An initial validation of a real-time cloud-based 'web-of-cells' energy management system

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Abstract

This paper describes the real-time, virtual-physical simulation environment developed to validate a cloud-based Distributed Energy Resource Management System (DERMS). This work forms part of the 'ScotCLUE' project which resides within the wider ERA-NET Smart Energy Systems CLUE consortium. CLUE aims to develop and validate a tool kit, across five European demonstration sites, which supports the implementation of sustainable local energy while considering future ICT architectures and the interaction with surrounding electricity systems.

1. Introduction

Facilitating the deployment of low carbon distributed energy resources (DERs) is becoming increasingly challenging for distribution system operators (DSOs) as they try to operate their assets within physical and regulatory limits. Social [1] and governmental pressure [2] to shift towards a 'net-zero' society, in Scotland by 2045, with some cities aiming to be carbon neutral by 2030 [3] [4], will undoubtedly create challenges for DSOs particularly as heat and transport sectors transition away from fossil fuels [5].

The ERA-NET SES (European Research Area – Networks – Smart Energy Systems) funded project, 'CLUE' [6] (Concepts, Planning, Demonstration and Replication of Local User-friendly Energy Communities) has been established to develop and validate a 'web-of-cells' (WoC) distribution system control approach across five European demonstration sites in Germany, Sweden, Scotland and two sites in Austria. The Scottish work package (ScotCLUE) will establish the first steps towards the design of a vector integration platform (VIP) by studying the interactions between different energy vectors (i.e. electricity, transport and heat).

With site access restrictions placed upon the ScotCLUE consortium due to the COVID-19 pandemic, a method to test the DERMS platform was required prior to system deployment (now scheduled for mid-late 2021). It was necessary for testing to consider a mix of controllable (e.g. EV chargers) and observable (e.g. uncontrolled generation) assets while incorporating electrical power system modelling to allow network constraints to be identified and managed.

This paper presents the methods used to test the DERMS platform using live data feeds from operational, laboratory and simulated energy assets.

2. Background

In the last decade there has been major changes in the make-up, organisation, and operation of the electricity sector. From being a primarily centralised system dependant on carbon-intensive generation sources to a more distributed system with significantly more generation connecting at the 'grid-edge'. While the electricity sector in Scotland has made substantial progress in reducing its reliance on fossil fuels (final figures for 2019 indicate that the equivalent of 89.5% of gross electricity consumption was from renewables, up from 76.2% in 2018 [7]), electricity only accounts for 24% of the final energy consumption in Scotland [5]. There is, therefore, a further challenge to reduce the emissions associated with heat and transport sectors [8]. It is widely accepted that the electricity system will be instrumental in reducing the emissions associated with these remaining sectors (e.g. storage heaters, heat pumps, electric vehicles and green hydrogen production).

The coordination between various energy vectors will be key to delivering the net-zero (and beyond) targets set by the Scottish Government [9]. It is anticipated that the potential controllability within distribution networks, particularly at low voltage (<1000 V), will increase significantly with the adoption of new low carbon technologies. For example, all government-funded home EV chargers installed after July 2019 must be 'smart-enabled' to allow EV charging to be slowed, or halted, to manage supply and demand [10].

As more DERs connect to the distribution network the associated management and the control of the system will quickly become too vast for centralised DSO control room operatives to manage on an individual basis. To help network operators manage their systems and allow community groups to prioritise local issues (e.g. offering lower tariffs to the fuel poor), the WoC smart-grid concept, often described as a

'divide and concur' approach, has been proposed and studied extensively via simulation and laboratory experiments [11]. The WoC concept essentially splits the distribution network into smaller, more manageable, areas which are controlled autonomously at a local level, while global objectives (e.g. managing a network outages) are set by the network operator. While this concept has attracted much discussion and associated research, there is little operational experience of this idea [12]. In the context of ScotCLUE, a 'cell' is defined as a managed group of, one or more, related and fixed assets which are operated to achieve an objective or series of objectives. A cell could, therefore, be a single asset, e.g., a community wind turbine, or a collection of assets, e.g. an office facility with rooftop solar PV and EV chargers, which are coordinated at a local (micro) level to achieve a goal, e.g. to minimise the export of generation to the grid.

