EEA 2016
Professional Development Award Report

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Introduction

As the EEA 2016 Professional Development Award recipient, I attended the GreenTech 2017 Conference, held in Marriott Tech Center Denver, Colorado, USA, between 29 and 31 March 2017.

The 2017 Green-Tech Conference was the major event for the green-tech development. It attracted not only key players and the most innovative green-tech companies, but also a large number of tech-savvy professionals from electricity industry and other utilities. In addition, Colorado is the hub for R&D in green-tech industries and companies specializing in sustainable development, including the National Renewable Energy Lab (NREL), National Institute of Standards and Technology (NIST), Colorado Clean Energy Cluster, Vestas Wind Turbines and many others.

The Conference was sponsored by, IEEE, IEE-PES, IEEE-USA, NREL, Western Area Power Administration, Regis University, and Snyder Industries. Having such big-name sponsors tells enough about the strategic relevance of the Conference to the electricity industry. IEEE recognizes that the green technologies will have a profound effect on the electricity sector.

The GREENTECH 2017 conference provided me a unique opportunity to interact with business and technology leaders, and to network with colleagues, customers, and suppliers from both the green-tech and traditional electricity industry. It was a single chance to see and learn about the latest green-tech innovations in one place and to study a potential impact on NZ electricity supply industry.

A brief outline of the Conference

Venue: Denver Technology Center, Marriott Hotel Denver, Colorado, USA
Dates: 29 – 31 March 2017
Main Sponsors: IEEE and NREL
Delegates: approx. 300; most delegates and presenters were high-profile professionals working in traditional networks/grids, R&D institutions, and or/with renewables

Keynote sessions:

- A keynote session on day 1 (30 March) with two speakers
- A keynote panel on day 2 (31 March) with three panelists

Panel sessions:

- Five separate panel sessions with 20 panelists
- Each panelist presented a full paper at the beginning of its panel session

Paper session topics:

- 156 authors presented 187 papers (oral and/or poster; some of them had 2 papers)
- 57 oral paper presentations in 13 Paper sessions:
    - Session #1 - Control of Distributed Energy Resources
    - Session #2 - Power Electronics for Microgrid Applications
    - Session #3 - Interconnection, Capacity, and Future of Renewable Energy
    - Session #4 - Power Electronics Control for Utility Integration
    - Session #5 - Energy Management and Power Quality
    - Session #6 - Renewable Energy Systems
    - Session #7 - Emerging Power Systems and Real Time Dynamics
    - Session #8 - Advanced Renewable Energy Power Systems
    - Session #9 - Photovoltaics Power Systems
    - Session #10 - Security and Critical Analysis of Power Distribution Systems

- Session #11 - Energy Storage for Distributed Generation
- Session #12 - Interconnection of Wind Energy Systems
- Session #13 - Renewable Energy Interaction with Data, Wireless Communication, and Future Trends

Workshops and Tours (held on 29 March 2017):

- Full Day Industry Tour (National Renewable Energy Lab (NREL) Facility Tour - Tour of the NREL campus and affiliated sites including Energy System Integration Facility (ESIF)& National Wind Technology Center (NWTC); or
- Full Day Energy Workshop (Distributed Energy Resources - Understanding the Current Challenges and Opportunities – NREL; or
- Full Day Continuing Education Training (2017 NESC® Code Changes - National Electrical Safety Code®)

A summary of sessions attended and related activities undertaken during the Conference

My main objective at the Conference was to learn more in the following areas:

- How will renewables impact NZ electricity industry grid and networks in terms of:
  - Physical security - Direct impact of renewables on traditional networks and potential challenges, issues or damages to the grid/network infrastructure
  - Cyber Security - Network security in light of interconnections with various renewable energy sources and relating integration systems
  - Innovations or 'good thinking' that could be useful for New Zealand electricity industry

