1. REPORT ON RESEARCH ACTIVITIES – YEAR 5

1.1 Survey analysis: Are perceptions of wind turbines related to reported health?

This research explored the relationship between reported health effects and psychosocial factors. The data was collected from a cross-sectional survey performed in eight Ontario communities with wind turbines in February 2013. This ORC-RETH survey "Quality of Life and Renewable Energy Technologies Study" incorporated validated scales and a number of questions to explore the unique context of wind turbine development in Ontario.

First, exploratory factor analysis was used to find relationships between survey questions dealing with perceptions of wind turbines. Survey questions that were highly correlated were grouped and referred to as "factors" which represent relevant research constructs. Second, these factors were compared to health outcomes reported in the survey using linear regression analysis. These health outcomes were satisfaction with life, sleep quality, mental health, and physical health.

These findings indicate that there are relationships between psychosocial factors, perceptions, and opinions of wind turbines and self-reported health, highlighting the complex psychosocial relationship between wind turbine exposure and health. The implication of this research for theory is that the relationship between wind turbine development and health effects may be mediated by perceptions of wind turbines. This study was the first of its kind to establish a relationship between mental and physical health status and concerns about the impact of wind turbines on health and environment.

1.2 Case study: experiences with development and suggestions for policy and decision-making processes

This research is an ongoing interview-based constant-comparison case study within a grounded theory approach involving local players in eight Ontario communities with wind turbines. Interviews are currently underway and are expected to be complete by December 2015. The research will capture experiences with wind turbines to determine which characteristics of development led to acceptance or opposition towards wind turbines, and to utilize the greater understanding of these experiences constructively to suggest improvements to the development process and add to energy planning theory.

The potential participants will be selected using the same stratified criterion sampling approach used for the epidemiological study of wind turbines and will select the same eight counties in Ontario. The potential participants will be mayors, MPPs (members of provincial parliament), provincial-level civil servants, and members of the community. Community member participants will be selected based on their "position" with respect to wind turbines. In each community, one concerned citizen and one "less concerned" citizen who may define themselves as a proponent, neutral, or "less concerned" compared to some community members who may be actively engaged in this debate. It is expected that these participants will give insight into the experience of wind turbine development in their community and their expectations of land-use development in their community. Community members will offer knowledge about what factors of wind turbine development are the sources of negative sentiment or opposition among local communities.

Interviews are taking place over the phone, last for approximately 60-90 minutes, and are recorded with the participant's permission. Some of the open-ended interview questions are as follows:

- What was your experience like leading up to the development and operation of the wind turbines?
- What have your experiences been like since the wind turbines were developed?
- What are some of the negative aspects of wind turbines?

    - What about ways wind turbine development has created problems in your community?
    - Do these problems impact your position on wind turbine development?
- How do other energy sources compare to wind on these aspects? (list each: Hydro, Solar, Nuclear, Gas, Wind, Solar, Coal)
- If we were to start over, how would you have implemented or developed wind energy in your community?

Once interviews are completed and thematic analysis of the data has been done, member checking will occur so that participants can review what they've said and whether the researcher has appropriately expressed their views. Participants will be emailed (or mailed) a document to review and a follow-up discussion will occur over Skype. After the member-checking occurs, feedback letters will be sent to the participants and they will be given the option to receive a draft of the study findings before publication. Interviews are expected to be complete by December 2015 with a manuscript prepared for submission by winter 2016.

1.3 Investigation of the Effects of Wind Turbine Noise Exposure Level on Sleep Disturbance

This is the first pre-post field study objectively measuring noise from wind turbines and its impact on sleep. By assessing physiological measures and sound pressure levels within the bedrooms of residents living near wind turbines, this research has objectively measured the noise to which individuals are exposed and assessed sleep quality using a polysomnography, a gold-standard measure.

Residents in the vicinity of a planned wind turbine installation were invited to participate in the study. Data collection involved the completion of a survey used in previous field studies of wind turbine health effects, both before and after the turbines were operational, as well as participation in comprehensive pre-post sleep studies. The impacts of wind turbine noise on annoyance, sleep, general health, and quality of life were determined from questionnaires as well as follow-up health assessment measures. Many of the limitations of previous studies which include cross sectional design, self-reported symptoms, subjective measurements of sleep, and limited ability to control for confounding factors were addressed by this study design.

