CIGRE-484

2022 CIGRE Canada Conference & Expo
Calgary, Alberta, Oct.31 – Nov. 3, 2022

Virtualization of the Experiential Learning Platform for Operation and Maintenance of Smart Microgrid Applications in Remote and Rural Communities in Canada

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SUMMARY

Canada has approximately 300 remote communities, primarily categorized as off-grid and inaccessible. Power generation in these communities is mainly thru diesel [1], using outdated and often poorly maintained diesel power plants. As such, there is universal agreement among all stakeholders, including first nation communities, Provincial Governments (and their crown-owned utility corporations), and the Federal Government, that the status quo is no longer sustainable. Various programs have been developed to help these communities transition out of diesel and move toward employing clean energy technologies for power generation [2]. However, the main impediment to that desire and drive is the absence of local and indigenous capacities within these communities to operate, maintain and upkeep such complex assets. Remote and isolated communities cannot transition to green and renewable energies without the active participation of informed citizens, operators, and community members. Nevertheless, the development of local and indigenous technical and vocational capacity required to empower the community to look after such solutions and technologies necessitates community members to be hands-on trained on similar technologies and solutions. Furthermore, such training is critical for training the workforce on the actual behaviour of critical infrastructure (such as power plants). For some time, the industry has considered simulation environments for analysis, planning and verification in the design stage. However, for system operators' training, the preference has always been to expose the trainees to real physical systems and how these would behave vis-a-vis actual operational scenarios and real inputs/stimuli. Yet, travelling long distances to such training locations for remote and isolated community members is often challenging and, in some particular circumstances, such as in the age of COVID-19, almost impossible. Therefore, an innovative remote vocational training program was needed to address this critical need. In 2020, BCIT's Smart Microgrid Applied Research Team (SMART) was granted funding by the Digital Technology Supercluster to develop safe and secure online access technologies to real physical assets, combined with pedagogical models and instructional material required to conduct experiential training over the cloud for underserved and remote communities. This paper details the necessary steps for virtualizing grid-tied and off-grid microgrid solutions utilizing physical assets by implementing multiple use-cases.

KEYWORDS

Virtualization, Distributed Energy Optimisation, Clean Energy Power Plant, Vocational Training, Pedagogical Models, Microgrid, Cloud Human Machine Interface

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INTRODUCTION

One of the most effective ways to prepare the job-ready workforce is to provide hands-on training in the classrooms and the field. The COVID-19 pandemic has significantly impacted education systems and how we teach and learn today. Nevertheless, experiential learning through exposure to real systems and physical assets was not exempt. Realizing that this pandemic is not the first one and will not be the last we encounter, BCIT has emerged more robust than ever and pivoted its offerings to embrace new ways of learning. For example, today, BCIT offers various online and distance courses compared to the years before the COVID-19 pandemic. Following suit, with funding support from the Digital Technology Supercluster [3], BCIT's Smart Microgrid Applied Research Team (SMART) aimed to develop digital competencies and skills in planning, operating, and upkeep clean energy power plants in remote and isolated communities. Hence, SMART equipped its Smart Microgrid Facility [4] with advanced virtualization technologies and cloud-based applications, which enabled BCIT to create a remote hands-on vocational training platform for remote communities who seek to learn vocational skills and training in such technologies and thereby make a career in technical services and maintenance activities related to power plants. Subsequently, SMART developed suitable pedagogical models for various scenarios using their existing microgrid infrastructure. SMART looked at microgrid solutions for conventional remote/isolated off-grid systems to reduce their reliance on fossil fuels for power generation. We developed models and tested various use-cases, such as penetrating renewables, specifically solar PV and wind, and integrating energy storage systems, i.e. batteries, to fulfill the loads. BCIT then replicated a digital copy of the command & control layer for the existing physical microgrid assets and moved that control layer into cyberspace, allowing remote access to the physical platform. In addition, a virtual cloud-based energy optimization solution was developed for cohorts of trainees to securely collaborate in cyberspace and work together on various aspects of the microgrid's operations, safely sharing observations and findings. The dashboard enables trainees to manipulate operational and control strategies for the microgrid components in real-time and receive instantaneous feedback from physical assets for their commands and actions. Moreover, BCIT developed instructional content and integrated it into BCIT's existing Learning Management System (LMS). Next, we will explain the details for virtualizing grid-tied and off-grid microgrid solutions utilizing physical assets by implementing multiple use-cases.