Leven, the trial area for the ScotCLUE project, Fig. 1, has a unique demographic of local energy assets (including several wind turbines, a solar PV park, electrical vehicles, hybrid diesel-hydrogen refuge collection vehicles and an industrial CHP network) with a community suffering from fuel poverty [13]. The ScotCLUE project plans to utilise this asset base to help create and study the effects of a vector integration platform which can control supply and demand across multiple energy cells under a variety of different regulatory and market arrangements. This will involve implementing a cloud-based distributed energy management platform - Fig. 2.

Fig. 1: ScotCLUE demonstration area.

Fig. 2: Conceptual design of the WoC VIP.

3. Pre-deployment testing

The pre-deployment demonstration and verification activities for the ScotCLUE project have had to adapt due to travel restrictions related to the COVID-19 pandemic. All initial testing and validation activities were conducted remotely using various testing approaches to test integration between the DERMS and controllable, observable, and unobservable assets. This off-site validation has allowed several new approaches to be investigated which may broaden the reach of the project going forward, for example, a cell could be formed between community generation assets sited in Leven with remote city centre office blocks.

There are three key elements to the off-site demonstration activities: a) cloud-based DERMS platform, b) real-time power system model, and, c). controllable and/or observable energy assets. These elements will be discussed in the subsequent sections.

3.1 Cloud-based DERMS platform

The ScotCLUE project will make use of several cloud hosted instances of the Smarter Grid Solution's "ANM Strata" platform [14]. This software is responsible for the coordination of multiple cells in the proposed system architecture. ANM Strata receives both telemetry data from field assets (e.g. power output from a wind turbine, battery charge level, circuit breaker status) and issues set-points to controllable assets based on network conditions, forecast events (e.g. weather) and user-definable schedules.

3.2 Real-time power system model

Since site access was limited, a real-time power system simulator, housed in the Dynamic Power Systems Laboratory at the University of Strathclyde, was used to represent the electrical network for the Leven area [15]. This real-time network model communicates system operating parameters, such as node voltages and power flows to the DERMS platform via integration software specifically developed for the project. This bridging software receives multiple network values from the real-time simulator, packetizes them, and issues them to a cloud database platform called Firebase [16]. ANM Strata polls this database once every ten seconds for changes. As discussed previously in section 3.1, energy assets will be instructed to target certain set-points based on this updating information and control objectives.

A subsection of the Leven network has been extracted for modelling and verification purposes. The single-line diagram for the network is presented in Fig. 3. Several additional assets have been added to the network including a grid-scale battery storage system and a 2 MW hydrogen electrolyser. The network includes two 11 kV busbars to which several controllable assets are connected.

Fig. 3: Single-line network model.

The assets connected to this network will be represented in several ways for testing and verification. These integration approaches will be outlined in the subsequent section.

3.3 Controllable and/or observable energy assets

Four main integration approaches have been developed for the ScotCLUE validation activities. These approaches are integrated both with the real-time power system simulator as well as the DERMS.

3.3.1 Recorded data playback

Historic real and reactive power values will be 'played-back' in real time into the electrical, real-time power system simulation platform and will act as set-points to modelled load and generation assets. These power traces are updated every second (although operating at higher frequencies is possible) and act as setpoints into the real-time digital simulation platform. Data playback is achieved via a time synchronised python script which runs on a low-powered compute unit and interfaces to the electrical simulation platform via a UDP socket connection, using a virtual private network (VPN) tunnel.

This integration method allows the DERMS to control assets against a wide variety of known grid conditions. This allows the response time and detection algorithms inside the DERMS platform to be benchmarked and tuned prior to full system deployment.

3.3.2 Live data-streams

Using a similar methodology to that outlined in section 3.3.1, live data from several assets in the field were streamed in real time directly into the power-system simulation platform. These assets make use of standard Modbus power quality

meters which connect, again, via a low-cost embedded computer. The translation between Modbus signals to the packet-based IP is achieved via the browser-based programming environment, Node-RED [11].

