG-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 Joós 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 David Michelson at University of British Columbia. 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.



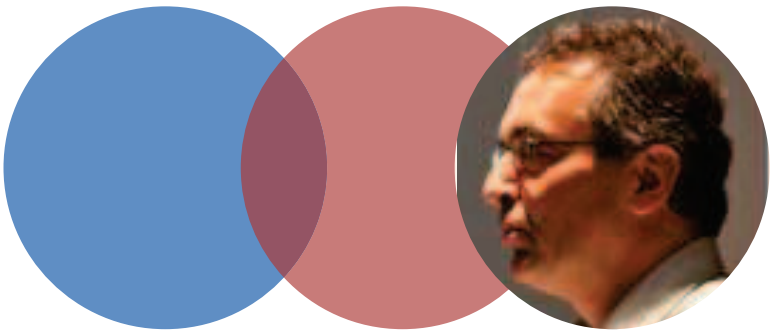
Theme One

All four projects within Theme 1 are proceeding well. Some the projects are ahead of original schedule in various research aspects and number of supervised graduate students and training of HQP.

The main focus of the project leader within Theme 1, in the 3nd-year of the network activities, was to establish and enhance (i) collaboration among the project researchers (ii) further involvement of industrial collaborators and (iii) outreach to new industrial partners.

The main action items in this regard was based (i) exchange of graduate students among themes, (ii) joint supervision of graduate students by researchers from different themes, (iii) sharing R&D resources and facilities among themes not only to enhance collaboration but also to address and cover expertise gap which inherently arise in multidisciplinary research of this nature, (iv) active solicitation of new industrial partners, particularly for graduate students internship positions, (v) seeking international research partners through from various international universities and research institutions, through individual contacts of project leaders, (vi) introduction/promotion of the network activities in international conferences and symposia, and (vii) dissemination the research results and the knowhow of the last three-years based on offering short terms (two-day) courses and research talks at various conferences, symposia and universities abroad.

Reza Iravani
University of Toronto



Theme Two

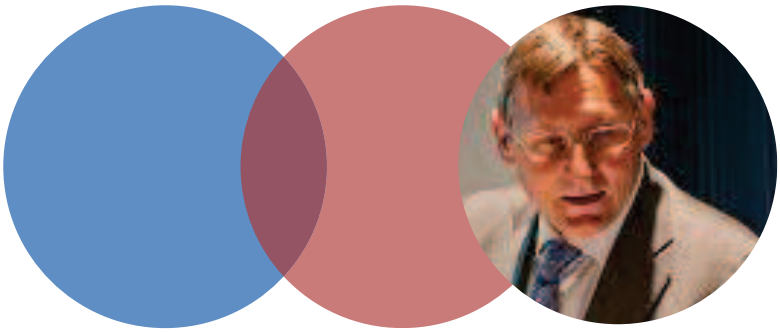
Three out of the 4 projects are on track. They are meeting the initially agreed upon research milestones, as stated in the original research program and no requests for readjustment of milestones have been received. The start of the last project, P2-4, was delayed and a revised proposal is expected from the project leader. This will be monitored more closely and remedial action will be taken.

Theme researchers met face to face in Toronto in April 2013 and at the AGM in Vancouver in July 2013. Telephone conferences have been organized as needed. Collaborations have been established within the Theme projects (P2-1, P2-2 and P2-3) and with projects outside the Theme (P1-1, P1-2, P1-3, P1-4). There have been exchanges between projects and themes (P2-1, P2-2, P2-3, P1-1, P1-2, P1-4).

Outreach activities in Theme 2 take the form of reporting of research results and presentations and posters at the AGM. Technology transfer outside the Network has been initiated (P2-2, P2-1).

Publication and presentation of the network research results at national and international conferences with specific reference to Network support and funding, has taken place on a regular basis, particularly by HQPs (as part of their training).