TECHNICAL OVERVIEW

BCIT transformed its Smart Microgrid training program from a physical hands-on training system into an online and remote hands-on training environment by focusing on the following:

a. Digital replication of the command-and-control layer of the physical assets and moving that control layer into the cyber-space, thus allowing remote access to the physical platform ;
b. Securing remote access to the training platform for cohorts/teams, enabling secure collaboration in cyberspace for team members to work together on various aspects of the microgrid's operations, safely sharing observations, tasks, and findings; and
c. Combining the virtual physical assets with advanced instructional materials, running over BCIT's LEM to support individual, cohort, and team-based learning.

The Control System was segregated into three hierarchical levels:

- Level 3 – Distributed Energy Optimisation (DEOP) Cloud Application helps the campuses, industry, utilities, IPPs and EPCs, aggregators and Energy Service Companies (ESCO) to improve performance and increase profitability. At a high level, DEOP provides for Transparency & Energy KPIs, Distributed Energy Resources (DER), Performance Monitoring & Microgrid Optimization [5]. This aggregator will collect information from all the assets via the MGC for dashboarding and optimization. The trainees will then use this platform to operate and monitor the microgrid remotely.
- Level 2 – Local Microgrid Control (MGC) Level: SICAM A8000 was utilized as the MGC and configured to achieve the use-cases described in subsequent sections. Information gathered from the field assets is sent to the controller via Siemens Intelligent Electronic Device (IED) 7SJ85

relay over IEC 61850 Protocol. Siemens IED was configured as IEC 61850 server, and MGC was configured as IEC 61850 Client. The MGC communicates upstream to DEOP via IEC104 Slave, and DEOP serves as the IEC104 Master.

- Level 1 – Field Assets Level: Solar Photovoltaic (PV), Wind Turbine (WT), Battery Energy Storage System (BESS), Diesel Genset (DG), Electric Vehicle (EV) charger unit, Loads & Grid Connection were considered within the virtual asset mix, which were configured within the existing RTDS system. Siemens 7SJ85 relay configured to support Commands / Inputs / Outputs / SMVs over the IEC61850 protocol received from the virtual assets and Real-Time Digital Simulator (RTDS) sends this information to MGC. All information coming to the 7SJ85 relay is over the communication network only, and no hardwiring was required.