- Technical tour to NREL:
  - Latest in renewable energy innovations
  - Computer modeling and testing of real physical processes using a supercomputer
  - Test labs for simulation and real-time testing of electricity grids and networks
  - Possible use of NREL facilities by third parties e.g. by New Zealand electricity industry

I have consequently selected and attended those Conference sessions and Industry tour which I believe have the most relevance to New Zealand electricity industry future, as follows:

- Two keynote sessions
- 12 panelist's paper presentations
- 7 'ordinary' paper presentations (technical papers)
- NREL Technical Tour

The Conference keynote and panel sessions, and technical presentations were at cutting edge of the clean energy R&D and its impact on the future of energy and electricity industry.

In addition, what I saw and heard during the NREL Tour was fascinating. Unfortunately, we were not allowed to take any photos except wind turbines. This is in an area which is normally closed to the public due to reasons of national security and other highly classified R&D activities.

On the following pages, I will summarise the main points, the learning and my impressions from the five of selected conference sessions and the NREL technical tour.

Conference session highlights

1. Keynote - Martin Keller, Ph.D., NREL Director

Key points:
More than half of CO_2 emissions in the USA come from industrial and transportation sector. Energy consumption is predicted to grow 56% by 2040. The USA can expect very high renewable electricity penetration. 80% of total US electricity generation by 2050 can be sourced from renewable technologies which are commercially available today and in combination with the more flexible electric systems.

Solar R&D:
- Globally, solar energy grew by more than 50% each year since 2011
- The cost of solar energy has fallen to less than $1/watt for solar module, pre-installation
- If all roofs in the USA are covered with solar panels, the annual electricity generation would equate to 39% of total national energy needs
- NREL is developing Next-Gen Si Solar cells with high efficiency (>23%)
- NREL is also developing Gallium Indium Phosphide solar cells and have already demonstrated world record 29.8% efficiency
- However, at this stage the most promising is the flexible and transparent thin-film solar cell based on Cadmium Telluride (CdTe), developed in collaboration with First Solar; it currently has 16.4% efficiency and it will be applicable for next-generation building technologies
- Perovskite solar cells are even more promising (material is stable and easy to manufacture)

Wind R&D:
- Current costs of electricity generated by the wind is 4-7 cents/kWh
- The USA has 74 GW installed capacity (2nd in the world), which covers 5.5% of total demand
- NREL's National Wind Technology Center (NWTC) has manufactured on site a 140 m tall tower, and 70 m long blades with 3D-printed blade molds

The list of new cutting edge technologies that NREL is working on is impressive. Most of them are home grown. Dr. Keler has also talked about NREL campus and affiliated sites – RSFM, ESIF, and NWTC. I will cover the NREL campus in the summary of Technical Tour section of this report.

2. Keynote - Samuel F Baldwin, Ph.D., CTO of DOE (Department of Energy)

Key points:
Dr. Baldwin talked about energy challenges (Progress and prospects of renewable energy technologies, Grid integration, and End-use energy sectors)

Security:
- Physical and Cybersecurity (potential damage to energy infrastructure)
- Availability of energy supplies, critical materials, equipment
- Conflict-related security impacting global energy supplies

Economics:
- Energy prices, price volatility, import costs
- Energy Finance, Energy system investments, and Disruption costs

Environmental impact: Water and Land; Atmosphere pollutants

3. Panel session – "Big Data Analytics for Power Systems"

This session had 4 panelists who presented their papers on data management and big data analytics.

Challenges:
There is ever increasing number of intelligent/smart devices and renewables connected to conventional networks which collect a lot of data. The following six challenges have been identified in the Paper "Data Analytics and Data Architecture for Operations of the Future Grids" by Kevin Tomsovic, University of Tennessee:

- Volume – several orders of magnitude increase in data
- Velocity – high-speed real-time streaming data
- Veracity – data uncertainty
- Variety – diverse data repositories
- Visibility – fundamental privacy, security and provenance concerns
- Value – variety of cost structures of data access

The question is: What do we do with that Data? Do we analyse it and use it, or just collect it?