Sleep-related physiologic signals were obtained by six electroencephalograms (EEGs) (C3/A2-C4/A1, O3/A2-O4/A1, F3/A2-F4/A1), right and left electrooculograms (EOGs), five electromyograms (submental, anterior tibialis) (EMGs), and left and right electrocardiograms (ECGs). In order to screen for breathing-related sleep disorders such as central or obstructive sleep apnea as well as periodic leg movements, the following data were also collected: finger pulse rate, oxygen saturation (finger pulse oximeter), nasal air flow (nasal cannula), respiratory movements (two piezoelectric belts), body position, and leg movements. Figure 1, a hypnogram, obtained by plotting different stages of sleep against the sleep time, shows the structure of sleep of the subject under study. Figure 2 also shows sleeper's reactions to a single noise event at distance of 508.06m from the turbine.

At two locations, varying each night, indoor noise was measured for a total of 16 nights before and 16 nights after operation of the turbines. In total 64 sets of data were collected. For each night and each location, noise data was recorded for 10 hours. The total time of noise measurement for the study was 640 hours. Z-weighted and A-weighted parameters were measured for each night. Figure 3 shows amplitude modulation of the wind turbine noise. The extensive data set of simultaneous sleep and noise signals are under detailed analysis and findings will be submitted for publication when the analyses are complete.

