Clean Energy Fund Smaller-scale Demonstration Project

Integration of Photovoltaic Panels and Li-Ion Storage for Level-3 Electric Vehicle Charge Station

BCIT Energy OASIS (Open Access to Sustainable Intermittent Sources)

Final Project Report

March 2015

Prepared for:

Natural Resources Canada (NRCan) Clean Energy Fund (CEF)

Prepared by:

Smart Microgrid Applied Research Team (SMART),
Centre for Applied Research and Innovation (CARI),
British Columbia Institute of Technology

Change Log

Table i Change Log

Rev	Date	Description:	By:
1.0	27-03-15	Final Release to NRCan - (Revised as per feedback)	JD
0.1	12-12-14	Initial Rough Draft – For CEF Review as per Contribution Agreement	JD
DA	19-06-14	Outline and Strawman – Internal Only	JD
D00	29-04-14	Initial Outline – Internal BCIT Only	JD

Executive Summary

The Energy OASIS (Open Access to Sustainable Intermittent Sources) at British Columbia Institute of Technology (BCIT), was developed with support from Natural Resources Canada (NRCan) Clean Energy Fund (CEF), and BC Hydro. Project partnerships included NRCan, BC Hydro, Panasonic Eco Solutions Canada (PESCA), Siemens Canada, Schneider Electric, and car2go. The major drivers for OASIS came primarily from BC Hydro, with an interest to incorporate storage technologies within its distribution grid, and from BCIT, with a clear desire to integrate renewable sources of generation into its campus microgrid.

In British Columbia, where the majority of electrical power is generated from hydro-electric systems, vehicle emissions constitute the largest portion of the province's emissions. Recent technology innovation is focused on electrification of the transportation system as one way to reduce emissions. Charging electric vehicles (EV) from clean energy sources would represent a significant reduction in greenhouse gas (GHG) emissions. At the same time, fast charging of electric vehicles represents a high instantaneous demand which could be challenging to the electric utility grid system. The overall vision of the Project was to demonstrate how mitigation strategies, such as energy storage, could be employed to help to protect the grid from this impact.

The OASIS project has successfully demonstrated the above concepts and substantially met project objectives. Key outcomes of the Energy OASIS Demonstration Project included four significant achievements:

1. Demonstrating the successful integration of a 250 kW solar photovoltaic (PV) system into the BCIT Smart Microgrid system.
2. Demonstrating the use of 500 kWh battery energy storage to support a portion of BCIT's islanded load, while isolated from the main grid.
3. Demonstrating the ability to mitigate the impacts of electric vehicle charging on the main grid, through use of a battery energy storage system (BESS) by concurrently charging 2 fully discharged electric vehicles at Level 3 (DC fast charging) with no impact on the power quality and reliability of the grid.
4. Demonstrating the ability to manage multiple distributed energy resources on the same distribution network including optimal dispatch and islanding such that the measurement of generation output at PV system will be equal to command for charging input to battery storage.

Furthermore, OASIS has disseminated knowledge gained throughout the project life-cycle for the benefit of Canadian utilities, and other stakeholders including: delivery of numerous presentations, tours and demonstrations of project use-cases to student, industry, representing a range of local, national, and international interest groups; publishing of a short video highlighting the OASIS project; and publication and delivery of several technical papers in technical journals and at relevant conferences.

The long-term vision for the BCIT Smart Microgrid is to be a fully functioning distributed microgrid, capable of supporting itself when isolated from the BC Hydro grid. The Energy OASIS project has successfully integrated components and demonstrated these concepts, applied to the BCIT campus Smart Microgrid. To realize the longer-term vision, more renewables and storage will be required, as the existing facilities can only provide a fraction of campus's power consumption requirement.

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1 Introduction

The purpose of this document is to provide a description of the Demonstration Project entitled "*Integration of Photovoltaic Panels and Li-ion storage for Level 3 Electric Vehicle Charging Stations*", conducted by the partnership to deliver the Project sponsored by Canada's Clean Energy Fund (CEF), and hereafter referred to as the Energy (Open Access to Sustainable Intermittent Sources) OASIS, or OASIS project. The document summarizes the objectives, the system and its applications, benefits, challenges, successes, and lessons learned. Based on the experience gained during the Project, a review of the solution tested, and recommendations for future development are provided. The document is not intended to cover all elements of the Project in detail.

2 Background and Project Consortium

In British Columbia, where the majority of electrical power is generated from hydro-electric systems, vehicle emissions constitute the largest portion of the province's greenhouse gas (GHG) emissions. Recent technology innovation is focused on electrification of the transportation system as one way to reduce emissions. Moreover, if electric vehicles (EV) can be charged from clean energy sources, then a significant reduction in GHG emissions can be achieved. However, DC fast charging of EVs can be challenging to the electric grid system, given the high instantaneous demand. The overall vision of this project is demonstrate mitigation strategies, such as energy storage, could be employed to help to protect the grid from this impact. The Energy OASIS project at the British Columbia Institute of Technology (BCIT) will demonstrate these concepts applied to the BCIT Smart Microgrid system.

BCIT is the owner of the Energy OASIS Demonstration Project which is located on BCIT's Burnaby campus. BCIT provided overall project management, and took a lead role in design and development of the EMS, overall system design and integration, and led the design and implementation of the system functional and use-case testing. The location was chosen due to the already existing infrastructure of the campus Smart Microgrid Initiative. The long-term vision is to be a fully functioning distributed microgrid, capable of supporting itself when isolated from the BC Hydro distribution grid. To realize that vision, more generation sources will be required, as the existing co-gen facilities can only provide a fraction of campus's load requirement. Natural Resources Canada's (NRCan) CEF program provided major funding for the OASIS project. The project consortium included BC Hydro, Siemens Canada, Panasonic Eco Solutions Canada (PESCA), Schneider Electric, and car2go.

3 Project Objectives and Deliverables

The Project successfully delivered on its objectives to:

- Demonstrate the successful integration of 250 kW solar PV system into the BCIT Smart Microgrid.
- Demonstrate the use of 500 kWh energy storage to support a portion of the islanded load, while isolated from the main grid by conducting intentional islanding of charging stations using storage as the source.
- Demonstrate the ability to mitigate the impacts of electric vehicle (EV) charging on the main grid, through use of energy storage by concurrently charging 2 fully discharged EVs at Level 3 without noticeable drop in feeder service quality.

- Demonstrate the ability to manage multiple distributed energy resources on the same distribution network including optimal dispatch and islanding such that the measurement of generation output at PV panels will be equal to command for charging input to storage.
- Disseminate knowledge for the benefit of Canadian utilities, and other stakeholders including: delivery of several presentations by end of the Project; publishing of a short video highlighting the Project; and publication and delivery of several technical papers.

A number of challenges were encountered during the course of the Project. In many cases these could be distilled down to the multi-discipline nature of the Project, including its technologies and its project teams. As a demonstration project, the component technologies selected were largely proven technologies that had already been applied in the field. However, integration of those technologies into such a targeted solution required considerable focus on the integration of these distinct technologies within the project blueprint, and integration of the diverse teams within a common working framework.

The OASIS project has allowed for BCIT and Consortium members to further refine the technologies for other projects.

4 Description of System and Component Technologies

This section provides a context for the overall OASIS system, and descriptions of key technologies that make up OASIS. In the corresponding sub-section, each main OASIS system component technology is described including the role of the component in the overall OASIS Demonstration Facility, and how the component functions, both in the context of the overall system, and in relation to the other main components. The OASIS project interconnection is a load displacement project and as such is currently not expected to export directly to the bulk grid, rather all power generated will be used within BCIT's internal power grid.

The Energy OASIS Microgrid is a demonstration facility for the viability of integrating firm and soft power under close supervision and control of a distributed energy management system (EMS). The OASIS EMS plans and dispatches the required power for a set of island-able cluster of loads, comprised of a network of DC Fast Charging stations capable of charging electric cars quickly without adverse impact on the Electricity Grid. OASIS is comprised of the following major sub-systems:

1. Battery energy storage system (500KWhr)
2. Solar PV parking canopy system (250KW)
3. Efficient 4-Quadrant bi-directional inverter (280KW)
4. A highly sophisticated energy management system
5. Networking and Communication System
6. Feeder Interconnection and Protection System (Compliant with IEC-61850)
7. User Interface & Communication Kiosk for EV Drivers
8. Cluster of DC Fast Charge (Level 3) and Level 2 EV Charging Stations

BCIT, working with all project consortium partners, specified and procured component technologies, and integrated these to create the Energy OASIS Demonstration Facility. The figure below presents a schematic of the OASIS System.

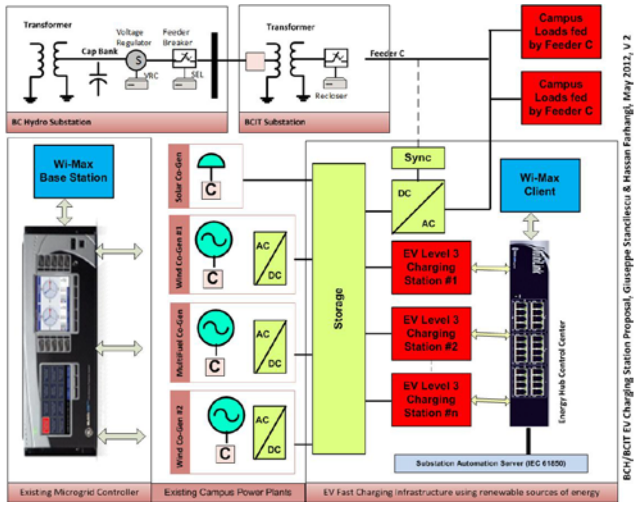


Figure 4-1: Energy OASIS System Schematic

As depicted in the above system block diagram, OASIS architecture would ultimately be comprised of various renewable sources of energy (not all of which were implemented as part of the current project) together with the intelligence required to rationalize, plan and dispatch such energy generation capacity for use by designated island-able loads (in this case, EV Charging Stations and a few other campus loads).

In general, compared to BCIT's peak load demand, these installations are relatively small. However as emphasized, renewable sources of energy present unique integration challenges for smart grid such as variable and intermittent output, which BCIT's Smart Microgrid intends to address. To counter the intermittent behavior of such sources, OASIS includes an Energy Storage Subsystem, which is comprised of a cluster of Lithium Ion Batteries, together with its dedicated Battery Management Units (BMU), as well as a 4-quadrant bi-directional Power Conversion System (PCS), comprising of DC/AC and DC/DC converters.