Example 1 - Intelligent Reclosers:
Mr. Tomsovic has used an example from his previous paper "Some Event Analysis for IntelliRupter PulseCloser through Sparse Reconstruction". Here are the basics on how reclosers work:

- Approx. 75-90% of the total number of faults are temporary, last for a few cycles only and can be cleared by a conventional recloser
- In case of permanent faults, every time a conventional recloser switches after an event, it stresses the equipment with fault current and produces voltage sag on adjacent feeders
- IntelliRupter injects a low-energy pulse into the line, verifies that the line is clear of faults before a reclosing operation and significantly reduces stress on equipment and voltage sags

However, not many companies realise that a smart device like IntelliRupter, in addition to its basic operation, offers much more useful data which can be analysed and used for other purposes:

- Both sides of these devices have accurate voltage and current sensors that provide high-resolution event data (time-stamped)
- Recorded data can be used for:
    - Fault classification
    - Estimation of the fault location
    - Verification of proper operation of the device

Mr. Tomsovic then talked about his "sparse reconstruction method" for analysing this useful data.

Example 2 - Smart meters:
Power Zhao, Ph.D., P.E., in his paper "Digital Transformation in Power Utilities" has identified several challenges with big data analytics in Power Utilities. The most obvious one is usability of Smart Meter Data and Advanced Metering Infrastructure e.g. in addition to 'Switch' and 'Measure' functions of Smart Meters, what do we understand about other functions and do we utilise data from smart meters for data analytics purposes?

Key messages from this panel session:

- With the ever increasing number of intelligent/smart devices and renewables connected to conventional networks, there will be more and more data
- However, it is not about how much data you have - it is about the quality of data and what do you do with it
- The next 'big thing' for a proper integration of renewables and smart devices with conventional networks will be the Big Data Analytics.

Questions, challenges, and opportunities for the New Zealand electricity supply industry:

- How many New Zealand Power Companies collect that readily available data from smart devices like smart meters and smart switches (e.g. IntelliRupters), and how many companies analyse that data and use it to improve their network reliability and safety?
- Are we ready for the Big Data Analytics?

4. Panel Paper – “NREL Cybersecurity R&D Briefing” by Erfan Ibrahim, Ph.D., Director of Cyber-Physical Systems Security & Resilience Center

Challenge:
Renewables and other add-on infrastructure create new cybersecurity vulnerabilities on the grid.
In terms of cyber security, the grid used to be a ‘fortress’; however, it is now just an ‘ordinary building’ with many ‘holes’ through different additional infrastructure like:

- Transmission EMS
- Power Generation and Distribution SCADA
- Photovoltaics and Wind energy
- Electric storage and EV charging
- Smart meters and smart home appliances

A cyber attack could penetrate any of so-called ‘smart devices’ (week points) within SCADA network and get to the Operations Center (e.g. through a smart meter, smart feeder switch, smart capacitor, microcontroller etc.). From the Operation Center, the attack could then easily take down a substation or spread out through the rest of the company network via the main server.

The traditional approach to cyber security is to lock-down everything e.g. implement a strict end-device level authentication and monitoring, encrypt all communications, and enforce protocols. However, this approach has limitations and doesn’t guarantee a defense against cyber-attacks e.g. it is reactive (hackers are always ahead of company’s defense systems), it requires too much memory, processing, and networking, and it requires constant upgrades of equipment which is very costly.