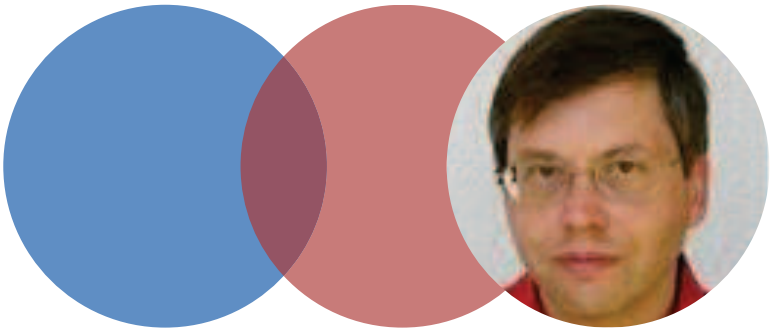
Geza Joos,
McGill University



Theme Three

Dr Michelson has not submitted a Theme report, nor a report for his Project 3.1. Please see Appendix B for the individual Project reports for Theme 3.

Please see Appendix D for the Year 4 budget, and proposed changes to Theme 3.



Partners

Our partnerships between industry, government and academia help us translate research into practical real-world applications.

University Partners

British Columbia Institute of Technology
Simon Fraser University
University of British Columbia
University of Alberta
University of Manitoba
University of Toronto
Ryerson University
McGill University
University of New Brunswick

Industry and Government Partners

BC Hydro
Hydro One
NRCan
Schneider Elecctric
Endurance Wind Power
Nebula Communications
Eion Wireless
Cyme
Ballard
Tantalus
Hydro Quebec,
Ontario Power Authority
IESO
New Brunswick Power
Manitoba HVDC
Ontario Centres of Excellence

Financial Statement

NSMG-Net is a Strategic Network generously funded by the Natural Sciences and Engineering Research Council of Canada, and by our industry, government and academic partners.

Over 80% of our funding goes directly to training the Highly Qualified People required by Canadian electrical utilities and technology companies. The remainder funds equipment, travel, networking events, outreach and management.

Please see the following notes, and Appendix C for more details.

	Year Ended September 2013	***Note***	***Budget for YE2013***	**Year Ended September 2012**
Funds available for year				
Balance at close of previous year	$156,053		*$156,053*	$63,397
Current year grant	$739,500		*$739,500*	$739,500
Partner contributions	$160,292	*1*	*$167,000*	$164,169
University contributions	$13,000		*$13,000*	$13,000
Total funds available for year	**$1,068,845**		*$1,075,553*	**$980,065**
Transfers to universities				
University direct cash contributions	$13,000	*2*	*$13,000*	$13,000
Transfer from host to universities	$732,238	*3*	*$764,600*	$715,800
Management expenses				
Network manager	$80,000		*$80,000*	$82,169
Researcher collaborative meetings and travel	$35,582	*4*	*$26,925*	$13,922
Outreach and dissemination	$10,115	*5*	*$22,975*	$6,933
Committee expenses	$9,920		*$12,000*	$5,189
Total transfers and expenses	**$880,855**		*$932,500*	**$824,013**
Balance at close of year	**$187,990**		*$156,053*	**$156,053**

Notes to the Financial Statements

1. Partner contributions were $6,708 lower than budgeted due to i) no $5,000 cash contribution received from Eion and ii) $1,708 reduced contribution of $23,292 by NRCan due to lower eligible expenses for reimbursement.
2. Contributions to Project budgets from universities are simply netted from transfers to universities, rather than being passed to BCIT and back. Amounts are as follows:

U of Toronto	$4,000
McGill	$3,000
Ryerson	$3,000
U of Manitoba	$3,000

3. Transfers to Projects were $32,362 less than budgeted due to the following withheld funds.
    a. $63,425 (vs budgeted $64,800 was transferred to Ryerson due to lower travel reimbursement.
    b. $33,813 (vs budgeted $64,800) to Manitoba, due to incomplete Y3 reporting
4. Expenditure on collaborative meetings and travel was 32% more than budgeted (at $35,582 vs $26,925 budgeted), principally due to hosting the AGM in Vancouver which involved more travel for more Eastern projects.
5. Outreach and dissemination expenditure was 56% under budget, due to the late start and timing of payments to the planned outreach assistant. Also outreach activity in Year Three was limited to materials presented and distributed at conferences, and online.