To demonstrate the viability of "soft power" (e.g. renewable sources of energy which are intermittent in nature) mixed with "firm power" (e.g. feeds from utility companies) to serve incrementally scheduled loads is the charging infrastructure for Electrical Vehicles, a distributed energy management system, capable of planning, dispatching and costing energy transactions is incorporated in the OASIS system.

That intelligence allows us to demonstrate ways to mitigate the intermittent nature of renewable sources of energy through the use of sufficient storage for time shifting of available power. To demonstrate the integration of renewable sources of energy as an alternate source, OASIS had to upgrade BCIT's power distribution system which would enable our Energy management System utilizing both "soft" and "firm" power to control loads such as Electrical vehicle Charging Stations.

OASIS Electric Vehicle DC Fast Charger (DCFC) Units

The OASIS project deliverables include requirements for at least 2 DCFC units. The BCIT OASIS team conducted a technology survey to support selection of the units based on initial functional requirements for the charger units. At the time of the survey, the choice of DCFC technologies was very limited. Final selection was made based on conclusions from our survey, and outcomes of discussions with technology providers around control and monitoring requirements. The OASIS DCFC units were provided by Schneider.

The DCFC units contribute to the overall system and project objective by providing the ability to:

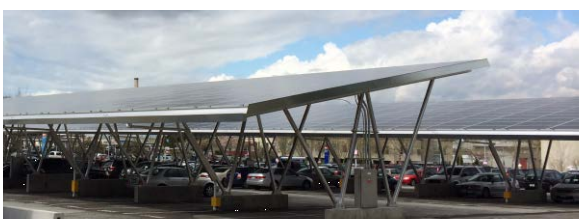
- Remotely throttle the charging current in real time while charging.
- Remotely read information on percentage state of charge of the EV's battery pack.
- Command to cleanly terminate the charging session at any time (without throwing an external breaker).
- Remotely obtain an identifier of the driver, such as the RFID[1] used to initiate the charging session.

A key initial design requirement was the ability to throttle the charging current in real-time while charging. The initial design evolved with the discovery that changing the charging current in real time while charging an EV constituted a violation of the CHAdeMO protocol. As a result, the design requirement was modified to the ability to throttle the charge just before a charging event. In other words, we wanted to be able to set a charger to deliver charges in increments of 10 kWs, ranging from 0 to 50 kW.

Each of the DCFC stations required internal electrical meters that communicate using the IEC 61850 protocol. This protocol is integral to the Substation Automation functions providing real traffic that can be communicated back to a substation to inform devices located there of the voltage and frequency at the distant end of a feeder.

OASIS Photovoltaic Component (PV)

The solar PV sub-system for Energy OASIS generates power from the solar irradiation to:



- Charge the storage battery and/or,
- Provide power to loads on the microgrid when islanded from the bulk grid, or
- To provide power to BCIT's internal power consumers when connected to the grid.

The decision was made very early on to size the OASIS system for 250 kW of solar PV generation. Initial solar analysis and design, and supply of the OASIS solar PV was by PESCA under their partner agreement with BCIT.

The parking canopy superstructure was proposed and adopted as the support for the solar PV installation when no suitable roof space was found to accommodate the original plan for a rooftop PV installation. Feasibility studies showed that a rooftop installation would have required significant building seismic upgrades.

[1] Radio-frequency identifiers provide a unique ID for the object in which they are embedded.

Battery Energy Storage System (BESS) Component

The battery storage modules and related Battery Management System (BMS) were designed and manufactured by Panasonic Japan. The design and installation was managed through the project partnership with PESCA. The BESS is rack mounted and housed in a standard 40ft. ISO shipping container. Powertech Labs was contracted by BCIT for the containerization including design, build and test of battery racks, fire safety system, and container electrical. The BESS container housing is divided into 2 separate rooms, the battery room and the E-house, as shown in the figure below. The E-house includes the electrical distribution panel, data communication devices, and servers for the energy management system component of the overall OASIS system.

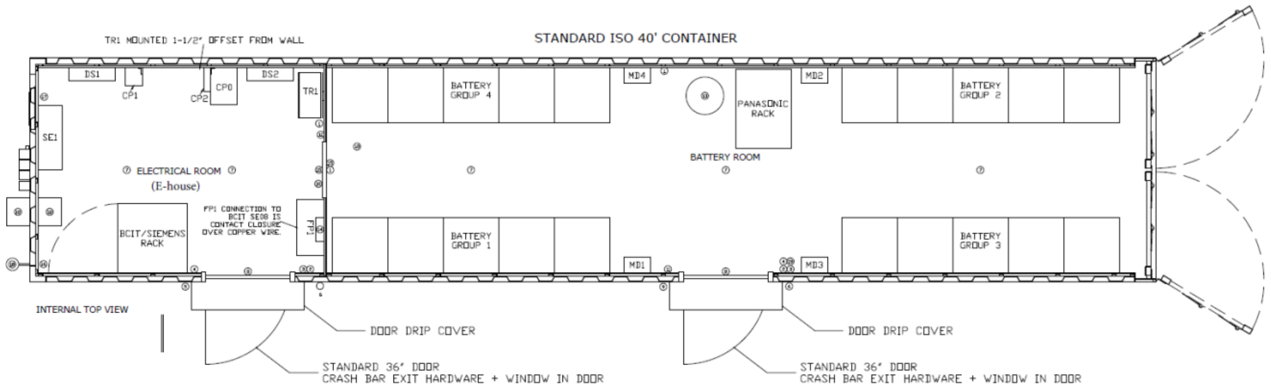


Figure 4-2: BESS Container and E-house General Layout

The role of the BESS component in the overall OASIS system includes storing energy from either the system's photovoltaic array or from the power grid. The OASIS system's local energy management system can use the BESS energy storage capability to time-shift power flow to and from the local power distribution grid. The energy management system, having use of a local energy reservoir, can choose optimal times to take power from the power grid and times to give power back to the grid, to meet energy management and demand management objectives while also meeting local power demand. Furthermore, the BESS can provide stored energy to support many hours of fully islanded operation of the Energy OASIS Microgrid; providing Electric-Vehicle fast-charging with no impact on the power distribution grid.

The BESS stores energy which can be used to charge EVs while the system is islanded (disconnected from the power grid). This supports the project objective to demonstrate EV fast-charging in an islanded microgrid.

The BESS can also discharge at a rate sufficient to meet the demand of at least two simultaneous EV fast-charges, while the system is connected to the power grid, thus demonstrating mitigation of the impact of EV charging load on the power quality or service reliability of the electrical grid which feeds it.

The BESS can be commanded to charge at the same power level as the system's PV array is generating, thus demonstrating the capability to store locally generated energy for optimal dispatch of the power. For example the BESS can subsequently be discharged to the power grid during demand peak times in the local distribution grid, demonstrating peak shaving / grid stabilization using distributed energy resources.

Depending on how the system has been scheduled to operate and commanded by the microgrid energy management system, the battery system is capable of generating energy locally and storing it in BESS. This in turn can be used to provide power to the DCFC units to charge EVs, and to other microgrid loads when the system is islanded from the grid. Subsequently, BESS can be discharged to the utility grid when commanded during demand peak times in grid.

Power Conversion System (PCS)

The PCS is critical to successful demonstration of the project objective to manage multiple distributed energy resources on the same distribution network including optimal dispatch and islanding. The OASIS PCS was provided under BCIT's project partner agreement with PESCA. PESCA's contractor, Dynapower Company designed and supplied the PCS. Dynapower worked with PESCA (as the solar PV provider) and Panasonic Japan (as the BESS provider), BCIT, and Siemens Canada on the specification and testing of the PCS. The PCS was designed, built, and subjected to rigorous testing and CSA certification process at the Dynapower test facility in Vermont, before being shipped to the BCIT.

The role of the PCS component in the overall OASIS system includes providing a highly flexible power platform that provides dispatch-able power to the BCIT microgrid for the Energy OASIS System.

The power conversion system supports two modes of operation: Grid-tied mode (operating fully connected to and parallel with BC Hydro network) and Stand-alone mode (Islanded mode). These operational modes provide the platform for demonstrating the system Use Cases that meet the overall objectives of the demonstration project.

Substation Automation System (SAS)

The SAS was delivered by Siemens and enables remote monitoring and control of Energy OASIS protection and control systems. The solution is a communication platform based on the international communication protocol IEC 61850. Siemens substation automation solutions integrate components from the feeder level to the OASIS control center.

Energy OASIS includes an "Energy Hub"[2], comprising of various protection and control IED's and functions supplied by different vendors, including Siemens MEM/PAS (Microgrid Energy Manager / Power Automation System) and substation automation gear, which are key to enabling the substation to act as an intelligent energy hub, protecting its assets, as well as allowing bi-directional flow of data, command and energy. The Intelligent Electronic Devices (IED) for protection and control are an integral part of the substation automation system. Combined together the SAS and IEDs lay the foundation for the remote functions such as power management and monitoring the condition of the equipment while it is in service. The goal of the

[2] Analysis and Validation of Interconnection Requirements of a Large Renewable Energy Installation with the Utility Grid, Minoo Shariat-Zadeh, Ali Palizban, Hassan Farhangi, Calin Surdu

substation upgrade component was to increase system productivity, with a view to reducing operational and maintenance costs and increasing system reliability and stability.

Energy Management System (EMS)

The OASIS EMS is comprised of several subcomponents which together provide the necessary functionality for command and control of the Energy OASIS system. The EMS server is rack mounted, and is housed in the E-house room in the BESS container at the OASIS site. It can also be remotely operated from the BCIT Applied Research offices. Some of the EMS subcomponents were developed by the BCIT team, and others were provided by Siemens Germany, managed through the project partnership with Siemens Canada.

The EMS is key to command and control functions of the OASIS system. Its purpose is to perform energy balancing between solar PV system generation, EV charging loads, battery energy storage system, and local power distribution grid. Through these functions the EMS supports demonstration of the following high level project objectives:

- Integrate PV panels and energy storage by charging batteries when and at the same level as the PV panels are generating power.
- Mitigate the impacts of EV charging on the grid by discharging batteries based on EV charging station demand.
- Manage multiple distributed energy resources (DER) on same distribution network including optimal dispatch and islanding.