Solution:
NREL’s cybersecurity R&D key strategy is to limit damage from the start. It is a new, disruptive approach to system security based on several layers:

- Identify gaps in cyber security and resilience, and apply strict cyber hygiene
- Be selective in use of the third party off the shelf technologies
- Make it modular, scalable, and compatible with legacy and modern equipment right from the beginning and limit unnecessary upgrades
- Don’t be dependent on cyber security controls at the end device or protocol level

NREL’s approach is based on the following premises:

- Expect to be hacked - Encryption is not a magic bullet
- Compliance doesn’t automatically provide security or reliability
- Device and protocol level security is expensive, reactive and usually incomplete
- Situational awareness is critical; people are the weakest link
- Information sharing reduces the time for recovery

NREL Cybersecurity R&D key expertise:

- Power systems SCADA, Cybersecurity, Networking and Distributed energy resources
- Electric systems testing for cyber security and resilience (expandable to water, oil & gas, and thermal systems)
- NREL Cyber R&D Program Team has only 9 staff members and yet they manage to successfully protect a major R&D facility in the USA

A message from Dr. Ibrahim: "Align your business continuity with you cybersecurity".

<u>Challenges and opportunities for the New Zealand electricity supply industry:</u>

Currently, most IT departments make the same mistake as identified in Dr. Ibrahim's paper. Locking down everything in IT space and making a layer upon a layer of encryption, protocols, and strict authentication and monitoring don't guarantee a defense against cyber-attacks. In contrary, it can be very inefficient and unproductive, making difficult for a business to operate, while there are vulnerabilities lurking at back-doors from smart devices connected to the grid and networks.

After the session, I had a discussion with Dr. Ibrahim regarding the catastrophic fault of transmission lines and the state-wide blackout in South Australia in September last year. According to the AEMO report (Australian Energy Market Operator) which I received one day before the Conference, the main cause of SA transmission outage was an overly sensitive protection mechanism in some wind farms [1]. Although in this case no a cyber attack was involved, this is a good example of how exposed and vulnerable are the electricity grids and networks from renewable energy system interconnections, and how they can affect each other, even if there are no direct communication links. It should never happen that a glitch in a wind farm protection setting brings down the entire national grid. One can imagine what would happen if there was a cyber-attack through the wind farm protection and if it was connected to the grid system.

5. Technical Paper – "Transformer Aging Due to High Penetrations of PV, EV Charging, and Energy Storage Applications" by Kerry McBee, Ph.D., PE, California State University, Fresno

Challenge:
Effects of high penetration of photovoltaic systems (PV), energy storage (ES), and electric vehicles (EV) on power transformer aging.

Study method:
Mr. McBee has studied the impact of high penetration of PV, ES and EV systems on a power transformer load profile over the prolonged period of time. He has developed a transformer transient model based on the tested attributes of a 50MVA transformer. He has used the modeling methods from relevant IEEE standards. He has analysed the transformer aging under normal and emergency operations, taking into account the changes in daily load profile and harmonic distortions. The study was focused only on the aging of transformer oil and winding insulation paper.

Study findings:
Utilizing the model, Mr. McBee has identified the relationship between aging, harmonic distortion, and load profile characteristics associated with high penetration of PV, ES, and EV as follows:

- These systems can flatten the transformer's daily load profile and minimize the cooling down period for the paper insulation, which in turn can affect the unit's aging
- The increased volume of harmonic currents caused by power electronics of these systems can also impact transformer aging

Historically, power transformers have always had a cooling down period at some point during the day because of traditional cyclic load profile. However, high penetrations of PV, ES, and EV systems can flatten the transformer load profile and introduce a high harmonic content, which can lead to increased transformer losses and accelerated aging over a longer period. It can significantly reduce the transformer operational life expectancy. Under the normal operating conditions, the aging is driven by load profile, not harmonics. Under the emergency operating conditions, the aging is driven by harmonic distortions.

After the presentation, I had a discussion with Mr. McBee. He gave me some empirical data and his thoughts regarding the derating of transformers due to the high penetration of PV, ES and EV:

- Power transformers derating: 4.5% to 8.9%
- Power transformers derating in Colorado (USA) due to high altitude: up to 11.6%
- Distribution transformers - the expected derating should be much higher

Note that Mr. McBee did not study distribution transformers. However, he believes that the derating for these transformers due to the high penetration of PV, ES and EV could be much higher than for power transformers. I have also asked Mr. McBee about the possible effects of high penetration of PV, ES and EV on transformer internal contacts due to high harmonic content and increased parasitic capacitances e.g. on tap changer contacts. In his study, he hasn't given any consideration to the effects of harmonic distortions on internal contacts.