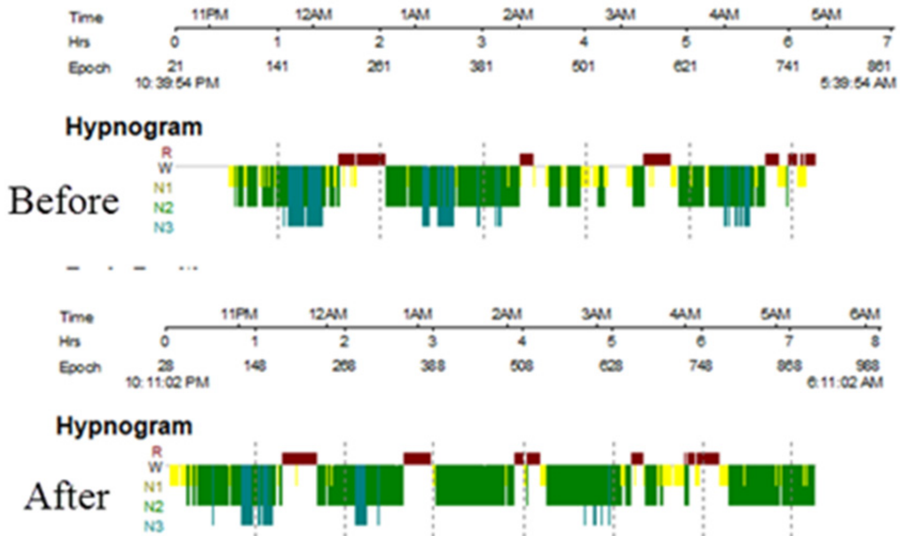

Figure 1: Hypnogram of the participant in field study

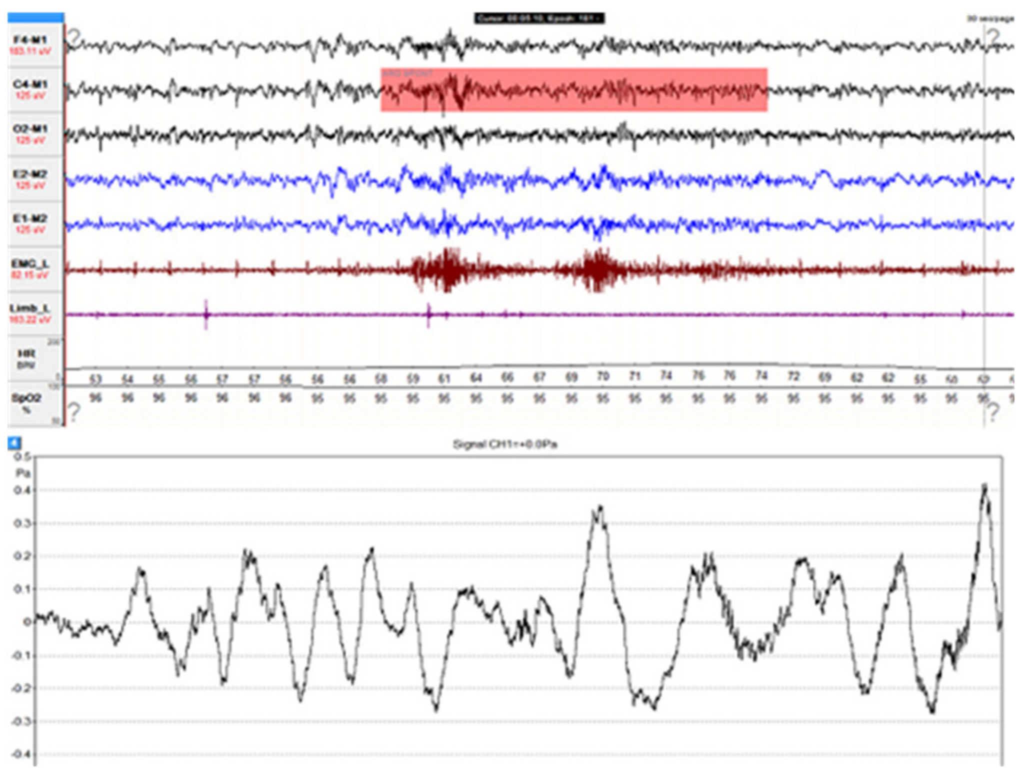

Figure 2: Sleeper's reactions to a single noise event at distance of 508.06m from the turbine

Initial findings show that participants had worse sleep after the wind turbines were operational as evidenced by the significantly poorer scores in sleep measures derived from the questionnaire data. Statistical data analyses are being conducted to determine the relationships of other independent variables with sleep quality to understand what factors are underlying this association. Findings derived from questionnaire data also showed that, after wind turbines became operational, the participants had lower self-reported general life satisfaction and mental health but their physical health was unchanged. Further statistical modeling of these data is also underway.

In our previously reported study of 4876 residents living near wind turbines in eight communities, we had examined dose-response relationships to provide evidence to support decisions around appropriate setback distances. In that study, based on questionnaire data, people living closer to wind turbines reported vertigo more frequently and poorer quality sleep. In our current sleep studies we are able to look at dose-response relationships for noise and dependent variables derived from polysomnography as well as from questionnaires. A total of 640 night-hours of indoor noise measurement on 32 nights were performed, at different distances and locations, before and after turbine operation.

The linked noise and polysomnographic data are currently being analyzed to examine dose-response relationships.

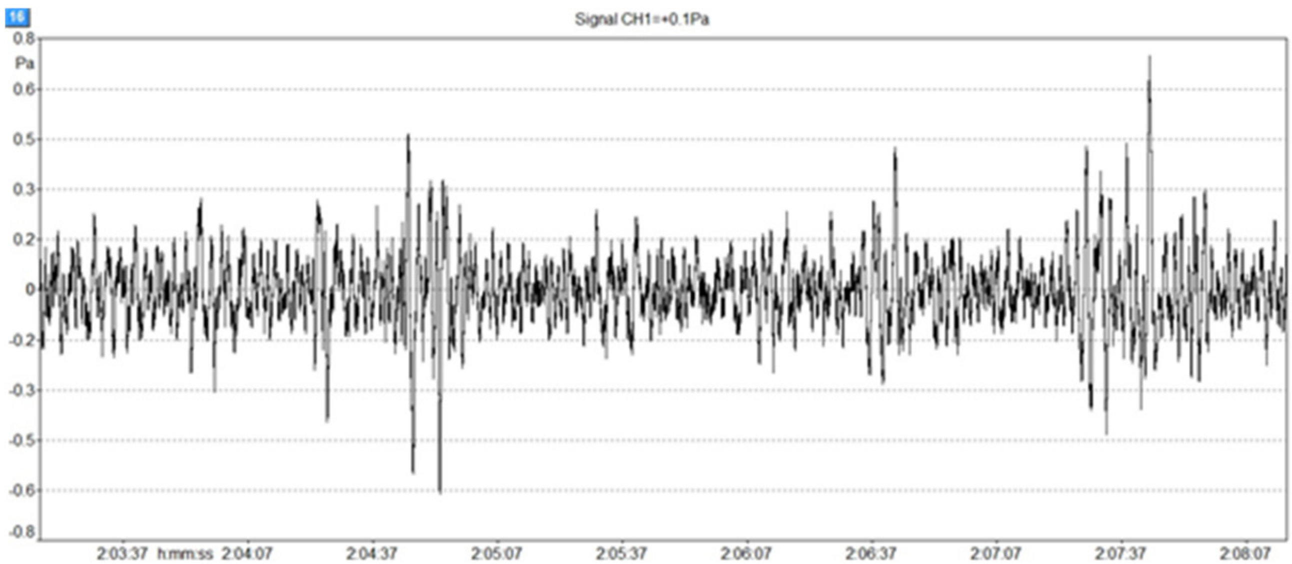

Figure 3: Time variation of turbine noise, indoors, 550m distant, showing amplitude modulation at 2am inside the bedroom

1.4 Exploring the socioeconomic composition of wind farm communities in Ontario: Implications for wind farm planning and policy

This research explored the socioeconomic composition of sixteen wind farm communities in Ontario, Canada, for wind farms commissioned between 2006 and 2012. Past research has shown that wind farms are disproportionately developed in socioeconomically disadvantaged areas and that socioeconomic factors influence wind farm support, an important factor in wind farm planning.