To meet these objectives, the EMS must be capable of integrating with other OASIS components, for example with a renewable energy source, and controllable loads. This includes the capability of understanding the characteristics of those components and the ability to communicate with them via established protocols. The EMS must perform energy optimization of the OASIS system in both grid-tied and islanded modes, where islanded mode can be either planned or unintentional islanding. The EMS, provides the human operators of the OASIS system with the ability to:

- Run the system in a number of major operating modes to demonstrate:
  - optimization of system lifetime (battery system protection mode);
  - optimization of purchased energy costs and/or transformer life (peak shaving mode);
  - optimization of use of solar energy for EV charging (solar + stored solar only charging mode); or
  - maintenance of critical loads in simulated campus power failure (islanded mode supplied by solar and storage).
- Monitor the OASIS system power generation and consumption history, power levels, battery storage state of charge, and solar generated power output.
- Be alerted about non-nominal operation of the system's equipment or power levels.

The OASIS EMS is comprised of three main subcomponents that combine to fulfill these requirements, including:

1. Microgrid Energy Manager (MEM)
2. System Operator Portal

3. EV Charging Station Demand Response (DR) System

Additionally, EV Drivers who use OASIS are supported through the EV Driver Kiosk, and a Mobile App. The EMS sub-components are illustrated in the following schematic.

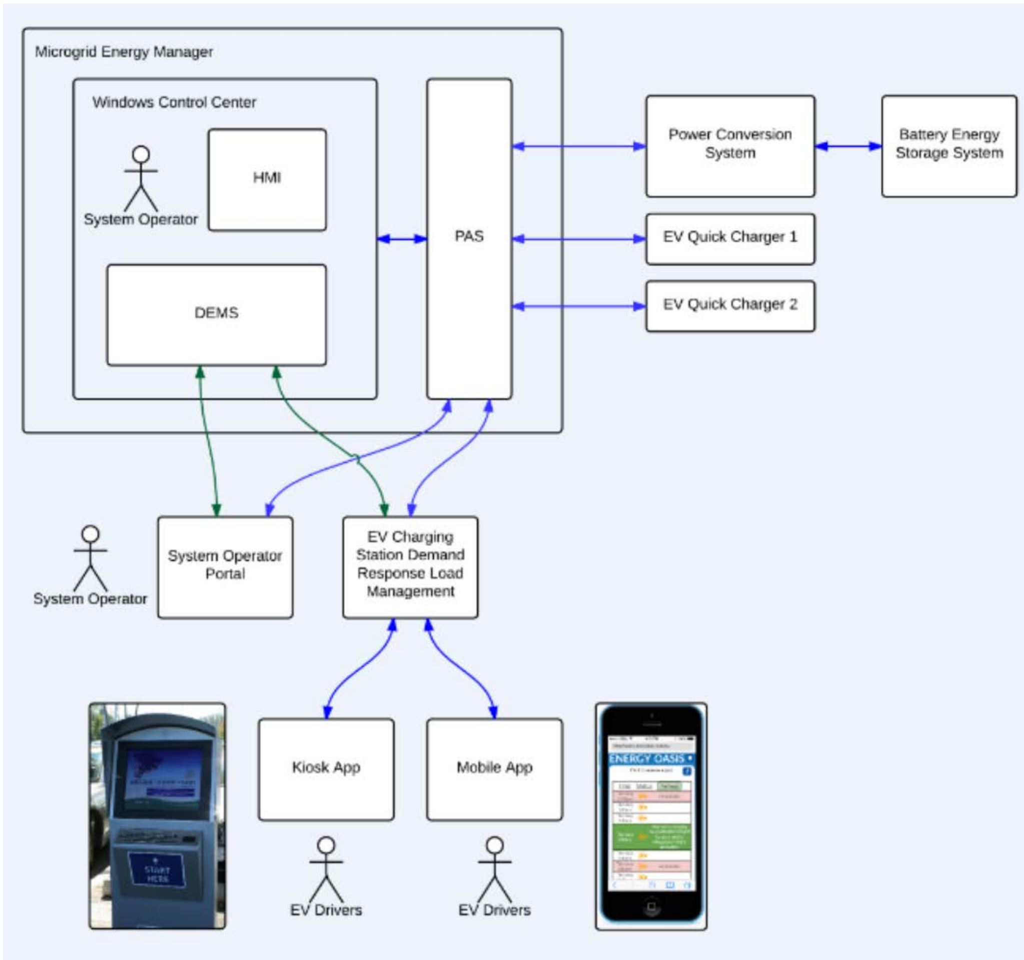


Figure 4-3: OASIS EMS Sub-components

The MEM is provided by Siemens and integrates with all other OASIS system components, through the PCS, including: solar PV panels; BESS; EV charging units; and the PCS. MEM functions are further divided between 2 sub-components.

1. The MEM/PAS (power automation system) unit handles communications for the critical command and control functions.
2. The MEM/DEMS (decentralized energy management system) unit provide energy balancing and optimization across the overall OASIS System.

During operation of Energy OASIS, energy balancing is planned every 15 minutes. Weather forecast data is converted into a PV generation forecast. After calculations are performed, a schedule similar to the figure below, is produced for optimally balancing the power use between sources and loads.

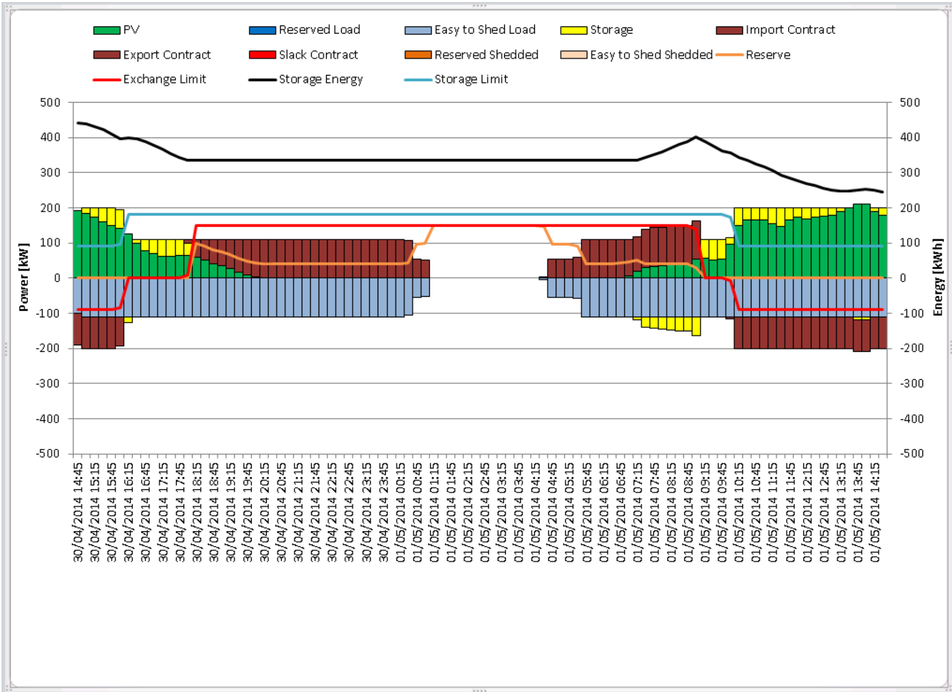


Figure 4-4: DEMS Generated Plan

The System Operator Portal and the Electric Vehicle Charging Demand Response (DR) System were developed by BCIT. The System Operator Portal allows human operators of the system to set and switch the operating modes of the OASIS system. It provides an overview of the system state and also notifies operators of alarms or faults. The EV Charging DR System provides capability for the OASIS system to interface with a range of EV charging products and related technologies. The EV Charging DR System also coordinates use of the DCFC units by EV drivers in a way that is supportable by the energy available from the OASIS system for vehicle charging.

The EV Charging Station Kiosk, provided and developed by BCIT, is located physically between the two Schneider DC fast chargers. The Kiosk is used to collect EV charging information from drivers which enables load management and near future load forecast. EV drivers coming to the EV charging station are directed to start at the Kiosk by a 'Start Here' indication on the Kiosk. Both EV charger displays also direct EV driver to begin at the Kiosk. The Kiosk runs a web application on a browser.

- The Driver logs in to the Kiosk with their license plate and PIN or create a new account.
- The driver is prompted to indicate charging needs - current battery state of charge and desire battery state of charge. This can be provided as a percentage on two sliders or driver can opt to select their destination on a map.
- Distance is calculated between charging station location and the selected destination. Required charge is determined by an algorithm and automatically adjusted on the slider.
- If the selected destination is too far, a warning message is

displayed.

- The Kiosk map is integrated with the *here.com* data source to provide locations for other EV charging stations nearby.

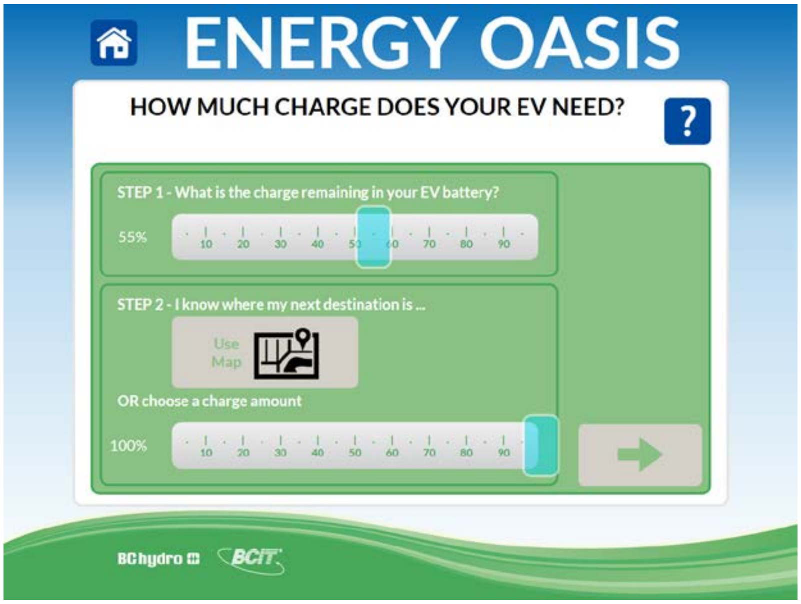


Figure 4-5: Kiosk - EV Driver Charging Needs Selection

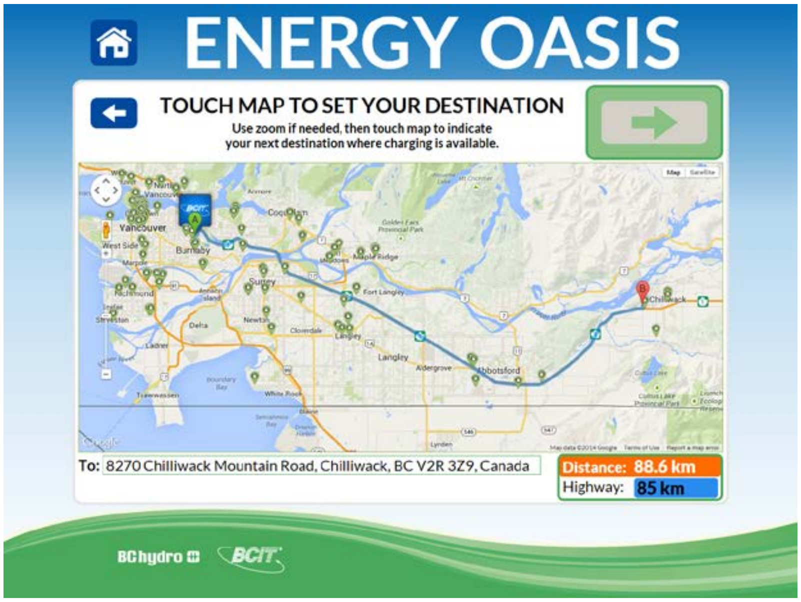


Figure 4-6: Kiosk - Map of Nearby Chargers

The BCIT Developed Mobile App enables EV drivers, from mobile phones and similar devices, to make reservations for the charging station within the current day and the next day. Reservation guarantees an available charger for the EV driver at the specified time slot and prioritizes the charging load in terms of load management over non-reserved charging sessions.