Monitoring equipment installed at a remote community centre is presented in Fig. 4. At this site, three-phase power measurements are captured every second in addition to the control setpoint of a 200 kW gas central heating boiler. This heating demand information will be used to inform hydrogen demand data for the H2_1 electrolyser at a future point in the ScotCLUE project. Traces of the three-phase power and heating demands are presented in Fig. 5 and Fig. 6.

Fig. 4: Electrical measurement and communication setup for mid-sized community centre. Boiler control setpoint data is collected via a BACnet over IP protocol [18].

Fig. 5: Example of a live data-stream of mid-sized community centre heating demand – 24th February 2021.

Fig. 6: Example of a live data-stream of mid-sized community centre electrical demand – 24th February 2021.

3.3.3 Virtual Modelling

Software modelling allows for the performance of future assets to be assessed against various operating scenarios. Modelling

is achieved via scalable python scripts hosted on a standard desktop computer. These models communicate to a Firebase database as discussed previously and can receive set-points directly from the DERMS or via user entry. Virtual models can be quickly developed and scaled using the containerised solution.

3.3.4 Hardware prototyping

This final integration method will allow small-scale demonstration of control of flexible power system assets. This approach will make use of a programmable logic controller (PLC) running a containerised Node-RED instance. For the purposes of demonstration, the PLC will control the setpoint of a variable frequency drive (VFD) which is connected to an asynchronous motor. Various telemetry metrics (including terminal voltages, current flow and real and reactive power) and control setpoints are made available to the DERMS system via the Firebase instance. Fig. 7 presents an example of the equipment used for this integration approach.

Fig. 7: Hardware prototyping test rig showing a) PLC with power monitoring capabilities, b) current transformers, c) VFD, d) gigabit network switch, and, e) asynchronous motor (0.75 kVA).

3.4 System overview

Integration of the DERMS platform, the real-time power system simulator and both the physical and virtual energy assets allowed for various testing scenarios to be investigated during development of the VIP WoC concept. Fig. 8 presents a diagram summarising all the integrations discussed in this paper. Note that the arrowheads show the primary direction of information flow between elements. This diagram captures the high-level process to support future validation in ScotCLUE.

Fig. 8: Network diagram showing the interconnections and dataflows between virtual/physical modelled assets, the power system simulator and the cloud-hosted VIP DERMS control platform.

4 Initial results and future works

The project is entering the field deployment stage at the time of writing this paper, so full results from the ScotCLUE project are not yet available for publication. Several initial tests have been carried out using this testing environment showing correct operation between the DERMS, the real-time power system simulator and both physical and virtual energy assets. These tests, importantly, proved that the DERMS software could observe the status of energy assets, make decisions based on programmed algorithms and issue updated setpoints to which devices responded correctly during testing.

Work to date on the ScotCLUE project has allowed the fundamental building blocks of the web-of-cells vector integration platform to be developed and verified. Going forward, the next steps in this project are to link existing physical assets in the community of Leven, including solar PV, battery and EV charging assets, to the DERMS platform. Once these links have been established, the WoC vector integration platform will be able to be validated on a live electrical network while providing benefits to the community of Leven.

This will allow several case studies to be investigated and trialled over longer time periods including remote battery operation and control, and green-hydrogen production.

For assets not presently connected in the Leven area, virtual representations will be used. For example, the virtual model of the hydrogen electrolyser will allow the benefits/challenges of aligning periods of high wind turbine output with production of green hydrogen to be investigated.

4 Conclusion

This paper has presented the initial progress and findings relating to demonstration activities associated with the ScotCLUE ERA-NET SES project. To date, several physical and virtual assets have been successfully controlled via the cloud-hosted distribution energy management system.

Going forward, several other test scenarios will be investigated and operated across longer time horizons to try and quantify the benefit and investigate potential servicing offerings of the web-of-cells concept. In particular, the cross-energy vector analysis will be investigated in detail.

The benefit of this hybrid virtual-physical demonstration approach will allow real-world distributed energy assets to be used in parallel with software models. This allows de-risking of future investment in energy assets by verifying their operation/performance prior to installation. Full results and dissemination for the ScotCLUE project will be available by mid-2022.

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