<u>Challenges and opportunities for the New Zealand electricity supply industry:</u>

Having in mind that transformers are high-value capital assets that have to pay back their cost over decades, this paper is highly relevant to long-term planning in NZ electricity industry. It directly addresses a potential issue with high penetration of PV, ES, and EV.

New Zealand Power companies should take into account the expected increased penetration of PV, ES and EV systems when identifying and calculating the peak capacity and the operational constraints of their substation power transformers. It may require derating of existing transformer capacity limits up to 10% in order to maintain its expected service life. It may also affect the long-term system planning and emergency operating procedures.

There is also a great opportunity for NZ electricity industry to conduct a study on:

- Effects of high penetration of PV, ES and EV on distribution transformer aging e.g. focusing on oil and insulation paper
- Effects of high harmonics from PV, ES and EV power electronics on distribution transformer internal contacts

(Note: I have a copy of this paper if somebody in NZ electricity industry is interested.)

A (political) flavour of the week at the GreenTech 2017 Conference

A remarkable coincidence between the USA Politics and Conference topics happened just one day before the Conference started. The new President of USA announced a decision to:

- Exit from Paris climate agreement and international efforts to curb global carbon emission
- Cut the tax credits and incentives for renewables in favour of fossil fuels (coal and oil)

This announcement flew in the face of keynote speakers and the Conference as a whole, sparking a hot discussion during the social time and networking hours. In summary, most delegates that I spoke believe that this decision will have a little or no effect on the renewables industry because:

- The industry is already mature and strong enough to survive, especially solar and wind
- In 2015 global new investment in renewables reached US$285.9 billion;
  Over the 12 years, the total amount committed globally has reached $2.3 trillion [2]
- Big companies like Tesla and Google have already made heavy investments in renewables
- Renewable generation costs continue to fall, particularly in solar photovoltaics
- Some less developed renewables like ocean wave may suffer
- However, it may even accelerate the development of some highly promising new technologies e.g. NREL may decide to focus all resources on Perovskite solar cells and stop the development of other less promising technologies

Technical Tour to NREL campus and affiliated sites

I have visited the following Research facilities. They are presented in the order of visit. Some sites were off limits to the public and visitors due to the current highly classified projects.

1. Research Support Facility Monitoring (RSFM)

RSFM provides daily and annual monitoring of NREL electricity generation and demand (load).
The electricity generation is mainly from solar photovoltaics.

Introduction:

- NREL is the leader in sustainability. Their facilities are Carbon-Neutral [3]. They try to minimize the use of energy, materials, and water while carrying out the R&D laboratory work on clean energy e.g. NREL buildings have only 27% glass
- NREL is the largest Net-Zero Energy Site in the USA e.g. the energy generated equals the energy consumed at a site [4]. In other words - local generation offsets the total load.
- Recycling everything e.g. NREL buildings made of reclaimed steel (64%), and other materials
- NREL have won 57 out of 100 USA technology awards since 1962

Solar Research Focus Areas:

Some advances have been made with traditional technologies:

- Conventional Silicon PV cells (with the best efficiency of 25.6%)
- Solar concentrators (produce hydrogen for fuel cells)

Major advances in efficiency have been made with new solar technologies:

- Perovskite solar cells (current efficiency limit approx. 31%)
- Gallium arsenide solar cells (current efficiency limit approx. 33%)
- Gallium Indium Phosphide Solar Cells
- Cadmium telluride (CdTe) thin-film solar cells
- Other thin-film solar cells based on amorphous silicon, copper gallium indium selenide

Some of the new solar cells have achieved more than 30% efficiency, but due to cost, they are still used only for NASA extra-terrestrial projects for space vehicles and concentrating PV systems.