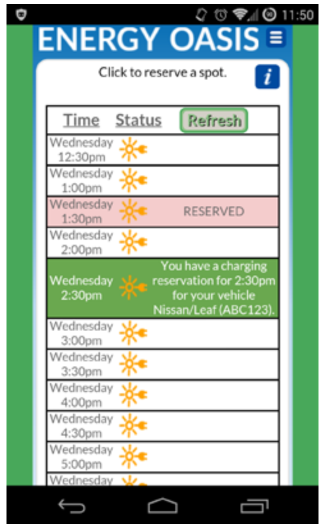


Figure 4-7: Mobile App - EV Driver Reservation Screen

The reservation data is used as an input to generate a load forecast. Should the energy level of the system be unable to support any EV charging, reserved charging sessions must also be curtailed, but this would be done only as a last resort by the EV Charging DR system.

OASIS Network and Data Communications (DCOM)

The Energy OASIS data communication network enables all of the system's smart components to communicate their status and measurements, and to accept commands from the local energy management system. The OASIS system's local energy management system uses the data communication network to read all sensor values and issue commands to time-shift power flow to and from the local power distribution grid. The energy management system, having use of a local energy reservoir, can choose optimal times to take power from the power grid and times to give power back to the power grid, to meet energy management and demand management objectives while also meeting local power demand. The following diagram shows the OASIS data network.

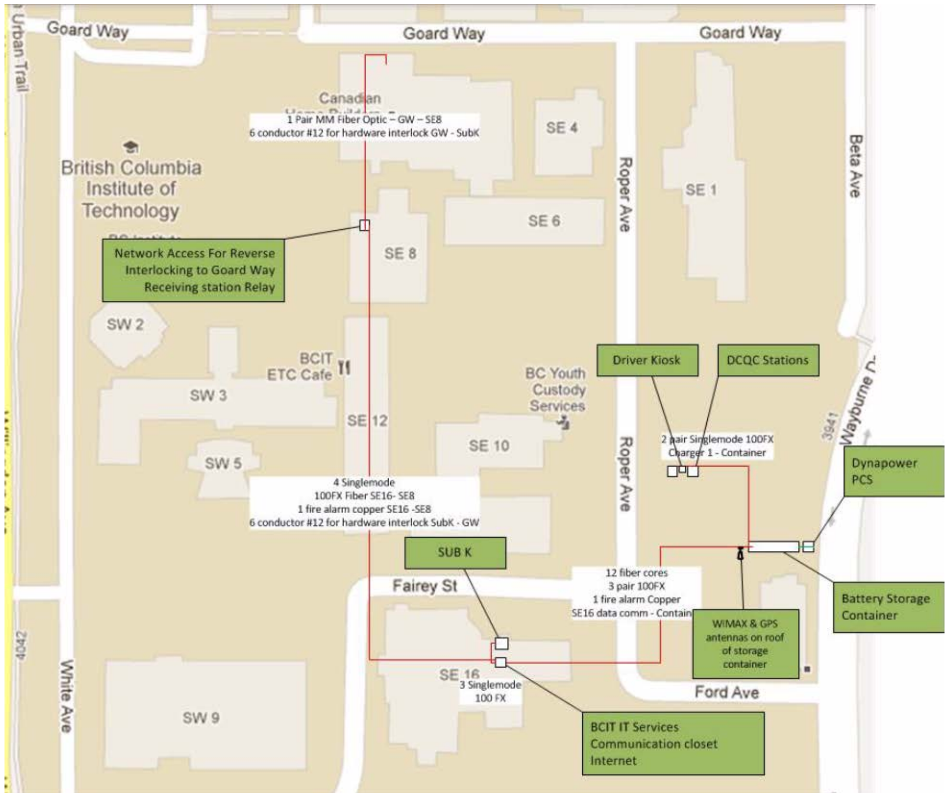


Figure 4-8: OASIS Data Network

The data communication network enables the Supervisory Control system to, for example, issue commands to the BESS and power conversion system to control generation and battery operations. This supports the project objective to demonstrate the ability to manage multiple distributed energy resources on the same distribution network including optimal dispatch and islanding.

Interconnection Agreement with Utility (IA)

An Interconnection Agreement with the utility, BC Hydro, is crucial in order to successfully deliver a demonstration project of this scale in this jurisdiction. Since OASIS is integrated with BCIT's internal distribution network, and downstream through that with BC Hydro's network, OASIS needs to demonstrate that its operation will not adversely impact the reliability, safe operation and maintenance of interconnecting networks. These requirements ensure safe isolation for maintenance, islanding, grid-tied operation, protection, fail safe, transient stability and harmonics propagation. These requirements and the tests/analysis conducted to prove full compliance with these requirements are then captured in an "Interconnection Agreement" document concluded by relevant stakeholders.

One of the objectives of the OASIS project is to demonstrate and validate the blueprint of Canada's future EV Charging Infrastructure, where charging services could be provided to EVs with minimal impact on the power quality or service reliability of the electricity grid which feeds it. In order to synchronize and connect OASIS to electrical grid, BC Hydro, as the main utility company of the province, as well as the local municipal authorities, imposed certain guidelines and technical requirements to make sure operation of OASIS may not create risks to her operating and maintenance personnel, and would not introduce adverse impacts on the reliability and power quality of the grid. Some of these requirements are stated below:

- Limitation of overvoltage transient due to BCIT Energy OASIS switching operation
- Anti-islanding mechanism to disconnect BCIT Energy OASIS from the network in case BC Hydro network overhead line experiences under voltage for prolonged period e.g. when power is cut or a fault on the line
- Prevent fault propagation form BCIT Energy OASIS to BC Hydro network. OASIS protection system should react and isolate faults before effecting BC Hydro network and before BC Hydro protection system reacts
- Power quality and harmonic content of the inverter should not exceed the standard level

With the measures taken in planning, design, construction and installation of the Energy OASIS, the Project was able to secure an interconnection agreement with BC Hydro and ensure a safe operation of the system.

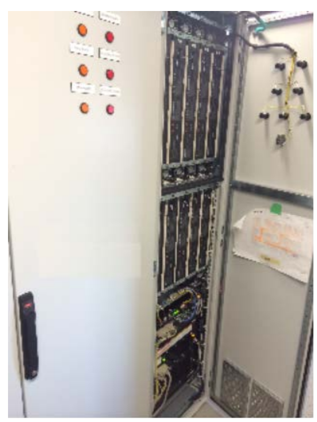
5 Key Challenges, Deviations and Resolutions

The Energy OASIS project was initially planned over three consecutive phases. As with any undertaking of this scale, as the Project evolved a number of unforeseen challenges emerged, requiring changes to the initial plan. It became clear fairly early on in the Project that in order to complete on schedule some overlap between the phases would be required. Furthermore, some activities in each phase became more significant, while others became less significant relative to what was envisioned in the Project proposal. As a result, there were three key unexpected challenges over the life cycle of the Project:

1. Design Deviations and Time/Cost Overruns
2. System Integration Challenges and Deficiencies
3. System Operations Learning Curve Challenges

Design Deviations and Overruns

There were a few unforeseen design challenges and deviations over the life-cycle of the project. A significant unforeseen design challenge occurred resulting in the need to re-design the racking system for the battery modules in the storage system. This resulted in project time and cost overruns. The initial configuration and layout called for horizontal installation of the individual battery modules similar to rack mounted computer servers. The intent was to use readily available, off-the-shelf rack systems. Because it was one of the first battery installations of this size, the requirements for scaling up the number of battery modules in the storage container were not fully understood. During testing in the detailed design phase, it was determined that a vertical mounting of the battery modules would be required to avoid over-heating issues. This increased the complexity of the battery installation and necessitated custom design, building and testing of a custom prototype. The vertical rack prototype proved successful but due to time and resource constraints the build was largely supported by the design engineers. The involvement of design engineers in this first rack build was a necessary step but ultimately incurred additional labour expenses. This issue also resulted in time



delays which were accommodated by amendment to the project which provided an administrative extension and allowed for additional the project operational commissioning to better complete the reporting purposes.

Ultimately, the associated cost overruns were negotiated by BCIT with costs being shared by BCIT, PESCA, and Powertech Labs (contractor for the containerization design / build). The positive outcome is that this effort has resulted in a novel racking system design which can be applied to future projects and has provided engineers with the knowledge to facilitate subsequent builds with lower cost labour.

System Integration Challenges / Deficiencies

The OASIS Demonstration Facility has included installation of proven technologies. However, to achieve project objectives and outcomes required integration of the component technologies in novel ways. This required customization of major components. Particularly the BESS, PCS, and EMS, but also the DCFC units. The project on-site testing timeline included: component commissioning; system integration; system functional testing; and use-case testing. The intent was that all partners be present on site for the duration of all these activities, requiring members of the technology provider technical teams to be on-site for over 2 months. At various points during this timeline, some of the technical teams were in sit-and-wait mode while other teams were actively testing. From a practical perspective, this kind of commitment was an impossible sell. Partner support teams hailed from Eastern Canada and the US, Japan, and Germany. It was extremely difficult to get buy-in from partners to stay on-site past the component commissioning, through the system integration and use-case testing. The feeling was that the technologies were installed and integrated and should work. The reality was that implementing the System Use-cases Tests would test the components in ways they may not have been tested previously. Indeed the first year of operations has proved this to be true.