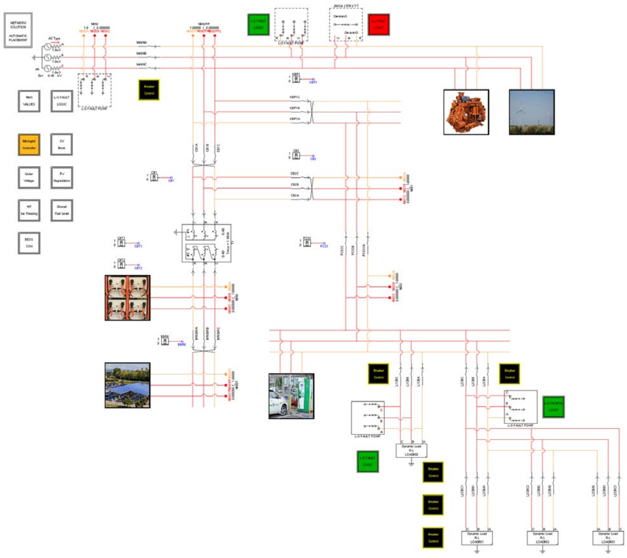

Figure 1 System Single-line Diagram _ RTDS Simulation

We simulated all virtual assets (DG, WT, PV, EV charging units, grid, and loads) within the RTDS. All necessary inputs and outputs to the RTDS flow through the 7SJ85 device via either IEC61850 MMS, GOOSE, and/or Sample Measured Values (SMVs). From a communication perspective[1], the 7SJ85 device utilizes IEC61850 for communication from RTDS. Upstream to SICAM A8000 MGC from the 7SJ85, IEC61850 client, MMS was utilized. The communication architecture was designed to use the PRP protocol between the devices and the layer 2 switches, and the RSTP protocol was configured to interconnect the layer 2 switches. The RTDS was configured with measurement nodes at particular points on the Single Line Diagram (SLD) in order to sample the required measurements for the 7SJ85 relay to carry out protection functions and utilize MGC for assessing the generation of the assets and utilization on the load side. These measurements will be sent across over IEC 61850-process bus SMVs. MAC filtering was configured on project switches to manage these SMVs and GOOSE messages within the network. The 7SJ85 relay used the IEEE 1588 Precision Time Protocol (PTP) as a requirement to use the process bus features, and all switches in the network function as a transparent clock for time synchronization. For protection and fault situations, from the laboratory setup perspective, only one fault location (main breaker at PoCC) has been utilized for fault generation by RTDS, and 50/51, 67, 27, 59, 81U/O, 25, and 86 protection functions are envisioned at PoCC.

FUNCTIONAL OVERVIEW

The overall system represents several use-cases. Therefore, we also explored several scenarios for each use-case, as described in items 1, 2, and 3 below. The general requirements to run all the three use-cases in normal operation are as follows:

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[1] For details, see CIGRE 2022 Paper #481

- RTDS is in a normal working condition with all virtual assets communicating. In this case, RTDS will be configured in such a way that at least one generation source (DG or BESS or the Grid) forms the grid
- The 7SJ85 relays and DER are online, and protections are active and functional
- MGC and DEOP must be online and operational
- Data flow must be suitable for all the SMVs, and
- All indications and switching device statuses must be operational

The generator control prerequisites are operating characteristics, fuel consumption vs power output, minimum on/off time, and ramp up/down limits. When applicable (use cases 2 and 3) for renewable control, the curtailable, grid forming assets or grid must be available. When either BESS or DG is grid forming, and renewable resources are "ON," the reserve margin will be calculated. Based on the BESS state of the charge (SOC), DG ramp max/ min operating limit, renewable will be curtailed or switched to "ON/OFF". For the BESS/DG control in the grid following mode, BESS/DG shall follow the setpoint commands, while in grid forming mode, it will balance the supply and demand by itself.

Use-cases:

1. **Conventional off-grid** addresses remote/off-grid systems comprise diesel power plants and typical remote community loads.

Normal Operation:
In the normal operation mode, once the respective system and assets are selected to be "ON" in DEOP, the Auto mode will be turned on and based on input received by MGC from DEOP, MGC starts the operation of sequences for opening/closing the breaker to accommodate system Auto Start/Black Start and Auto Stop. For the load shedding and restoration, the protection relay at the Point of Common Coupling (PoCC) monitors the under/over frequency phenomena in this scenario and during the out-of-range frequencies, the non-critical load(s) will be disconnected. Once the frequency returns to the healthy range for a set period, the non-critical load will be reconnected.

Faults may occur due to the following:
- Communication failure (RTDS to relay or relay to MGC or MGC to DEOP) is detected. In this case, the DEOP will trigger an alarm. No control modes can be activated, and the current status of the assets will be unknown.
- Diesel generator faults can also happen due to internal failure. In this case, RTDS will trigger an alarm, the diesel generator will be switched off, and the conventional off-grid operation will not be possible.
- MGC faults occur when MGC is unavailable due to internal failure, communication infrastructure failure, etc. The DEOP will push an MGC failure notification, and once the MGC fault occurs, it stops all the automation and locks out the system. A remote lockout reset from the DEOP can reset the lockout, and MGC goes back to its respective mode. The decision tree can evaluate the respective fault investigation steps.

2. **Off-grid Microgrid solutions** will look at remote off-grid systems powered by DG, BESS, RET(s), EV charging units and typical remote community loads. Use-case #2 at a high level is a diesel offset play through increased penetration of renewables – specifically solar PV and wind – focused on load fulfillment of typical remote community loads.