This research finds that wind farm communities do not exhibit characteristics of disadvantage compared to host counties. Investigating the association between when wind farms were commissioned and community-scale characteristics, this research observes that communities with wind farms operational before 2009 had significantly lower median income compared to communities with wind farms operational after 2009. This provides one perspective on how community-scale characteristics may shape wind farm planning, specifically the influence of local opposition and financial incentives on the location of wind farm developments. The research findings will appear in the Canadian Journal of Urban Research in 2016.

1.5 Synthesis of safer, and environment-friendly quantum dots materials for future photovoltaic devices

Among the materials considered for application towards third generation photovoltaic (PV) devices, quantum dots (QDs) stand out due to their potential to increase the efficiency of PV devices. The optical and electrical properties of quantum dots can be tuned by controlling their size, surface charge, concentration, quantum yield, and surface coating, making them advantageous for PV applications. The most prevalent materials that have been used to synthesize QDs are cadmium and lead, but the use of such compounds may pose toxicity and safety challenges when it comes to large scale processing for PV technology. Moreover, common synthesis methods require sensitive, precise injection of volatile and reactive materials, which are difficult to scale up for mass production.

A simple and scalable synthesis process for non-toxic Copper Indium Sulfide (CIS) QDs has been developed as a safer alternative to carcinogenic cadmium and lead based QDs. In addition to being a toxicologically favorable option, CIS quantum dots can be produced with high quantum yield, and the ability to cover a wide range of the solar photon spectrum. Organometallic synthesis methods were used to produce the CIS QDs without the complexity of traditional injection-based techniques. The synthesis of QDs was carried out under an oxygen and moisture free atmosphere using Schlenk line technique. A condenser was added to the setup to condensate the escaped fumes back into the flask. The cold trap captures and densifies any fume before reaching to the vacuum line connected to exhaust. The synthesized CIS core QDs were over coated with zinc sulfide (ZnS), resulting in surface passivated core/shell CIS/ZnS QD structures with enhanced photoluminescence (PL) efficiency and stability.

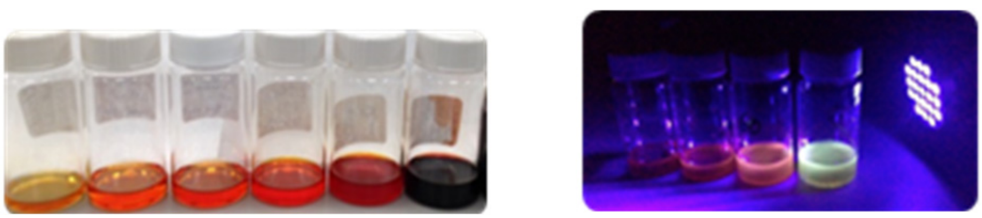

Figure 4: Solutions containing the synthesized CIS QDs of different sizes extracted at different growth times before (left,) and after (right), illumination with ultraviolet light.

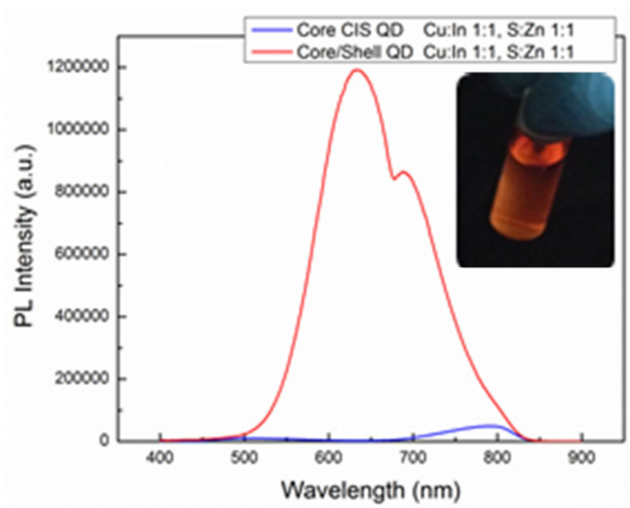

Figure 5: Photoluminescence (PL) spectra of the synthesized CIS-core (blue,) and CIS/ZnS core/shell (red), quantum dots. The inset shows the red-shifted glow of the QD solution when illuminated by UV light.