Ultimately the system integration testing was completed, some partners remained on-site through the Use-case Testing phase, and others provided support remotely from their home location. OASIS has been operating, with some exceptions, since March 5th, 2014. Ongoing operation has uncovered deficiencies that are addressed as they arise with support from partners via email exchanges. Future projects will benefit by securing partner commitment through a longer system integration and use-case testing phase. And by ensuring that development of operational and maintenance support agreements are explicitly scoped during project planning, and that development of these agreements includes appropriate stakeholder representation.

System Operational Learning Curve Challenge

The OASIS system represents the addition to campus of new technologies and processes, and on a fairly significant scale. Operating the facility requires new skills and processes. Many of these already exist under existing campus infrastructure maintenance routines. In other cases new skills and processes have been learned by members of the BCIT project team through hands-on activities over the life-cycle of the Project. The OASIS team has faced operational challenges throughout the system startup and system commissioning phase. Some of these are due to the integration issues mentioned above, and could benefit from those mitigations. Future projects could further mitigate this issue by:

- Incorporating an appropriate transition and operational plan with stakeholders, during the early planning and conceptual design phase of the Project. This should include developing a shared understanding of current operations and processes, what changes may be required to accommodate the new technologies, and a clear delineation of roles and responsibilities for ongoing operation and maintenance.

- Incorporating a project transition phase at the end of the Project that includes knowledge transfer overlap between with resources from Campus Facilities and Operations, and experts from the technology providers.

6 Project Evolution

The following subsections describe key work items performed throughout the Project. The sections generally follow a chronological order, but in many cases the project phases and activities proceeded in parallel. This section is intended to provide a general sense of the overall process, and is not intended to cover all project activities in detail.

Project Initiation and Planning

A joint working group between BCIT and BC Hydro developed the initial blueprint for the OASIS project. A business case was developed, followed by a project funding proposal. Work on confirming project timelines, budget and resources began at BCIT in 2011. In late 2011, partners began initial discussions including planning, responsibilities, and conceptual design. The OASIS project received final sign-off June 20, 2012. This late sign-off shortened the project timeline from 2 years to 21 months. In February 2014 parties agreed to an amendment which extended final technical reporting milestone to mitigate delayed project start and allow additional time for final integration and system functional testing.

Site Selection and Studies

The original intent was for the solar PV to be a roof-top installation. Two buildings were identified as potential candidate locations, however structural analyses indicated need for seismic upgrades to both. The time and cost associated with these upgrades exceeded project schedule and budget.

As an alternative solution, a solar PV parking canopy structure installation was proposed. Three BCIT parking lots were identified as potential candidate locations. Student Parking Lot N on the south west corner of campus was quickly eliminated due to the presence of large areas of shadow from adjacent trees for much of the day. Solar analysis of Student Parking Lot D and Staff Parking Lot 7 on the east side of campus indicated both parking were potentially suitable locations. BCIT Facilities Services Campus Planning department agreed in principal to Staff Parking Lot 7 (shown in Figure 6-1: OASIS Final Site Layout, later in this document), pending an appropriate feasibility study, including geotechnical analysis, and a subsequent review of a site layout plan.

The site feasibility study and final selection process for the OASIS project was completed in November 2012, with final approvals of site selection from owners and stakeholders following shortly thereafter. The site feasibility and selection process included a number of consultations and related studies:

- An Environmental Analysis (EA) was developed using the Canadian Environmental Assessment Agency (CEAA) template. In the end the EA requirement was waived for this project.
- An Aboriginal Consultation process was completed by the Government of Canada stakeholders for the Project. BCIT is located within the Consultation Area of First Nations groups.

- A geotechnical survey for the proposed project site in Parking Lot 7, including a soils analysis and a drainage study, was commissioned and approved. The information provided in this report later used in the detailed design of the superstructure for the solar canopies.

Additional studies which contributed to the project in various stages included the following:

- A Harmonics Study was conducted to identify the potential for harmonics related issues. Under the assumption that the developed network model is representative of the existing/planned system, and the available inverter harmonic injection data is applicable to its full range of operation, the results observed that the network is not susceptible to any of the characteristics harmonics that may be injected by the power conversion system.
- A Short Circuit and Coordination Study were conducted as part of general requirements, and as input to the Interconnection Agreement. The coordination study outcomes included recommended settings for the relays and power quality meters included in the Substation Upgrades component of the Project. The short circuit analysis determined that all of the equipment included in this study has the proper withstand or interrupting ratings for the fault current available at their respective locations.

Conceptual Design

Given the protracted approval and sign-off for the Project, and in order to be able to meet the project completion timelines, there was some overlap between start of planning and design, and formal project sign-off. It took three consecutive design summits and an integration to bring together these often diverging considerations and points of views, mainly:

- An overall system architecture was developed through a series of high-level design summits (Summit #1 - April 26, 2012; Summit #2 – July 25, 2012; Summit #3 - September 5, 2012; Integration Summit – March 21, 2013)
- A key outcome of the first design summits was a High-level System Design document for the Project. This document set the requirements for each of the components of the system. In subsequent summits, partner technology providers worked together to submit, review and revise the high-level designs for the individual component contributions to the overall solution.

As a demonstration project, a key design criteria was application of proven technologies. System components were selected from technologies that had already been applied in the field. At the same time, the fact that such technologies existed in the marketplace meant that the design team had to focus on the integration issue and how such seemingly divergent technologies could be integrated within the desired blueprint. The first design summit focused on mapping of OASIS blueprint specifications to available technologies, while the second summit was spent on system sizing and rationalization of scale. And the last summit was the forum to discuss the interfaces, standards and pairwise testing which needed to be done to ensure the validation of interfaces before full scale integration in the larger OASIS system.

Site Layout

The parking canopy superstructure for the solar PV formed the basis for much of the civil design and construction. A feasibility study was commissioned for potential design options for the parking canopy superstructure. A carport design proved the most cost effective of the options and was selected for the final design. The final design is structured and installed as two parking canopies covering approximately

120 car stalls in an area of 1664 m^2. The Carport system design is modular in structure and can be customized to fulfill the demand of any parking area project. Design of the superstructure included rainwater and runoff collection as well as bird control. Configuration of the module arrangement and spatial cut of the parking area took place according to project requirements and is drawn up in accordance with local boundary conditions (ground conditions, wind loads, and snow loads).

The solar PV, the electrical distribution substation, power conversion system and battery storage system all needed be closely co-located in order to reduce the voltage drops, and to reduce installation costs. Based on the requirement for 250 kW installed capacity, the final footprint for the planned PV installation would be just over 1600 square meters. Given this space requirement, finding a location for PV component was a key driver in determining a location for the Project. These space requirements had to be balanced with location requirements for the energy storage system including:

- Proximity of storage system to PV and EV charger loads to minimize feeder cable runs.
- Safety considerations (distance of storage system from occupied structures).
- Weight, ground loading and seismic considerations.

Figure 6-1: OASIS Final Site Layout

Site Preparation and Construction

BCIT relied on RFPs, existing contractor relationships, recommendations from BC Hydro, and direct solicitation for quotes and contractor selection.

Read Jones Christoffersen Ltd. (RJC) consulting engineers was engaged as Prime Construction Consultant for the Project. RJC was chosen because of their prior experience working with BCIT and familiarity with the BCIT Facilities Services and Campus Development department guidelines and processes. RJC's involvement with the Project was expected to contribute to BCIT Facilities Services acceptance of the work being performed, due to the confidence that the work be performed to BCIT's standards and practices. RJC had also contributed to initial feasibility study for the Project, including input on roof-mounted PV, and a feasibility study for the design of the canopy structures to support the solar photovoltaic system. They had demonstrated flexibility to adjust to the project schedule, and were available to work within the project timeline constraints.

RJC developed the tender package which went out for bid solicitation, and closed on May 7, 2013. The construction work was scheduled to coordinate with BCIT's annual electrical maintenance shutdown of the South Campus, scheduled for the August long weekend. A General Contractor was selected and substantial completion of the construction work was targeted for end of September 2013. The scope of the tender work included:

- Trenching and installation of electrical conduit and conductors
- Installation of footings for canopy structures, EV Chargers, battery storage container, and power conversion system
- Mechanical drainage for overall OASIS site
- Coordination for and installation of individual components supplied by BCIT and the Project Consortium partners.

Construction coordination was complicated significantly by the multiple sub-contractor relationships on the project site, some with the General Contractor, and others directly with project partners. Ultimately this was managed through vigilance by the Prime Consultant in holding regular construction meetings. Construction was also complicated by a few unforeseen challenges. For example, a couple of obstacles were encountered when digging the trenches for cable runs to the substation and required working around. The cable pulls were significantly complicated by the size of the electrical cable specified in the design and required a couple of attempts to successfully complete the cable pull. Delays in completion of the container for the battery storage and E-house required some wait before the electrical trades doing installation work could be rescheduled.

Detailed Design

From project perspective the OASIS system was comprised of proven technologies. From a system perspective, specification and design activities were undertaken by each technology provider. As with any integration exercise, component technologies require some adaptation to ensure they can be integrated in such a way as to provide an overall solution design to meet the project objectives.

The focus of the detailed design activities was ensuring key components would integrate to demonstrate an overall solution. These activities were coordinated by the BCIT team working with each of the technology partners. Before any of the components could be shipped to the project site, a blueprint for component subsystem interactions needed to be designed, implemented and factory tested.

OASIS components were delivered by partners under the Partnership Agreement as "black box" components. Detailed design adaptations of these constituent components of the OASIS system was performed by partners providing the specific technology.

Control interface specifications were one of the most critical aspects of the OASIS detailed design and system integration. This was achieved through a process of negotiation, refinement and elaboration of control interface specifications between key partners. Siemens and BCIT took the lead on coordinating interface specification for signal processing and communication between the subsystem components. Rigorous factory testing, including signal testing between partner subsystems, was conducted prior to shipping the components to the BCIT site.

CSA Certification Process

Intertek Testing Services was selected to investigate and conduct standards compliance for project equipment requiring certification including: electrical panels in the E-house side of the BESS container; the Battery Room racks, switching modules and battery modules; the electrical cabinets for the SAS; the PCS; and the DC Fast Chargers. All of OASIS equipment and devices requiring certification are now CSA and/or cUL approved. Approval labels are permanently attached to each device.