Normal Operation:
In the normal operation, MGC will accommodate scenarios such as Auto Start/Black Start-with either DG or BESS-, Auto Stop, Intelligent Dispatch with resilient mode or renewable mode and Load Shedding and Restoration.

The *Intelligent Dispatch mode* in MGC determines the real-time dispatch of the PV, WT, DG, and BESS according to the mode triggered by the DEOP, current loading condition, selected assets, renewable generation, and limits assigned to the assets.

Note: for conventional off-grid systems, the default mode is the resilient mode for dispatch, in which the use of diesel generators is minimized. However, MGC does not need to send any dispatch setpoint to the diesel generator as DG will operate in grid forming mode, balancing the supply and demand.

In the *Resilient mode of dispatch*, the DG must be selected to be "ON" and a "Grid- forming" asset. As a result, BESS SOC will always be at its maximum limits, and the excess renewable generation will always be curtailed.

In the *Green or Economic mode of dispatch,* if DG is a grid-forming asset, loads first will be met by renewables keeping the least generation from DG; BESS will be charged or discharged based on excess renewables after feeding load, keeping the least generations required from DG.

If BESS is a grid-forming asset, the load will be first met by renewables, and BESS will keep SOC close to its 50% level. The DG will operate if renewables cannot meet the load or BESS SOC drops to certain thresholds. Conversely, renewable generation will be curtailed if the load is insufficient and BESS SOC exceeds certain thresholds.

Faults may occur due to communication failure, diesel generator internal fault, BESS internal fault, PV internal fault, WT internal fault, EV charger internal fault, MGC failure

3. **Grid-tied (All-inclusive) Microgrid – BCIT OASIS Simulated Microgrid** in which the participating assets are the grid, BESS, PV, WT, EV Charger and typical loads

Normal Operation:
In the normal operation, MGC will accommodate Auto start/Black start with either grid or BESS, Planned/Unplanned Islanding, Intelligent Dispatch with Economy Resilient or Renewable mode, and Load Shedding and Restoration.
When the *grid is connected* and in the *resilient mode of dispatch*, the BESS SOC will always be at maximum and loads will be met primarily from renewable generation and remaining fed from the grid. Conversely, if BESS SOC is at maximum and there's a low demand (load), renewables will be curtailed.

In the *Green or Economic mode of dispatch*: If the grid is available, the use of renewable energy is maximized, the excess renewable generation charges the BESS, and when renewable generation is not enough to meet the load, BESS discharges to meet the remaining load. The grid will meet the remaining load if renewables and BESS cannot meet the load. If there is excess renewable generation, the load is not enough; and BESS SOC reaches its maximum limit, the excess renewable generation will be exported to the grid.

During the *islanding operation,* if BESS is a grid-forming asset, the load is first met by renewables, and BESS keeps SOC within its limits. Renewable generation will be curtailed if the load is insufficient and BESS SOC exceeds certain thresholds. If BESS SOC reaches its minimum level, the system will be in blackout mode. BESS shall follow the setpoint commands in the grid following mode, while it will balance the supply and demand in grid forming mode.

The *Load Shedding, Restoration, and Intelligence Dispatch* are similar to use-case 2.

Fault scenarios may include communication failure, BESS fault, PV fault, WT fault, EV Charger fault and protection faults- when there is a critical protection fault, the relay trips and locks out the breaker at the PoCC for further investigation-.The triggered protection function can be investigated using DEOP and accessing the DIGSI5 software.