Publications

Network research results since September 2012 were disseminated by the following channels.

Title/Source	*Refereed Journal Articles*	*Non-refereed Journal Articles*	*Invited Conference Presentation*	*Non-invited Conference Presentation*	*Other*
A. Haddadi, 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", published, IEEE Trans. On Power Delivery, Early Access, July 2013.	✓				
A. Haddadi, A. Yazdani, G. Joos, and B. Boulet, "A Generic Load Model for Simulation Studies of Microgrids", proceedings of the IEEE Power and Energy Society General Meeting, July 2013.				✓	
F. Bhuiyan, A. yazdani and S. Primak, "Modeling, Simulation, and Performance Analysis of Power Management Strategies for an Islanded Microgrid", International Journal of Energy Science (IJES), accepted Jul. 2013.	✓				
M.A. Zamani, A. Yazdani and T. S. Sidhu, "A Communication-Assisted Protection Strategy for Inverter-Based Medium-Voltage Microgrids," IEEE Trans. on Smart Grid, vol. 3, no. 4, pp. 2088-2099, Dec. 2012.	✓				
M.A. Zamani, A. Yazdani and T. S. Sidhu, "A Control Strategy for Enhanced Operation of Inverter-Based Microgrids under Transient Disturbances and Network Faults," IEEE Trans. on Power Delivery, vol. 27, no. 4, pp. 1737-1747, Oct. 2012.	✓				
M.A. Zamani, T.S. Sidhu and A. Yazdani, "A Communication-Based Strategy for Protection of Microgrids with Looped Configuration", Elsevier Electric Power Systems Research Journal, 104 (2013), pp. 52-61, Jun. 2013.	✓				
M.A. Zamani, T.S. Sidhu and A. Yazdani, "Investigations into the Control and Protection of an Existing Distribution Network to Operate as a Microgrid: A Case Study", IEEE Trans. on Industrial Electronics, Accepted May 2013.	✓				
M. Davarpanah, M. Sanaye-Pasand, R. Iravani, "Performance enhancement of the transformer restricted earth fault relay", IEEE Trans. PWRD, vol. 28, no. 1, pp. 467-474, January 2013.	✓				
J. Bloemink, R. Iravani, "Control of multiple source microgrid with built-in islanding detection and current limiting", IEEE Trans. PWRD, vol. 27, no. 4, pp. 2112-2122, October 2012.	✓				
M.Z. Kamh, R. Iravani, "A sequence frame-based distributed slack bus model for energy management of distribution networks", IEEE Trans. Smart Grid vol. 3, no.2, pp. 828-836, June 2012.	✓				
One patent application: "Systems, methods and controllers for managing ans controlling a microgrid", US patent application 61/567,045, December 2012					✓
K. Kobravi, R. Iravani, H. Kojori, "3-leg/4-leg matrix converters generalized modulation strategy – Part I – A new formulation", IEEE Trans. Industrial Electronics, vol. no. 60, pp. 848-859,March 2013.	✓				
K. Kobravi, R. Iravani, H. Kojori, "3-leg/4-leg matrix converters generalized modulation strategy – Part II – Implementation and verification", same as above, pp.860-873.	✓				
H. Yazdanpanahi and R. Alaei, "Output power and harmonic currents analysis of photovoltaic systems in net-zero-energy houses," presented at IEEE PES General Meeting, Jul., 2013.				✓	
A. P. Grilo, 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.	✓				
H. Yazdanpanahi, W. Xu, and Y. Li, "A novel fault current control scheme to reduce synchronous DG's impact on protection coordination," accepted by IEEE Trans. Power Delivery, July 2013	✓				
H. Yazdanpanahi and W. Xu, "Impact of induction generators on fault currents and feeder protection," CCECE 2013 Conf., May 2013.				✓	