System Functional and Use-case Testing

The System Functional and Use-case test plan was designed to verify that the Energy OASIS control system and electrical power components can operate in modes which demonstrate the project objectives. Furthermore, the system level plan includes tests to verify that the Energy OASIS system responds safely and in a manner to reduce risk of faults in any subsystem, and to actively notify remote system operators of fault occurrences. Five Use-case tests were developed and have been implemented successfully, demonstrating that the project objectives have been substantially met. In some cases there were minor deviations from expected results. Mitigation strategies are in progress to address these.

1. TC-001: Storage and later use of PV for EV Quick-Charging – No Impact on Grid: demonstrates the project objectives to:
   - Store Photovoltaic (PV) generation in Lithium-ion batteries (BESS) for later use.
   - Demonstrate the ability to manage multiple distributed energy resources on the same distribution network: Charge BESS batteries at the power level that PV is generating.
   - Discharge BESS batteries based on EV charging demand.
   - Demonstrate the ability to mitigate the impacts of EV charging on the grid, through use of energy storage: Concurrently charge 2 fully discharged EVs at Level 3 (DC fast charging) without noticeable drop in feeder service quality.

   The expectation is that the system is able to quick-charge two EVs with no net energy taken from the grid, and with no significant adverse power quality effects on the local distribution grid. Testing found that the system successfully quick-charged the EVs, consuming only 0.45 kWh from grid (average power delivered 0.61 kW). The EVs were charged with approximately 21 kWh during this period, so the ability to charge EVs with no power draw from the grid was confirmed.

2. TC-002 – Support Loads During Power Outage: demonstrates the project objectives to:
   - In the event of an outage, island and support a portion of the campus load.

   The expectation was that the system synchronize and reconnect to the grid after the feeder breaker was closed. This test was considered passed with no significant deviations.

3. TC-003 – Intentional Islanding – EV Charging Using BESS Storage: demonstrates the project objectives to:
   - Demonstrate the use of 500kWh of energy storage to support a portion of the islanded load, while isolated from the main grid: Intentional islanding of charging stations using storage as the source.

   In the test, an EMS plan input was given specifying a 2 hour intentional islanding period after a 45 minute delay. It was observed that the EMS planned and caused BESS SOC to be raised rapidly from 26% to 48% by importing grid power. The system disconnected itself from the grid at the scheduled time and two EVs were fully quick-charged. At the scheduled reconnection time, the system reconnected to grid power. This test was considered passed with no significant deviations.

4. TC-004 – Optimal Dispatch of Energy in a Microgrid: demonstrates the project objectives to:
   - Optimally dispatch energy from multiple distributed energy resources in a grid-interactive Microgrid

   The test was conducted by giving as an input to the EMS a time-of-day schedule of grid power targets, with a pattern of first allowing import of power from the grid for a time period, then allowing no import of power from the grid for a time period, then requiring at least a certain level of power supply to the grid for a time period. This test was considered passed with no significant deviations.

5. TC-005 – Fault Handling at the System Level: demonstrates the ability of the OASIS system to:
   - Verify that the Energy OASIS system's control system and electrical power components:
     - Detect faults and failures in critical components,
     - Act together, upon a fault or failure in a critical component, to automatically render the Energy OASIS system as a whole safe and in a known state,
     - Notify actively and quickly, upon a fault or failure in a critical component, a pre-specified list of human operators of the occurrence.

   This test was considered passed with no significant deviations. The number of error notifications is currently significantly higher than necessary. More work needs to be done to ensure that the notifications are reliably addressed and to apply filters to facilitate prioritizing of events.

7 Project Achievements and Results

Successful Deliverables

The OASIS Project has successfully met its objectives and deliverables including:

1. Demonstrating the successful integration of 250 kW solar PV system into the BCIT Smart Microgrid system.
2. Demonstrating the use of 500 kWh energy storage to support a portion of the islanded load, while isolated from the main grid by conducting intentional islanding of charging stations using storage as the source.
3. Demonstrating the ability to mitigate the impacts of EV charging on the main grid, through use of energy storage by concurrently charging 2 fully discharged EVs at Level 3 (DC fast charging) without noticeable drop in feeder service quality.
4. Demonstrating the ability to manage multiple distributed energy resources on the same distribution network including optimal dispatch and islanding. The measurement of generation output at PV panels will be equal to command for charging input to storage.
5. Disseminating project knowledge gained for the benefit of stakeholders. Including completion and delivery of a number of presentations, videos, and technical papers as discussed in Section 9

The OASIS Facility has successfully demonstrated how a diverse portfolio of different energy sources, including firm and soft power, could be dispatched in support of rationalized controlled loads. OASIS captured the essential ingredients required to realize the future "Gas Stations" for Electric Cars, by demonstrating that coordinated cloud-based charging transactions could be realized within the confines of a highly constrained electricity distribution system to provide a much needed service to facilitate the emergence of green transportation in Canada.

Preliminary Project Data

Energy OASIS has been significantly operational since March 2014, with most of its components such as the SAS, solar PV system, battery energy storage system, and DC fast chargers, integrated and functional at the beginning of March 2014. The exception to this is the Level 2 chargers which were integrated at the start of June 2014. The "Data Year" (the yearlong period of March 2014 to March 2015) involves ongoing extended commissioning and testing that runs the system under a variety of occurring weather conditions and in the various use case scenarios. Under these conditions, data has been collected from each component of the system and analyzed to draw some initial conclusions.

Solar PV Data

The total PV solar generation for the Data Year is 49.462 Megawatt hours (MWh). The highest averaged PV generation power in 15 mintues was close to 200 kW. The highest instantaneous power monitored was 246 kW. These values are collected from partial operation of the system. As discussed earlier in this document, a number of factors affected the uptime of the system and prevented continuous operation.

The percentage of time the system was operational per month was calculated by comparing the solar forecast data (times when there should be generation) with measured generation data (0kW in cases when system was not operational). As represented in the chart below, in the early half of the Data Year, when component problems were being resolved, the operational percentages were low with 4 months below 20%. There is a significant improvement in the latter half of the Data Year where system uptime is consistently close to 65% in recent months. The overall operational time for the Data Year is about 42%. Based on operational time for the year and the measured PV generation value, a fully operational system at 100% could be projected to result in solar PV generation of 142.29MWh per year.

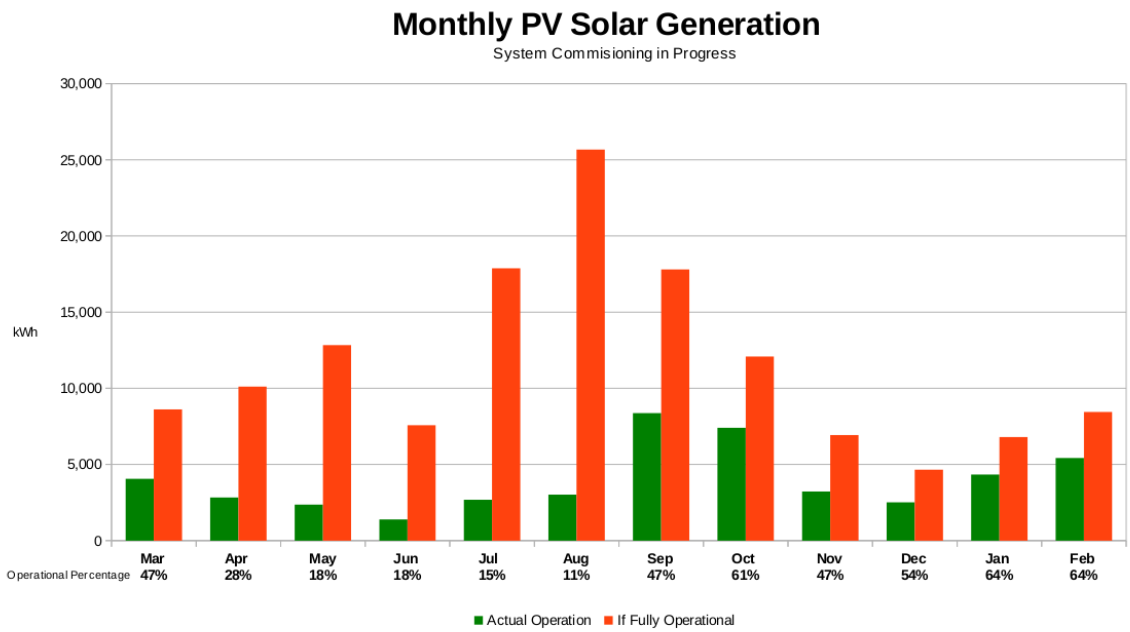


Figure 7-1: Monthly PV Solar Generation Chart

We are working towards 100% continuous operation of the system is the main target for the upcoming year. The data collected will then better represent the actual amount of PV solar energy the system is capable of generating.

DC Fast Charger Data

The 2 DC fast chargers at Energy OASIS were used approximately 169 times over the year, consuming 1.296 MWh of energy. The vehicle models which used the chargers were Nissan Leaf, Mitsubishi i-Miev and Tesla Model S. The Tesla Model S had a CHAdeMO adapter, a new technology that was tested at Energy OASIS prior to a recent release. An average charging session was approximately 23 minutes long and used 7.67kWh of energy. While the OASIS EV charger availability has not yet been publicly announced, their usage had seen an increase over the past few months. However it is still far from the capacity that the system is capable of sustaining.

As shown in the chart below, the overall energy consumption of the chargers, a large portion of the energy is used by the charger in idle mode (while not charging vehicles). It accounts for 7182 kWh / 7.182 MWh or nearly 85% of the 8.478 MWh the chargers had used in total. There is a constant power draw of approximately 400 watts per charger while it sits idle. This is most likely used by the transformer within the units.