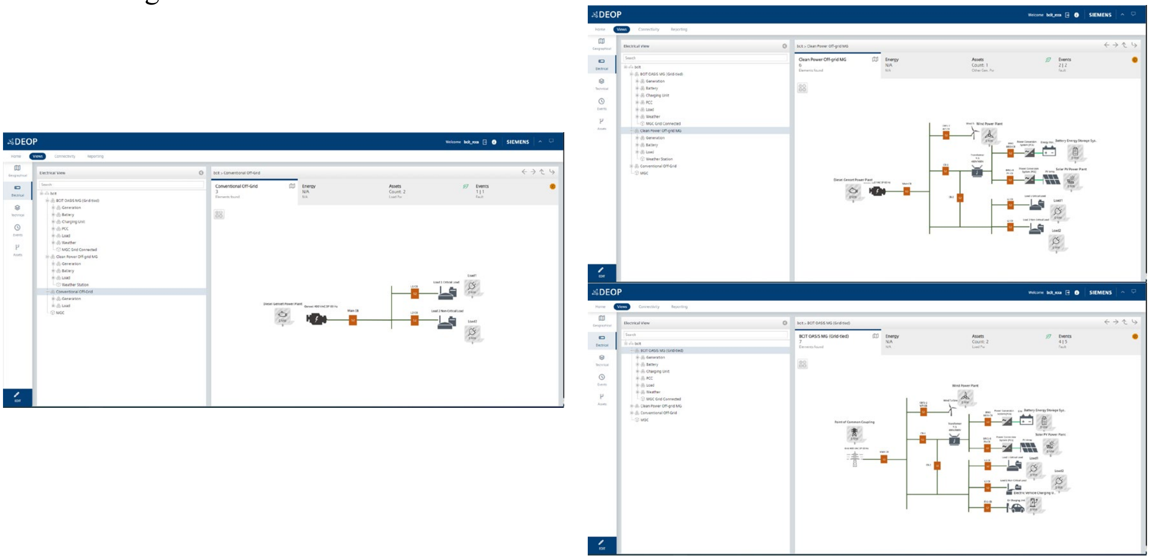

Figure 2 Conventional Off-grid(left), Off-grid Microgrid Solutions(top right) and grid-tied MG (bottom right) on DEOP Solution

TOOLS FOR THE VIRTUALIZATION OF MICROGRIDS

We used three different tools[2] to configure the microgrid's control levels. For level 1, DIGSI was used to parameterize the protection functions, configure the signals and test the SIPROTEC 7SJ85 relay. In level 2, TOOLBOX II was used to configure the SICAM A8000 MGC, signals, and communication protocols and to develop and test the logic created for three use-cases and their respective power dispatch schemes. Finally, for level 3, the DEOP interface was used as cloud HMI to control and monitor the microgrid, with optimization features as a third level in the system automation. As the primary tool utilized for this training program, next, we will describe various features of DEOP.

Distributed Energy Optimisation (DEOP):

DEOP is a cloud-based software with multiple tools that allows the trainees to monitor and control the use-cases represented in the microgrid. Through various screens, such as "Geolocation" and "Electrical views /Single-Line Diagrams", the trainees can monitor the microgrid assets, their connectivity status, decision tree, events, alarms logs, and control the assets. For example, the below flowchart (Figure 3) illustrates how DEOP user interface visualizes all the actions that the trainee can perform within the tool through a menu with the following main features: Home, Views, Connectivity, Reporting, and Optimization.

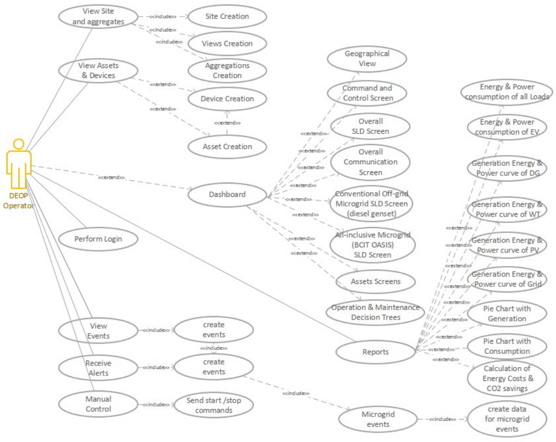

Figure 3 DEOP User- interface Diagram

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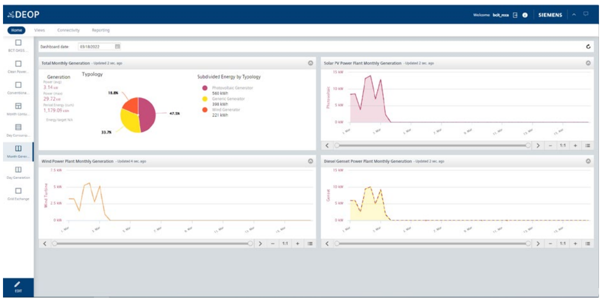
[2] Siemens Products

- **Home**

The Home feature (Figure 4) provides an overall view, charts and historical data of the main variables in the running/functional microgrid system, where trainees can evaluate the performance and status of the assets. In addition, this screen allows for high-level aggregated monitoring & control of the PV, WT, Loads, BESS, DG, and Grid.