1.6 Toxicological assessment of nanoparticles in processing tools and environments

Despite the undeniable role of nanotechnology in future technologies, safety procedures concerning nanoparticles and nanomaterials need to be studied in depth. There is still some degree of incompleteness of environmental health and safety (EHS) protocols to govern work with nanomaterials and nanoparticles (NPs). Although quantum dots (QDs) and nanoparticles are widely investigated for a variety of applications including imaging, light emitting diodes (LEDs), and photovoltaics (PV), the potential toxicological implications of technology scale-up on processing environments not fully understood.

Due to QDs' ability to increase efficiency of PV devices, QD solar cells are a significant area of focus among researchers. Cadmium (Cd) is the most popular material used for QD synthesis, forming the basis of commonly found QDs such as cadmium selenide (CdSe), cadmium sulfide (CdS), and cadmium telluride (CdTe). However, the known toxicological nature of cadmium raises safety concerns for researchers working with QD-based devices. Although studies on the toxicological effects of quantum dots can be found in literature, most safety studies are based on the use of QDs as a fluorescent sensor or in bioimaging, which may not be relevant to device processing due to the differences in characteristics of the quantum dots used, as well as differences in conditions for exposure. Therefore, studies were designed to specifically investigate the risk of environmental exposure in device processing during synthesis, implementation, and testing. The goal of these ongoing studies was to investigate sublethal conditions for QD exposure, characteristics that contributed to toxicity, and procedures and precautions to help mitigate exposure.

Although protective measures such as fume hoods and glove boxes are used when handling QDs in solution form, once formed as solid QD films they are assumed to be stable. In one study, a layer of adsorbent gold (Au) nanoparticles were deposited in the vicinity of QD layers. As well, samples were placed in different processing environments for CdSe QD detection, to determine the possibility of QD aerosolization. Inductively Coupled Plasma (ICP) Spectroscopy was used in this study to detect Cd and Se. As shown in Figure 6, the ICP results showed aerosolization of Cd and Se. This type of studies allows us to investigate different processing environments and to establish the protocols for materials handling.

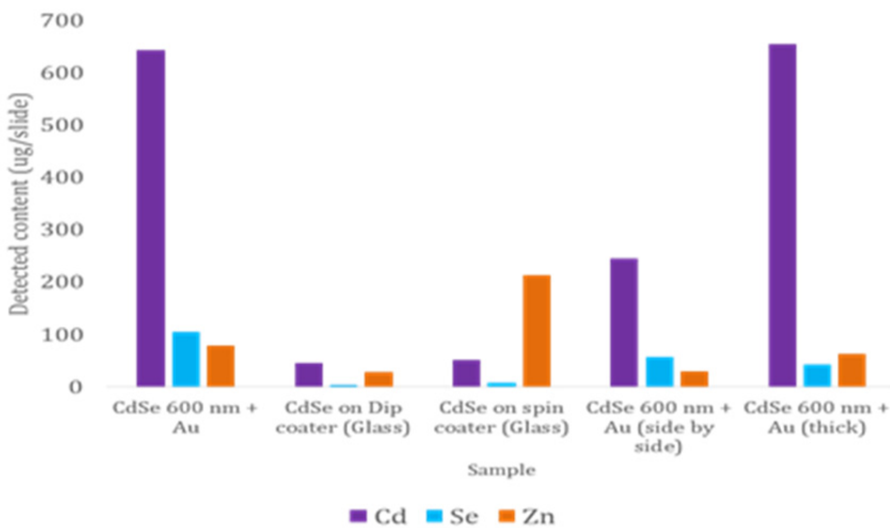

Figure 6: ICP spectroscopy results for samples placed in different PV processing stages for the detection of aerosolized Cd and Se.

In another study approach, in collaboration with the Department of Biology, we used *HeLa* cells as an in-vitro model to determine the potential cytotoxic effects on QDs on mammalian cells. We used two different methodologies to study HeLa exposure to QDs as a means to compare different QD materials. Initial results indicate the CIS QDs are not likely to induce cell death. The study is ongoing.

1.7 Addressing the Challenges in Grid Integration of Renewable Energy Sources as Distributed Generators

A study has been carried out to analyze the challenges in the grid integration of different and hybrid renewable energy sources as distributed generators (DG) of electricity. The PLECS computer simulation software for power electronics (from Plexim Inc.) was used for the study. In the first part of the study power flow modeling was used to study the overloading issue. In a case example, by considering a substation with radial feeders various loads were modeled before and after connection of a wind turbine. The important result is the estimation of the DG's effect on the traditional (i.e. non-DG) flow of real and reactive power from higher to lower voltage levels. In any hybrid systems, prior to installation of the DGs power flow studies along with the loading and generation profiles are necessary.