Challenges and opportunities for the New Zealand electricity supply industry:

- The Research on new solar technologies is accelerating with highly promising results re efficiency. Once some technological barriers are overcome and the manufacturing costs become competitive, these new technologies will take over from traditional PVs
- This R&D could have a profound impact on conventional electricity networks/grids
- New Zealand utilities that have already adopted a solar approach into their business (or are planning to do so) should keep abreast with NREL current research and eventually tap into the leading-edge developments in NREL facilities. Although many parallel developments are happening elsewhere at Universities, the NREL is where the hard large scale testing is done.

2. Energy Systems Integration Facility (ESIF)

ESIF is focused on energy systems research, development, and demonstration (RD&D). It is a facility where new technologies are tested using state-of-the-art equipment and resources, providing support to energy system innovators. They perform power engineering research and test the integration of renewables into the electricity grid.

There are multiple labs under ESIF umbrella. Here are some of them which we were allowed to visit:
- High-Performance Computing (HPC) Data Center and Visualisation Lab
- System Performance Lab
- Energy Storage Lab
- Hydrogen Testing Lab
- Battery and Thermal Storage Material Lab
- Hardware-in-the-Loop at Megawatt Scale Power Lab

2.1 High-Performance Computing (HPC) Data Center and Visualisation Lab

Basic facts:
The National Renewable Energy Laboratory (NREL) provides High-Performance Computing (HPC) to support the Department of Energy (DOE) and Office of Energy Efficiency and Renewable Energy (EERE). In the heart of NREL's HPC system is the supercomputer Peregrine. It is the largest supercomputer in the world dedicated to advancing renewable energy and energy efficiency. The HPC system consists of Computing, Storage, and 3D Visualization.

Computing:
Peregrine has almost 60,000 Intel processors and a processing speed of approx. 2.2 Petaflops. In simple terms - it is equal to 22 times the speed of all the networked computers in the US combined [5]. Peregrine runs the Linux Operating System and has 2.25 Petabytes of online storage. Peregrine is cooled with water. It is the world's most efficient water cooling supercomputer. Hot water from the Peregrine's cooling system is used to heat the entire facility.

Storage:
The long-term storage of user data has a capacity of over 3 Petabytes [6].

3D Visualization:
The ESIF Insight Center (adjacent to Peregrine) provides 3D viewing and analysis of experimental data, high-resolution visual imagery, and large-scale data simulation. It uses advanced visualization technologies (sensors, lasers, and cameras) in order to visualise physical processes which were previously modeled on Peregrine and to support knowledge discovery in energy systems integration.

3D Visualisation Demo:
NREL scientists have performed a fascinating demonstration for our Technical Tour. They took us to a large visualization room and gave each of us a 3D goggles. The room is equipped with an array of sensors, cameras, and lasers on walls and ceilings. They then turned on Peregrine and a hologram appeared in front of us showing a room scale 3-blade wind turbine and a flow of the wind from the front to the back of turbine. It was a fascinating experience. I was virtually immersed inside the hologram. I could 'walk through' the virtual wind and turbine blades, and could see different vortices behind the blades in different colours. I had a feeling that I am 'flying through' the turbulent air, wakes, vortices, and disturbances behind the turbine.

In this way, a scientist can visualise and analyse physical processes which are otherwise very difficult to reproduce and understand. For example, it is well known that wind turbines extract energy from the wind, creating the wake turbulence (vortices) behind the turbine, where wind speed is reduced. When an adjacent turbine falls within these vortices, its efficiency can decrease dramatically. Using this visualisation technology NREL scientist discovered that the turbulence (vortices) behind a large wind turbine (say 54m in diameter) can extend behind the blades as far as 3 to 4km. It now allows them to design wind farms in such a way to reduce or eliminate losses caused by the impact of the turbines on each other. Furthermore, NREL scientists are able to identify different types of vortices, and they present them visually in different colours.