Figure 4 DEOP Home Screen



- **Views**

The DEOP has various screens for microgrid monitoring and control, allowing the trainees to see the status of the assets from different perspectives. For example, the “Geographical View” (Figure 5) uses a Google Maps style to present the assets' physical location, status, and power consumption/generation. The “Electrical View” (Figure 6) illustrates the single-line diagram for each use case, showing the asset mix, status, and power flows.

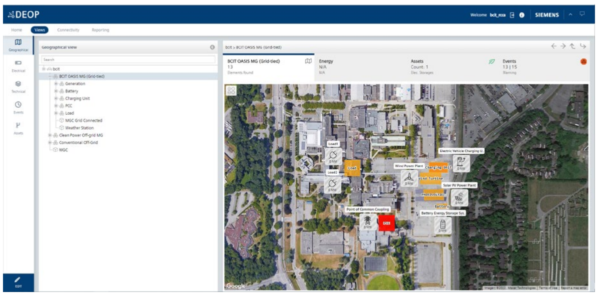


Figure 5 Geographical View

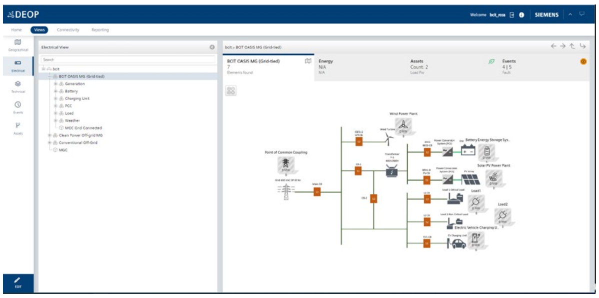
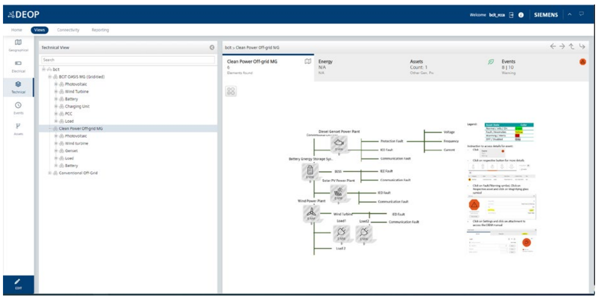
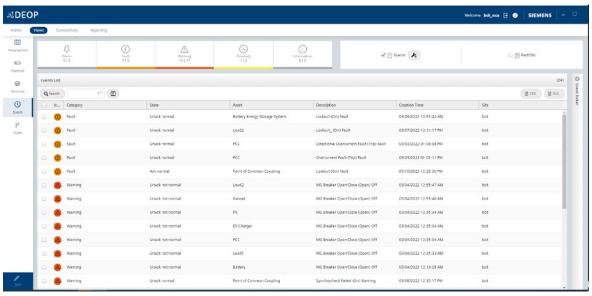


Figure 6 Electrical View

Each asset has a detailed view and enables the users to see the signals coming from the MGC. This detailed view allows the trainees to evaluate all the measurements and check the microgrid assets' time stamps, alarms and status. Furthermore, this detailed view enables the trainee to control the MGC or individual assets according to the use-case asset selection, control mode (resilient/green mode), or the interaction (manual/auto) the trainee wants with the microgrid. In general, the DEOP interface has been designed to illustrate two different screens to help the trainees diagnose and understand the flow of faults and events in the microgrid in a simple but detailed way. Each use-case has a decision tree (Figure 7) where trainees can see the system's assets’ failures, sources, and locations. Additionally, there is an event and alarm log (Figure 8) where the trainees evaluate which alarms are active, their respective time stamps, and their priority in the system (fault, warning, etc.). The entire alarms and events configuration uses a specific colour scheme to help trainees understand the situation.