Modifications to protection systems were also studied by simulating the effect of installing DG on the existent fuse protection of the distribution system. The fault currents can be altered by the added DGs. Results showed that both the sizing of the fuses and the tie-up location of the DG have an influence for reliable operation.

The effect on voltage regulation when DGs get connected and disconnected to the distribution system was also analyzed. A simulation example is shown in Figure 7, where a distribution line is shown with eight equal loads and with equal spacing at various nodes along the line that is fed from a transformer with a load tap changer (LTC). The voltages at the nodes were investigated when DG is connected and disconnected. When more DGs are connected the voltages would not remain the acceptable 5% range of variation. It was observed that voltage regulation will improve more if the DG unit is installed further from the source.

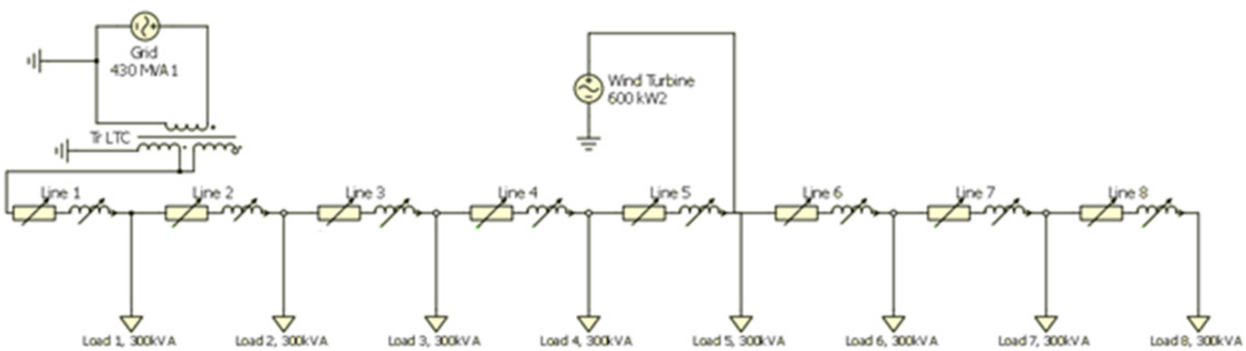

Figure 7: An example of a distribution line modeled in PLECS© simulation package for investigation of voltage level effects from DG.

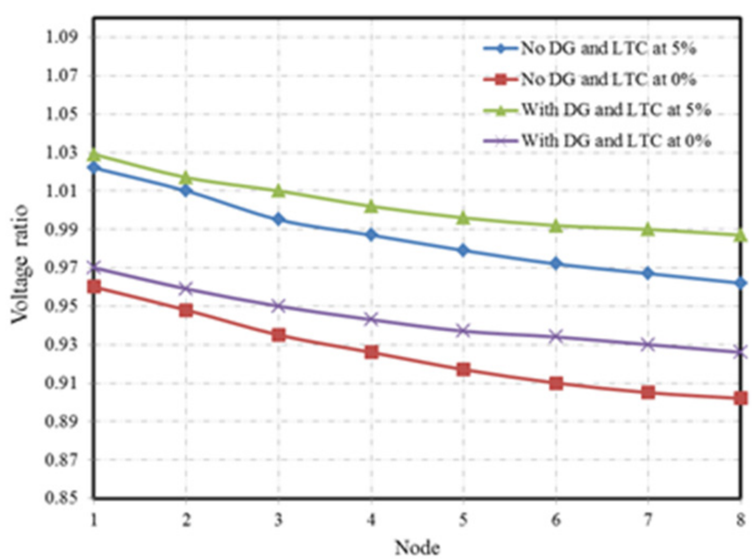

Figure 8: The voltage profile of the simulated model with and without DG connected at 0% and 5% LTC tap.