<u>Opportunities for the New Zealand electricity supply industry:</u>

1) I spoke to Dr. Nicholas, a key scientist at visualization lab, and asked him can they model other physical processes. He confirmed that they can perform a computer modeling, visualisation and analysis of any physical process, in solids as well, not only gasses.
2) The viewing can be done on-site or remotely e.g. an overseas company running an experiment on Peregrine can see the results remotely
3) I also spoke to James Bosch, NREL's Senior PA Specialist. He said that NREL is 'open for business'. They perform work on various research programs for different organisations around the globe and they are happy to cooperate with New Zealand companies as well. Those companies that have R&D projects aligned or funded by EERE are eligible to utilize NREL resources. The pricing for work on Peregrine seems to be reasonable e.g. starting from US$20,000 for our own research. (For more info contact the ESIF User Program [7].)

2.2 System Performance Lab

Key research areas:

- ADMS – Advanced Distribution Management Systems
- Testing the Smart homes equipped with commercially available appliances
- Residential energy management and demand response
- Micro-grid model simulation and testing in real time
- Controller and power hardware loop
- Distributed grid-edge control hierarchy e.g. interactions, control, and management at several levels - home, metering, el. vehicles, batteries, local distribution, grid

ESIF has successfully partnered with Solar City and Hawaiian Electric Company.

2.3 Energy Storage Lab

Key research areas:

- Test setup for Hardware-in-the-loop evaluation of microgrid controllers, containing:
    - RTDS – Real-time Digital Simulator
    - PHIL – Power Hardware-in-the-loop
    - CHIL – Controller Hardware-in-the-loop

Outdoor testing facilities:
Several spans of 13kV OH lines and poles, OH switches and battery storage

2.4 Hydrogen Testing Lab

Key research areas:

- Production of hydrogen using solar PV and electrolysis for testing the fuel cell, electric, and hybrid vehicles
- NREL regard and use hydrogen as a platform e.g. the renewables drive train (solar –> hydrogen atoms –> production of methane and other energy or chemical derivate –> fuel for vehicles and other devices etc

Fuel cells testing ground - at the time of the technical tour the site was off limits to the public and visitors due to the current highly classified project.

2.5 Battery and Thermal Storage Material Lab

Key research areas:

- Inverters and Bi-directional batteries (liquid)
- Integrated power systems: Micro-grid switch, intelligent CB, Hybrid box (diesel, hydrogen, el. vehicle, battery, solar)
- Thermal Storage

2.6 Hardware-in-the-Loop at Megawatt Scale Power Lab

Research hardware:

- 7 MW grid simulator - largest in the world, built by ABB
- Electrical distribution bus – the power integration test circuit made up of 2x AC and 2x DC buses connecting multiple sources of energy and plug-and-play testing components

Capabilities:

- Can replicate any transmission grid, distribution network or micro-grid, and then conduct real-time integration tests at full power and actual load levels
- Can simulate any 1, 2 or 3 phase system
- Can simulate and test any real condition (e.g. any fault scenarios, frequency events, transient voltages, disturbances caused by renewables etc.)
- Can replicate and simulate any grid or network around the world

<u>Opportunities for the New Zealand electricity supply industry:</u>

- I spoke to the Chief Scientist at the Lab about various fault and pre-fault conditions on grids and networks, and he has confirmed that there is absolutely no scenario that they can't replicate, test and analyse. They can perform computer modeling, simulation, testing, analysis, visualisation, and fundamental research of energy systems from micro-level up to multi-megawatt scale, for any kind of network and under any scenario

- I then spoke again to James Bosch, NREL's Senior PA Specialist. He has repeated that NREL is 'open for business'. NREL would be happy to conduct any RD&D (Research, Development, and Demonstration) for New Zealand transmission grid or distribution networks [7].
- This research facility offers great opportunities to New Zealand electricity industry for testing NZ grid and networks under NZ conditions. For example, NREL may help New Zealand electricity companies to reduce their risk of investment when developing and implementing leading-edge technologies, new hardware or design philosophy for transmission grid or distribution networks.