Title/Source	*Refereed Journal Articles*	*Non-refereed Journal Articles*	*Invited Conference Presentation*	*Non-invited Conference Presentation*	*Other*
Y. Wang, H. Yazdanpanahi, and W. Xu, "Harmonic impact of LED lamps and PV panels," CCECE 2013 Conf., May 2013.				✓	
A Haddadi, A Yazdani, G Joos, and B Boulet, "A Control Strategy for Enhanced Transient Performance and Stability of An Islanded Droop-controlled Active Distribution Network", IEEE Transaction on Power Delivery, 2013	✓				
A Haddadi, A Yazdani, G Joos, and B Boulet, "A Generic Load Model for Simulation Studies of Microgrids", in Proc IEEE PES General Meeting, Vancouver, July 2013				✓	
M Ross, C Abbey, and G Joos, "A Methodology for Optimized Energy Storage Sizing with Stochastic Resources", in Proc IEEE PES General Meeting, Vancouver, July 2013				✓	
O Saadeh, F Bouffard, and G Joos, "Decentralized Agent-Based Microgrid Control with Renewable Generation", in Proc CIGRE Canada Conference, Calgary, Sept 2013				✓	
M Quashie, G Joos, "A Methodology to Optimize Benefits of Microgrids", in Proc IEEE PES General Meeting, Vancouver, July 2013				✓	
J Clavier, M Ross, G Joós, "Dispatch Techniques for Canadian Remote Communities with Renewable Sources", in Proc Electrical Power and Energy Conference, Halifax, 2013				✓	
J Clavier, G Joós, S Wong, "Economic Assessment of the Remote Community Microgrid: PV-ESS-Diesel Study Case", in Proc Canadian Conference Electrical and Computer Engineering, Regina, July 2013				✓	
A. Etemadi, R. Iravani, "Overcurrent and Overload protection of the voltage-sourced distributed resources in a microgrid", accepted for publication in the IEEE Transactions on Industrial Electronics.	✓				
F. Badrkhani-Ajaei, S. Farhangi, R. Iravani, "Fault current interruption by Dynamic Voltage restorer", IEEE Trans. PWRD, vol. 28, no. 2, pp. 903-910, April 2013.	✓				
A. Mehrizi-Sani, R. Iravani, "Constraint potential function-based control of microgrid" IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1885-1892, December 2012.	✓				
A. Mehrizi-Sani, R. Iravani, "Online set point modulation to enhance microgrid dynamic response", IEEE Trans. PWRS, vol. 27, no.4, pp. 2167-2174, November 2012.	✓				
R. Iravani, "Real-time simulation of distributed feeders including large number of dispatchable DER units' Distinguished Lecturer Series, Arizona State University, November 2012 .			✓		
"Systems, methods and controllers for managing and controlling a microgrid", US patent application 61/567,045, December 2012					✓
"Systems, methods, and controllers for control of power distribution devices and systems", US Patent application 61/660,915, September 2012.					✓
E. Nasr, C. Canizares and K. Bhattacharya, "Stability and Control of Unbalanced Synchronous Machine Based Distributed Generators, Presented at the IEEE PES Task Force on Microgrid Control, IEEE PES Annual General Meeting, Vancouver, BC, 22nd July 2013.			✓		
F. R. Gaete, C. Canizares and K. Bhattacharya: "Effect of Price-Responsive Demand on Dispatch and Costs in Microgrids", Presented at the Student Poster Competition, IEEE PES Annual General Meeting, Vancouver, BC, 21st July 2013.			✓		
M. Pirnia, C. Canizares and K. Bhattacharya, A. Vaccaro, "A Novel Affine Arithmetic Method to Solve Optimal Power Flow Problems with Uncertainties", Presented at the Technical Conference on Increasing Real-Time And Day-Ahead Market Efficiency Through Improved Software at the Federal Energy Regulatory Commission (FERC), Washington, D.C., 25th June 2013.			✓		
M. Pirnia, C. Canizares, K. Bhattacharya, A. Vaccaro, "A Novel Affine Arithmetic Method to Solve OPF Problems with Uncertainties in Microgrids", Presented at the Student Poster Competition, IEEE PES Annual General Meeting, Vancouver, BC, 21st July 2013.			✓		