2. PUBLICATIONS – YEAR 5

Published/Accepted Papers:

- B. Janfeshan, B. Sadeghimakki, N. Mohammad, and S. Sivoththaman, "ZnO nanowire arrays synthesized on ZnO and GaN films for photovoltaic and light-emitting devices", *SPIE Journal of Photonics for Energy,* vol.4, pp.041599 1-10, 2014.
- F. Liu, S. Sivoththaman, and Z-C Tan, "Solvent Extraction of 5-HMF from Simulated Hydrothermal Conversion Product", *Sustainable Environment Research,* vol.24, no.2, pp.149-157, 2014.
- M. Moradi and S. Sivoththaman, "Design and Modeling of a Chevron MEMS Strain Sensor with High Linearity and Sensitivity", IEEE Sensors Journal, vol.15, pp.4791-4798, 2015.
- M. Moradi and S. Sivoththaman, "MEMS Multisensor Intelligent Damage Detection for Wind Turbines", *IEEE Sensors Journal,* vol.15, pp.1437-1444, 2015.
- S. Fast, W. Mabee, J. Baxter, T. Christidis, L. Driver, S.Hill, J. McMurtry, and M. Tomkow, "Navigating the social friction of wind energy development: Lessons from the last five years of wind energy development in Ontario, Canada", *Nature Energy,* Accepted (2015).
- T. Christidis, G. Lewis, P. Bigelow, and C. Paller, "A Factor Analysis of Psychosocial Factors related to Industrial Wind Turbines and their relationship with Sleep", *Mental and Physical Health. Quality of Life Research,* Accepted (2015).
- L. Jalali and P. Bigelow, "Current status and future trends of wireless and mobile health technologies in sleep medicine", pp.129-144, Book Chapter in *Moblie Health: A Technology Roadmap,* Springer Series in Bio-/Neuroinformatics 5, ISBN 978-3-319-12816-0. (2015).
- B. Sadeghimakki, Y. Zheng, N. Jahed, P. Pham, A. Babujee, N. Bols, and S. Sivoththaman, "Toxicity and Safety Aspects of Nanoparticle Spread in Third Generation Photovoltaic Device Processing Environments", *Proc. 42nd IEEE Photovoltaic Specialists Conference* (New Orleans, June 2015), DOI 10.1109/PVSC.2015.7356390 pp.1-6.
- N. Jahed, M. Mahmoudysepehr and S. Sivoththaman, "Highly Conductive TCO by RF Sputtering of Al:ZnO for Thin Film Photovoltaics", *Proc. 42nh IEEE Photovoltaic Specialists Conference* (New Orleans, June 2015), 10.1109/PVSC.2015.7356300, pp.1-4.
- H. Siboni, B. Sadeghimakki, S. Sivoththaman, H. Aziz, "Very High Brightness Quantum Dot Light-Emitting Devices via Enhanced Energy Transfer from a Phosphorescent Sensitizer", *ACS Applied Materials and Interfaces,* vol.7, pp.25828-25834, 2015.
- C. Paller, T. Christidis,P. Bigelow,J. Law, J. Aramini, and S. Majowicz, "Delivering environmental health research surveys to precise geographic locations in rural Ontario communities using Geographic Information Systems and Canada Post AdMail", *Canadian Journal of Rural Medicine,* In Press.
- M. Quick, J. Law, T. Christidis, and C. Paller, "Exploring the socioeconomic composition of wind farm communities in Ontario: Implications for wind farm planning and policy", *Canadian Journal of Urban Research,* Accepted (2015).

Submitted Papers:

- A. Hegazy, N. Kinadjan, B. Sadeghimakki, S. Sivoththaman, N. Allam, and E. Prouzet," Decoupling crystallinity and size of TiO_2 nanoparticles for optimized photoanodes in Dye-Sensitized Solar Cells", submitted to *ACS Applied Materials and Interfaces*.

- C. Baldus-Jeursen, R. Tarighat, and S. Sivoththaman, "Optical and Electrical Characterization of Crystalline Silicon Films Formed by Rapid Thermal Annealing of Amorphous Silicon", submitted to *Thin Solid Films*.
- T. Christidis, G. Lewis, and P. Bigelow, "Energy Transitions and Planning: The Mismatch of Participatory Planning with Electricity Generation Decision-Making".
- C. Paller, T. Christidis, P. Bigelow, J. Law, J. Aramini, and S. Majowicz, "Health effects and exposure to industrial wind turbines: examining possible dose-response relationships".