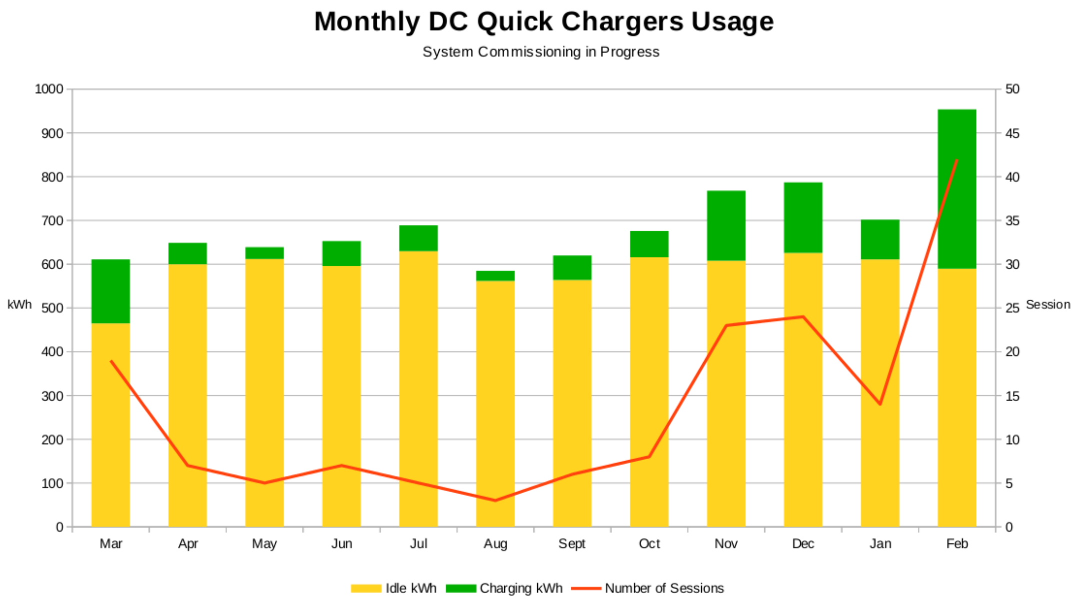


Figure 7-2: Monthly DC Fast Chargers Usage Chart

When large scale deployment of DC fast chargers occurs, the combined idle energy consumption becomes non-trivial with respect to impact on the grid. There is an opportunity to further study this condition. Currently Energy OASIS uses DC fast charger from one vendor (Schneider). Idle power draw from other vendor's (Eaton, ABB etc.) DC fast chargers should also be examined and compared. If the observed idle energy consumption is an inherent characteristic of these chargers, mitigation strategies can be developed. For example, additional control software can be implemented to turn off transformer component of the chargers when they are not in use.

Level 2 Charger Data

The two Level 2 Chargers were operational for three fewer months than the DC fast chargers. However, they have seen more usage, consuming approximately 2.071 MWh of energy in 199 charging sessions. Unlike the DC fast chargers, the Level 2 chargers do not have a transformer and use little energy while idling. The vehicle models seen using these chargers include Smart Fortwo EV, Chevrolet Volt, and Nissan Leaf. The average energy consumption per charging session is 10.4kWh with each session typically lasting several hours. The consumption for the Data Year for the Level 2 chargers is shown in the chart below.

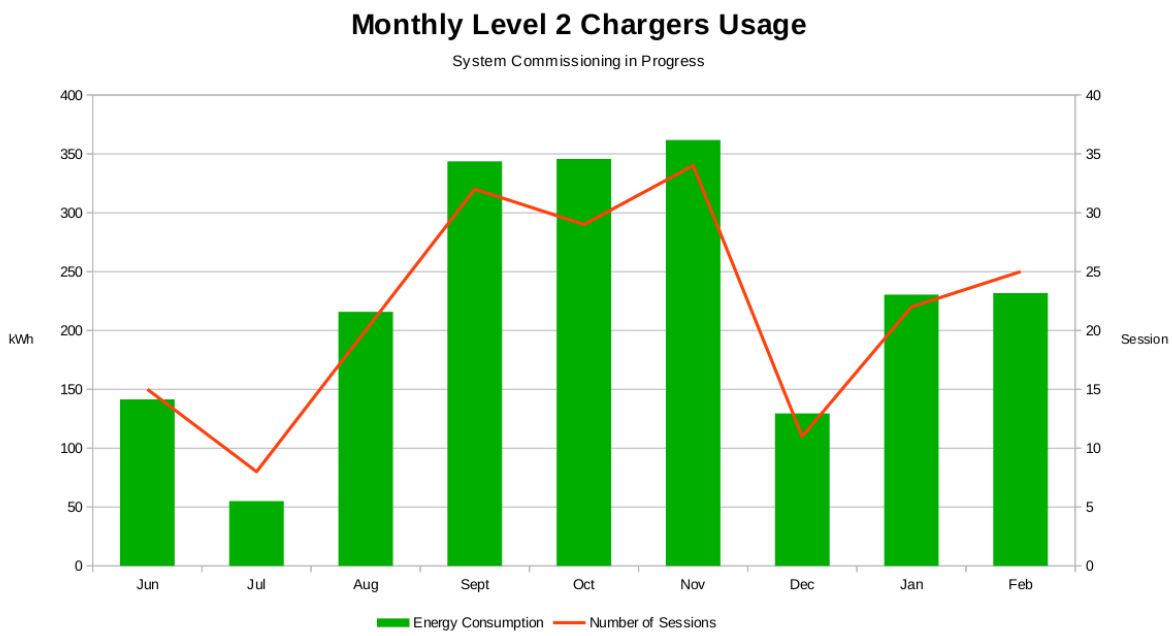


Figure 7-3: Monthly Level 2 Chargers Usage Chart

The chargers are mostly used by several instructors at BCIT who own EVs. It is evident that during holiday months (June, July, August, December), there is less usage. As charging from Level 2 chargers requires a lengthy period of time, it is unlikely that the usage of these chargers will see a significant increase.

Since the Level 2 chargers were a later addition to Energy OASIS, they are currently not being controlled by the Energy Management System (EMS) software. Potential future work involving these chargers is to add the controllable contactors linked to each charger to the EMS which allows them to be switched on or off. Additionally, they can be included in the energy planning and load control algorithms.

Preliminary Observations and Findings

Integration of Lithium-Ion Battery Storage

The BESS is the only component within Energy OASIS which can act as both an energy source (when discharging), and a load (when being charged). How this unit behaves is dependent on the energy planning and control of the Microgrid Energy Manager (MEM) based on operational modes, weather condition and load forecasts. In other words, how the BESS is used is highly variable. Therefore, meaningful conclusions cannot be draw by simply looking at battery charging and discharging data.

However, several observations were made during this operational year which can be further tested. The BESS is capable of storing energy from both the grid and the solar PV system and discharging it back to the grid or to the EV chargers but with some conversion losses. It has been observed that a round trip to and from the grid incurs about 30% loss. That is, 100 kWh charged from the grid will only result in 70 kWh being exported back to the grid. This type of data is important for the study of community storage where typical usage involves storing energy during low energy demand times and discharging during high energy demand times. The efficiency can have an effect on the feasibility of this usage of batteries. Longer term testing is required to confirm or disprove the observed 30% loss. The general use of Energy OASIS does not treat the BESS like a community storage. Therefore, special use cases will need to be designed for such purpose.

At the end of September 2014, after about 7 months of operation, a battery capacity test was performed to update the state of health of the BESS. The result shows a slightly less than 2% drop in battery capacity. This test will be run again soon to revise the health of the system after one year of operation. Charging and discharging data can be correlated to the state of health to evaluate the performance (capacity loss per charge cycle) of the BESS over time. A more detailed analysis could include the state of charge of the batteries when they were charging or discharging to better represent a charge cycle.

Solutions for DC Chargers and EV Infrastructure

At the start of the OASIS project, the DC charging stations on the market were still in early development. They had not been fully tested against the conditions experienced in a system where power fluctuations happen on a semi regular basis. Under these conditions the charging stations would detect the power fluctuations and immediately fault or cause the charging station to reboot. The OASIS team is currently working with technology providers to continue to investigate and test solutions to correct these faults.

Historically end users have not generally had access to equipment like DC chargers that control such a large amount of power. For example, vendors are still learning how to engineer equipment that exposes EV drivers to this type of power. One common issue is the electrical code requirement for an accessible emergency stop (E-stop) button on the DC charging units. In case of emergency the E-stop works by tripping a 480V breaker inside the charger. In an environment that consists of trained personnel an E-stop is well understood. However, in a public space it creates a target for passers-by, who see a big red button, and whose curiosity can lead to un-warranted E-stops being triggered. The reset procedure requires an electrician to be called to open up the charging station and reset the breaker. OASIS project knowledge sharing activities have shown this isn’t an isolated issue. More testing with the public is required to find a workable solution to address this issue. Furthermore, every vendor has their own ideas about what information needs to be displayed to the EV drivers and how big to display the data. Looking at a gasoline pump, the information is always the same and quite standardized. Future work could be developed in conjunction with the manufacturers on standardizing information and controls on EV charger units, and on how to represent these to the end user in a consistent manner.

OASIS use-case testing and early operation activities have identified an issue when the charging station experiences a blackout condition while a vehicle is actively charging. The EV may register some error codes that prevent the car from accepting a charge from any source until a service technician clears the error codes. This condition has been repeated and tested on several different charger units, and all tests have left the car in the same condition. While the likelihood of this happening often are small, those manufacturing and installing DC Charging stations should take precautions to make sure this is prevented. OASIS has identified and tested installation of an uninterruptable power supply (UPS) as one means to mitigate this issue.

IEC 61850 Upgrades to Existing Substations

Implementing an IEC 61850 network in an existing substation was challenging from several aspects. BCIT's Facilities Management department had concerns about the reliability of the new equipment and whether it would provide the same level of safety that their proven methodology provides. BCIT's IT Services department had routed the new fiber optic connections through their normal fiber pathways, which included several fiber segments. BCIT Facilities flagged this as a potential risk that the fiber optic connection could be inadvertently or maliciously unplugged, and potentially take down the substation. The OASIS team was able to mitigate the risk and address Facilities Management concerns by designing in a backup copper connection. This provided a direct connection between the relay in the substation to the relay in the receiving station, configured as fail safe, while the messaging service (GOOSE) over fiber was configured so that if the fiber connection was lost the relay would not react. Having the fiber optic connection improved the response time in an incident detected at the receiving station by 17ms. This has been acknowledged as a significant improvement over the traditional copper only trip signal.

Interconnection of a Microgrid to the Utility Primary Network

BCIT's Energy OASIS is an inverter-based grid-interconnected system. Given the need to have access to the available power on the utility feeder, interconnection of such a system with the utility grid is critical. Such an interconnection needs to meet the applicable technical requirements of IEEE-1547 Standard as well as jurisdictional requirements set by BC Hydro, City of Burnaby and BCIT Facilities Services for reliable operation and safety. These requirements and the tests/analysis conducted to prove full compliance with these requirements are then captured in an "Interconnection agreement" document concluded by relevant stakeholders.