3. National Wind Technology Center (NWTC)

3.1 National Wind Testing Lab

Key research areas:

- Designing new and innovative wind turbines
- Smart sensing devices for wind turbines
- Intelligent control e.g. a radar detects flocks of migratory birds and shuts down the turbine until birds are gone
- LIDAR built in some turbines
- Computer modeling on Peregrine and visualisation/testing in 3D Visualisation Lab

Testing methods (testing wind turbine blades to the failure):

- Static (3 to 6 months)
- Fatigue bending
- Model test – exciting to resonant frequency

3.2 Field tests:

Currently testing five large wind turbines at utility scale (1 to 6 MW):

- Alstom (France; efficiency 46%, based on capacity)
- Siemens (Germany; 3.3MW, 80m tall tower, blade diameter 46m, 6 degrees angle incident)
- Gamesa (Spain)
- 2x for NREL/US DOE (Department of Energy)

Also testing some small (<100 kW) and intermediate (100 kW to 1 MW) wind turbines. For example, SWIFT and Urban Energy wind turbines have been tested here. They are occasionally testing some small Vertical Axis Wind Turbine (VAWT).

3.3 Dynamometer testing facilities

5 MW and 2.5 MW Dynamometer testing sites for the drive trains and gear boxes

3.4 CoMET (Composite Manufacturing Education and Technology) Facility

Key research areas:

- Rapid prototyping and testing of new blade materials and production methods
- Materials for blades: recyclable resin, pro-balsa, carbon fiber, fiberglass and elium resin
- Elium resin is the most promising for the future wind turbine blades e.g. it has excellent toughness, excellent fiber impregnation, can be molded by infusion at room temperature

Summary and Conclusions:

The energy industry is going through dramatic changes driven by new technologies, sustainability concerns, increasing energy demand, and the need for energy security. It has been widely recognized that the disruptive green technologies such as solar, wind, energy storage, electric vehicles, and emerging new business models will have a profound effect on the electricity sector. Renewables have a potential to disrupt the existing electricity supply industry in many ways:

- Distributed energy resources and digital revolution will enable the Blockchain concept in energy markets, thus democratising energy distribution and disrupting the monopolies
- As a consequence, Utilities may lose the electricity market to technology companies
- High penetration of distributed renewables will require adjustments to the existing operating procedure and design philosophy of power systems.
- There will be redundant hardware especially in remote and islanded areas
- High penetration of distributed renewables will accelerate the aging of transformers
- There could be other disturbances due to intermittent nature of renewables
- Utilities will have to improve Cybersecurity due to vulnerable back-doors via renewables
- New business models will be required that include all stakeholders and customers

The biggest challenge that the existing electricity supply industry is facing is how to integrate technological changes, economics, and environmental concerns into a workable and winning business model. There are also significant challenges (and opportunities) for the New Zealand electricity supply industry to 'catch the train' to the next-generation electricity networks.

New Zealand electricity sector needs to strengthen the leadership potential necessary for the anticipated 'time of disruptive innovations'. For example, the industry will have to be innovative in transforming its current business models, its current infrastructure maintenance, and development of new networks, while considering environmental sustainability and safety.

Also, New Zealand electricity sector needs to boost R&D and to utilise innovation skills of its people in solving the current industry problems in light of incoming challenges. For example, more innovations in predictive maintenance will extend the service life of existing infrastructure and defer unnecessary capital expenditure. The resources can then be redirected to boost more R&D in order to mitigate future challenges and risks.

"The best way to predict your future is to create it." - Abraham Lincoln

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Photo: Wind turbine testing at NREL site

Group Photo: NREL Technical Tour in front of 5 MW Dynamometer testing facility
(Note: I am under the NREL green protective hat)