Posters/Presentations:

- T. Christidis, "Wind Turbines in Ontario: Perceptions, Health Effects, and New Approaches to Development", Poster presented at the *Energy Council of Canada 2015 Canadian Energy Summit* (Toronto, ON, May 2015).
- T. Christidis, G. Lewis, and P. Bigelow, "Do perceptions of wind turbines and psychosocial factors relate to reported health effects?", Poster presented at the *Ontario and Canada Research Chairs Symposium* (Toronto, ON, April 2015).
- T. Christidis, G. Lewis, and P. Bigelow, "Understanding support and opposition to wind turbine development and assessing possible steps for future development", Poster presented at the *Ontario and Canada Research Chairs Symposium* (Toronto, ON, April 2015).
- T. Christidis, "Research Findings from the Ontario Research Chair in Renewable Energy Technologies and Health", Social and Community Aspects of Wind Power in Ontario Workshop (Kingston, ON, February 2015).
- B. Janfeshan and S. Sivoththaman, "Fabrication of ZnO Nanowire Based Quantum Dot Sensitized Solar Cells and Analysis of Device Parameters", 17th Canadian Semiconductor Science and Technology Conference (Sherbrooke, QC, August 2015).

3. CONFERENCES / MEETINGS ATTENDED – YEAR 5

- 42nd IEEE Photovoltaic Specialists Conference, New Orleans (LA), June 2015.
- Energy Council of Canada 2015 Canadian Energy Summit, Toronto (ON), May 2015.
- Ontario and Canada Research Chairs Symposium, Toronto (ON), April 2015.
- Social and Community Aspects of Wind Power in Ontario Workshop, Kingston (ON), February 2015.
- 17th Canadian Semiconductor Science and Technology Conference, Sherbrooke (QC), August 2015.

4. NUMBER OF STUDENTS SUPERVISED – YEAR 5

Doctoral Students:	**7** Electrical and Computer Engineering: 5 School of Applied Health Sciences and Health Systems: 2
Master's Students:	**1** Electrical and Computer Engineering: 1
Thesis completions:	**2** Masters thesis: 0 Doctoral thesis: 2

5. MEMBERS OF THE RESEARCH TEAM (other than graduate students) – YEAR 5

Faculty Members*:

Dr. Siva Sivoththaman, Professor, Electrical and Computer Engineering
Dr. Philip Bigelow, Associate Professor, School of Public Health and Health Systems
Dr. Stephen McColl, Associate Professor Emeritus, School of Public Health and Health Systems
Dr. John Vanderkooy, Distinguished Professor Emeritus, Dept. of Physics and Astronomy
Dr. Laurie Hoffman-Goetz, Professor Emerita, School of Public Health and Health Systems
Dr. Shannon E. Majowicz, Assistant Professor, School of Public Health and Health Systems
Dr. Jane Law, Associate Professor, School of Planning
Dr. Fue-Sang Lien, Professor, Mechanical and Mechatronics Engineering
Dr. Zhongchao Tan, Associate Professor, Mechanical and Mechatronics Engineering

*The team members also collaborated with several other faculty members on campus.

Post-doctoral Fellows:

Dr. Bahareh Sadeghimakki, Electrical and Computer Engineering
Dr. Roohollah Tarighat, Electrical and Computer Engineering

Technical Support:

Mr. Joseph Street, Facility Manager, Centre for Advanced Photovoltaic Devices and Systems
Ms. Julia Guan, Research Technician, School of Public Health and Health Systems

6. LINKAGES AND COLLABORATIONS – YEAR 5

- A doctoral student is collaborating with attendees from the Queen's Wind Workshop to co-author a paper describing wind turbine development in Ontario. Co-authors include community members, developers, and researchers from a variety of disciplines from universities across Ontario.

- Team members continued to work collaboratively with researchers from Ryerson University and a local Health Unit on noise measurements and health studies.

- A collaboration has been established with the Department of Biology at the University of Waterloo in order to assess the toxicity and establish safe of processing conditions for nano-materials in photovoltaic cell development.

7. MEASURES TO PUBLISIZE THE RESEARCH – YEAR 5

- Research results are published in peer-reviewed journals or in conference proceedings (12 papers in year-5).

- Team members also make poster/oral presentations in symposia and workshops. The following are some of the venues where presentations were made in year-5:
  42nd IEEE Photovoltaic Specialists Conference
  Energy Council of Canada 2015 Canadian Energy Summit
  Ontario and Canada Research Chairs Symposium
  Social and Community Aspects of Wind Power in Ontario Workshop
  17th Canadian Semiconductor Science and Technology Conference

- Completed graduate research works are also documented in the form of theses. The following theses were completed in year-5:

  "Heterojunction Photovoltaic Devices by Rapid Thermal Annealing of Thin Amorphous Silicon Films" (PhD Thesis)

  "Development of Zinc Oxide Nanowires and Quantum Dot Incorporation for Photovoltaic Applications" (PhDs Thesis)

- Other instances of public communication (year-5):

  A doctoral student was interviewed by CBC Radio in Ottawa regarding wind turbine research.