Events List (24)

Category	State	Asset	Description	Creation Time	Site
Fault	Unack normal	Battery Energy Storage System	Lockout (On) Fault	03/09/2022 10:53:42 AM	bcit
Fault	Unack normal	Load2	Lockout_ (On) Fault	03/07/2022 12:14:17 PM	bcit
Fault	Unack normal	PCC	Directional Overcurrent Fault (Trip) Fault	03/03/2022 01:08:38 PM	bcit
Fault	Unack normal	PCC	Overcurrent Fault (Trip) Fault	03/03/2022 01:03:11 PM	bcit
Fault	Ack normal	Point of Common Coupling	Lockout (On) Fault	03/10/2022 12:28:36 PM	bcit
Warning	Unack not normal	Load2	MG Breaker Open/Close (Open) Off	03/04/2022 12:55:47 AM	bcit
Warning	Unack not normal	Genset	MG Breaker Open/Close (Open) Off	03/04/2022 12:55:46 AM	bcit
Warning	Unack not normal	PV	MG Breaker Open/Close (Open) Off	03/04/2022 12:35:34 AM	bcit
Warning	Unack not normal	EV Charger	MG Breaker Open/Close (Open) Off	03/04/2022 12:35:34 AM	bcit
Warning	Unack not normal	PCC	MG Breaker Open/Close (Open) Off	03/04/2022 12:35:34 AM	bcit
Warning	Unack not normal	Load1	MG Breaker Open/Close (Open) Off	03/04/2022 12:35:33 AM	bcit
Warning	Unack not normal	Battery	MG Breaker Open/Close (Open) Off	03/04/2022 12:19:28 AM	bcit
Warning	Unack normal	Point of Common Coupling	Synchrocheck Failed (On) Warning	03/08/2022 12:35:17 PM	bcit

Figure 7 Decision Tree

Figure 8 Events and Alarm Logs

- **Connectivity**

DEOP allows the trainees to verify the communication status of each asset, helping to diagnose possible failures that the system may present and check the parametrization of the protocol (IEC104) the MGC uses to communicate with DEOP.

- **Reporting Screen**

In the cloud interface, the trainees can create reports with all the available variables in the system, configuring a specific time frame and a custom time precision.

- **Optimization**

DEOP was also configured as a third-level controller with optimization algorithms based on the weather forecast, power interchange, and BESS SOC.

CONCLUSIONS

BCIT's SMART transformed its Smart Microgrid Training program from a physical hands-on training system into an online and remote hands-on training environment. The project developed safe and secure online access technologies to real physical assets, combined with pedagogical models and instructional material required to conduct experiential training for underserved and remote communities over the cloud. The direct impact of such training programs is the systemic creation of indigenous capacities within these communities, enabling them to be in charge of and true owners of their community's economic development programs. Communities with indigenous capacity and skills can not only define, specify and determine their critical infrastructure needs but also operate, maintain and repair such assets. The "Experiential Learning Platform for Operation and Maintenance of Smart Microgrid Applications in Remote and Rural Communities" could be offered to remote communities in Canada without compromising the learning objectives and pedagogical outcomes associated with experiential and hands-on training programs. Such a training program could soon incorporate digital skills required for maintaining and operating Clean Energy Power Plants. Since this training program presented a critical body of knowledge, we hope to leverage our learnings and utilize this platform to include systems such as Water Treatment Facilities, Sewage Treatment, Pipeline Pumping Stations, Cellular Communication Systems, Food Processing and other typical systems in Canada's isolated and remote communities.

ACKNOWLEDGMENT

« Virtualization of the Experiential Learning Platform for Operation and Maintenance of Smart Microgrid Applications in Remote and Rural Communities in Canada was funded by the Government of Canada under the Digital Technology Supercluster's Capacity Building Program.»

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