The interconnection process for OASIS provided a great opportunity for BCIT researchers and industry partners to grow their expertise in the areas where interconnection of power generators to BC Hydro's network is required. Knowledge gained during the technical screening and approval process for Energy OASIS could be applied to similar projects where those projects need to meet the specific requirements as stated in the BC Hydro's "*35 kV and Below Interconnection Requirements for Power Generators*[3]". It is realized that the scope of this document has been recently extended (May 2010) to include inverter-based generator technologies such as solar photovoltaic systems. Energy OASIS intended to also provide opportunity for BC Hydro's interconnection and distribution department to flesh out the details of technical requirements for this type of applications.

8 General Lessons Learned

Design and realization of a complex system, using a consortium of diverse partners with different corporate cultures, way of working and technologies is extremely challenging. Aside from technical challenges in integrating such diverse technologies, the development team learnt the following valuable lessons:

- It is extremely important to ensure a smooth transition and handover between various groups and teams within partner organizations. For example, in some cases, commitments made by

[3] BC Hydro Document – Accessed March 23, 2015: http://www.bchydro.com/content/dam/hydro/medialib/internet/documents/info/pdf/info_distribution_interconnection_requirements.pdf

technical sales teams were not properly communicated with implementation teams within the same organization.

- The need to negotiate and conclude a role and responsibility matrix upfront. Any ambiguity in who is responsible for what in the early stages of the development can cost the Project valuable time and efforts later on to elaborate and identify.
- More time spent at the system design phase will help with smoother transition between various stages of the development. In particular, detailed specification of each and every component upfront can be extremely beneficial to the overall project schedule later on.
- It is critical to enquire with each and every partner the specific definitions which different companies have for the same objects, implementations and flavors of the same standards. Confusions which can arise in the debugging phase due to seemingly similar, but different definitions for the same parts of the applicable standards could be extremely time consuming.

9 Demonstration and Knowledge Transfer

Community Event

A BCIT Internal community awareness event was held prior to start of construction for BCIT's faculty, students, and staff. Speakers at the event included both BCIT and BC Hydro project stakeholders.

Figure 9-1: OASIS BCIT Community Awareness Event

OASIS Demonstration Tours

A schedule of visits to the OASIS project site in 2014 is included in Appendix D. Demonstration tours of the site have included groups from:

- APEGBC (British Columbia Association of Professional Engineers and Geoscientists),
- National Research Council Western Lab (NRC)
- CEATI (Centre for Energy Advancement through Technological Innovation)
- Wilfred-Laurier University (WLU)
- Alpha Technologies

OASIS Education and Outreach

Education and outreach activities to-date, or currently in-progress include:

- Participation in NRC / NRCan Energy Storage Workshop
- Ongoing lectures and demonstrations to BCIT Students in BCIT's School of Energy Bachelor of Engineering in Power Systems program.
- Student projects including BCIT Bachelor of Engineering Life Cycle Analysis project using OASIS Facility components.
- MOA in-progress with APEGBC to deliver professional development seminars.

10 Benefits

Energy OASIS is a demonstration facility designed to optimize its charging services based on the total cost of available energy from different sources, for example from the utility feed, battery energy storage system and/or the solar photovoltaic installation. In both Grid-tied and Islanded modes use-case and operational scenarios have been applied to test, validate, and demonstrate technologies, and to enrich learning experiences. From Grid-tied mode use-cases such as experimenting with energy balancing plans to time-shift peak demands can be explored. Islanded-mode use-case experiments that supply and provide power to the loads from either solar and/or energy stored in the battery storage can be explored. As a living lab environment energy OASIS has the components and control systems required for demonstrating a range of applications within a microgrid. Going forward, there are many more use-cases that can be developed and explored by educators and researchers as demonstration scenarios.

Benefits to Canada include increased use of similar solutions in other jurisdictions in Canada for:

- Grid-scale battery energy storage system installations.
- Integration of renewable intermittent energy sources.
- Remote community electrification.

Benefits to Stakeholders:

- Panasonic, the BESS manufacturer and integrator, will use the OASIS battery system remotely monitored test bed and demonstration site. Data gathered from BESS operation through remote monitoring will inform ongoing development and operations of battery energy storage.
- Panasonic will also test and demonstrate the viability of its Photovoltaic technology in a North American utility-grade microgrid environment.
- Siemens will test and demonstrate the integration and functionality of its Distributed Energy Management System (DEMS) within a typical North American microgrid environment.
- Schneider Electric will demonstrate and validate the features and functionality of its new generation of Fast DC charging stations in a real clustered installation.
- Car2Go will experiment with the feasibility of cloud-based charging technology and solutions.
- BC Hydro will look into the viability of the integration of large scale storage technology and renewable sources into its grid.
- BCIT will expand research opportunities for its students, staff and researchers by adding more capabilities and functions to its already existing Smart Microgrid Initiative.

11 Conclusions

The OASIS project has shown how soft and firm sources of energy could be integrated in a distribution environment to provide reliable service for unplanned loads, such as Electric Cars. In the process, OASIS demonstrated the viability of battery energy storage technologies as a means to counteract the intermittent nature of soft power, as well as the role an Energy Management System can play in ensuring the dispatch-ability of diverse portfolio of energy sources.

OASIS has shown the strong potential for solar PV as a generation source. In general, grid-scale energy storage must be increased from present-day levels, in order to balance the expected increase in intermittent clean renewable energy sources, and to balance and stabilize the grid as grid power becomes more variable due to factors such as:

- Flexible Smart Grid control strategies exploiting computers in the grid and digital protection and control communications,
- Bi-directional power flow at the transmission and distribution levels,
- Grid-interactive microgrids and small- to mid-scale distributed energy resources.
- A combination of grid-scale energy storage, microgrids with local storage, efficient HVDC very-long-distance power transmission capable of spanning weather systems, and demand-response control is likely needed to maintain grid stability in the face of the needed significant penetration of intermittent clean electricity generation into the electrical power grid.

At the start of the OASIS project, the DC charging stations on the market were in early development. There is still work to be done to facilitate integration of EV Charging systems with the mainstream. OASIS project knowledge sharing activities have shown that many issues are not isolated ones. Historically end users have not generally had access to equipment like DC fast chargers that control such a large amount of power. Vendors of DC fast chargers are still learning how to engineer equipment that exposes EV drivers to this level of power. Looking at a gasoline pump, consumer information signage and labeling is consistent and quite standardized. For EV charging stations in general there are many different philosophies about what information needs to be displayed to the EV drivers and how big to display the data. More testing with the public is required to find a workable solution to address this issue. Additional work is needed to in order to ensure adequate planning of DC charger locations. OASIS is a position to facilitate sound strategic planning of EV infrastructure by providing gap analysis and reporting capabilities.

Project Opportunities and Next Steps

The OASIS Demonstration Facility is working to increase the operational run-time with continued system level commissioning and operational testing under diverse conditions. Follow-on activities are also being explored in a number of areas including:

- Data collection and analysis of installed system and components (generation, consumption, electric vehicle charging, battery, etc.).
- Further development of BCIT's Driver HMI software (Kiosk and Mobile App)
- Addition of reactive power (VAR) management to OASIS EMS.
- Integration with other smart nano-grids within the BCIT campus Smart Microgrid.
- Integration of OASIS in Plugshare.

- Development of further networking capabilities for OASIS.
- Integration of Navigational capabilities and queuing technologies within OASIS.
- Continued knowledge dissemination activities with stakeholder communities.

The Energy OASIS Demonstration Facility provides unique education and research opportunities:

- Utility technician training
- Community-scale microgrid data analysis, modeling, research
- Grid-scale Lithium-ion battery storage research
- Conservation technology demonstrations and validation
- Power automation system training
- EV charging and related technology testing & validation.

Appendix A: OASIS Project Tour and Demonstration List

Visits to the OASIS Demonstration Facility in year 2014, consisting of presentation and system demonstration include, but are not limited to the following:

- November 20, 2014 - OASIS and Microgrid Tour for CEATI (Centre for Energy Advancement through Technological Innovation) Protection and Control Conference attendees. Interests: Substation upgrades for OASIS, OASIS use of IEC 61850 communication protocol, OASIS application of demand response, potential training opportunities.
- October 30, 2014 - OASIS Tour for EV/VE Conference attendees. Interests: PV and EV Charging, application of demand response.
- October 23, 2014 - OASIS and Microgrid tour for attendees of IA-HEV event hosted in Vancouver by NRCan. Interests: OASIS and Microgrid general and as relates to electric vehicles.
- October 8, 2014 – OASIS Tour for Schneider Electric. Interests: OASIS system, particularly overall control. Follow-up tour on Monday, Oct 20th with a view to developing an SDTC project related to OASIS.
- October 7, 2014 – OASIS and Microgrid Tour for members of the Sustainability group at Wilfred Laurier University. Interests: Operational efficiency and business case for solar energy.
- September 10, 2014 – OASIS and Microgrid tour for approximately 26 delegates from the CEATI AGM for the Smart Grid Working Group and AMI Working Group.
- September 3, 2014 – OASIS and Microgrid tour for the New Westminster chapter of APEG BC Approximately 10 attendees. Interests varied - Professional Engineers in various disciplines.
- June 12, 2014 – OASIS and Microgrid tour for Hong Kong Electrical Engineers delegation, organized by BC Hydro. Interests: renewable energy, OASIS, AFRESH.
- June 11, 2014 – OASIS and Microgrid tour for management team from Grand Villa Hotel. Interests: solar energy, renewable energy, OASIS, Gateway rooftop PV, as part of a business case they are developing for installing solar energy at a new facility in the Okanagan that is currently in the planning stages.
- May 28, 2014 – OASIS and Microgrid tour for Comision Federal de Electricidad (CFE), Mexico. Approximately 12 delegates. Interests: renewable energy and integration, OASIS, AMI.
- May 16, 2014 – OASIS and Microgrid tour for Steven Wong from NRCan/Canmet Energy. Interests: OASIS, solar forecasting, EVs & EV modelling.
- May 1, 2014 – A project close-off presentation and tour of OASIS for BC Hydro Executives Kip Morison, Don Stuckert, Helen Whittaker, Giuseppe Stanciulescu, Raymond Lings, Mark Dubois-Phillips, Sara Mellard. Interests: As key contributors and stakeholders of OASIS project.
- April 25, 2014 – OASIS tour for UBC Sustainability Staff. Interests in solar energy, EV charging, and operational efficiency and developing a business case.

Appendix B: Project Fact Sheet

See separate document: CEF_OASIS_Project_Final_Report-Project_Fact_Sheet.doc / pdf