Title/Source	*Refereed Journal Articles*	*Non-refereed Journal Articles*	*Invited Conference Presentation*	*Non-invited Conference Presentation*	*Other*
Gowdemy Rajalingham, Yue Gao and Quang-Dung Ho, "OMNET Implementation of RPL for Smart Grid Neighbor Area Networks", Technical Report, McGill, December 2012.					✓
Quang-Dung Ho, Yue Gao, Tho Le-Ngoc, "Challenges and Research Opportunities in Wireless Communications Networks for Smart Grid", IEEE Wireless Communications, June 2013, pp.89-95.	✓				
Chon-Wang Chao, Quang-Dung Ho and Tho Le-Ngoc, "Challenges of Power Line Communications for Advanced Distribution Automation in Smart Grid", 2013 IEEE Power & Energy Society General Meeting, Vancouver-Canada, 21-25 July, 2013.				✓	
Gowdemy Rajalingham, Quang-Dung Ho and Tho Le-Ngoc, "Attainable Throughput, Delay and Scalability for Geographic Routing on Smart Grid Neighbor Area Networks", 2013 IEEE Wireless Communications and Networking Conference (WCNC 2013), Shanghai-China, 7-10 April 2013.				✓	
Moein Manbachi, Hassan Farhangi, Ali Palizban, Siamak Arzanpour, Impact of V2G on Real-time Adaptive Volt/VAr Optimization of Distribution Networks, IEEE PES General Meeting Conference, Dec. 2012.				✓	
Moein Manbachi, Hassan Farhangi, Ali Palizban, Siamak Arzanpour, "Real-Time Adaptive Optimization Engine Algorithm for Integrated Volt/VAr Optimization and Conservation Voltage Reduction of Smart Microgrids", in Proceeding of Cigre Canada Conference, Montreal, Canada, Sep. 2012.				✓	
Hassan Farhangi, Book Chapter on "Smart Grid and ICT's Role in its evolution", Green Communications: Theoretical Fundamentals, Algorithms and Applications, Published: Sept 20, 2012 by CRC Press, edited by Jinsong Wu; Sundeep Rangan; Honggang Zhang					✓
Moein Manbachi, Babak Shahabi, Hassan Farhangi, Ali Palizban, Siamak Arzanpour, Daniel. C. Lee, A Real-time Adaptive Volt/VAr Optimization Engine using Intelligent Agents and Narrow-Band Power Line Communication, Presented at Utility Telecom Conference, Vancouver, Canada, Sept 2012.				✓	
Moein Manbachi, Maryam Nasri, Babak Shahabi, Hassan Farhangi, Ali Palizban, Siamak Arzanpour, Mehrdad Moallem and Daniel C. Lee ,"Real-Time Adaptive VVO/CVR Topology Using Multi Agent System and IEC 61850-Based Communication Protocol", Publication pending in IEEE Transactions on Sustainable Energy	✓				
Maryam Nasri, Hassan Farhangi, Ali Palizban and Mehrdad Moallem, "Multi-Agent Control System for Real-time Adaptive VVO/CVR in Smart Substation" in Proceeding of IEEE Electrical Power And Energy Conference, London, Ontario, Oct. 2012.		✓			
Giuseppe Stanciulescu, Hassan Farhangi, Ali Palizban and Nikola Stanchev, "Communication Technologies for Smart Microgrid", in Proceeding of IEEE PES Conference, Washington DC, Jan 2012		✓