特集論文

REACT：離島での持続可能な再生可能エネルギー利用

REACT: Renewable Energy for Self－Sustainable Island Communities

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要　旨

気候変動対策として，再生可能エネルギーの活用が強く求められている。気象条件で発電量が変動する再生可能エネルギーによって電力需要を100%満たすことは困難であるが，自給率は需要側の柔軟な対応で大きく向上させることができる。ヒートポンプは冷暖房や温水供給を高効率に行う技術であり，蓄電・蓄熱機器と組み合わせて柔軟な運転を行うことで，変動する再生可能エネルギーを有効活用できる。今回，欧州での分散型再生可能エネルギーの有効利用のため，コミュニティ規模でヒートポンプと蓄電・蓄熱機器を組み合わせた，クラウドベースのエネルギー管理技術を開発した。さらに，この技術を適用して欧州の離島での実証プロジェクト“REACT”に参画した。

1. Introduction

The transition to a low－carbon future depends on an increased penetration of renewable energy sources (RES) to displace the burning of fossil fuels. For remote geographic islands, the problem of energy security under increasing levels of electrification is particularly acute due to the limited interactions with the mainland electricity grid. This can result in high energy costs for consumers and an over－reliance on backup systems such as diesel generators [(1)]. Such challenges have inspired new approaches to energy infrastructure and planning that combine distributed generation and storage technologies with demand－side response.

REACT is an Innovation Action project funded by the European Commission Horizon 2020 programme, that focuses on a community－centric approach to energy management for off－shore islands. The main output of REACT is a scalable digital platform for the planning and management of renewable energy and storage－enabled infrastructures, which has been piloted at three island demonstration sites in Europe [(2)]. The project objectives are to increase renewable energy generation capacity and enable distribution grid flexibility through automated demand response actions delivered by the cloud platform. End－users are also encouraged to participate in manual demand response actions based on recommendations delivered through a bespoke smart－phone application. In this paper, we will provide an overview of the REACT technology components and interfaces; with a particular focus on heating, ventilation and air conditioning (HVAC) equipment provided by Mitsubishi Electric, which serves as a key technology for demand－side flexibility.

2. REACT Platform Architecture

A simplified representation of the REACT platform architecture is shown in **Figure 1**. The core cloud－side components include a relational database, a time－series database and a semantic repository. Advanced services are deployed in the REACT platform as secure containerized applications, each running with its own schedule based on specific temporal triggers. These services include energy production and demand forecasting, energy optimization, distribution－grid state estimation (DGSE) and consumer－recommender services. Visualization services are provided in the form of a web dashboard and mobile phone application.

The REACT platform uses well－established communication structures based on Internet of Things (IoT) technology. The middleware core application is based on MQTT (Message Queuing Telemetry Transport), a lightweight publish－subscribe protocol that runs over standard networking. The middleware application allows the exchange of measurement data and control actions between all field devices and the cloud-level components using a common canonical data model (CDM) to ensure full interoperability. Field devices, which include heat pumps, battery systems and smart meters, are shown on the right-hand side of **Figure 1**. The field devices used in the REACT demonstration can be classed in two categories: assets that communicate via a local gateway device using open protocols, such as Modbus, and assets that use a proprietary cloud-based communication interface. For the former category, the local gateway device also provides CDM translation and MQTT publish and subscribe functions via the OpenMUC software.

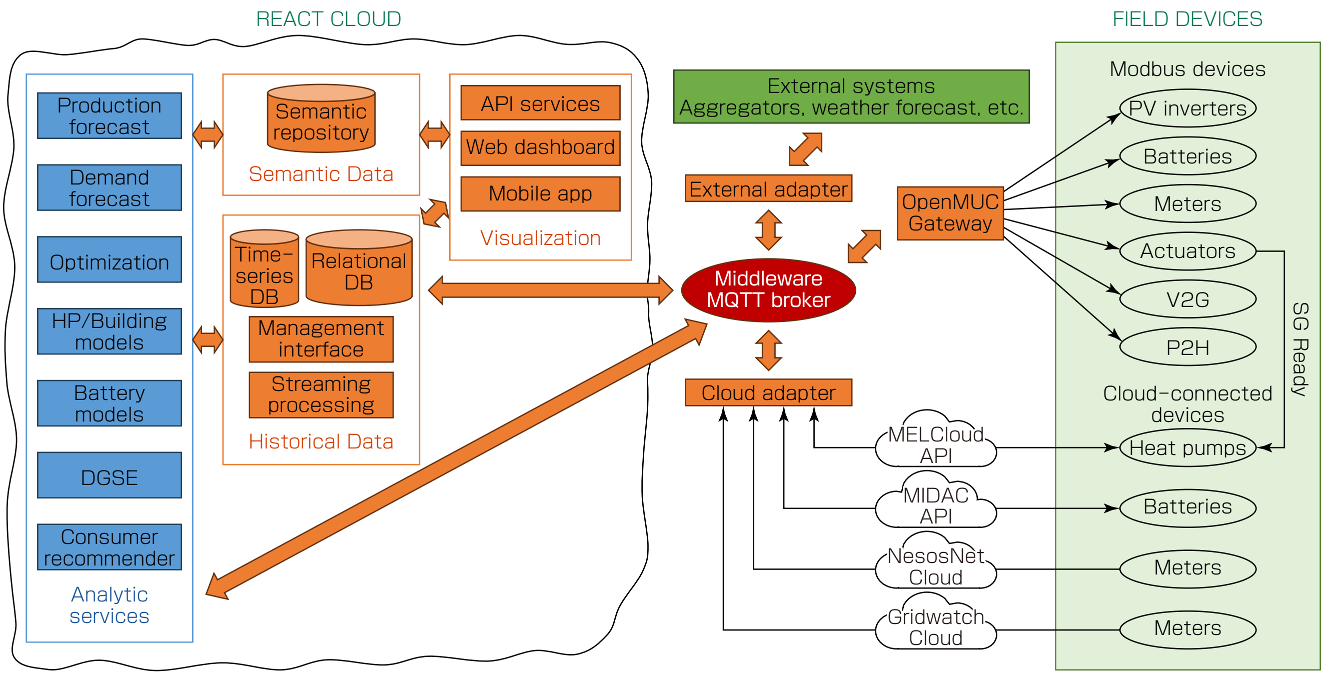

Figure 1-REACT platform architecture

3. HVAC System Interfaces

3.1 MELCloud

MELCloud is the Mitsubishi Electric cloud solution for monitoring and control of residential and commercial HVAC systems in the European region. MELCloud was chosen as the primary HVAC system interface for the REACT demonstration due to the simple installation procedure and reduced setup time compared to conventional building management system (BMS) solutions. The MELCloud interface is connected to a port on the heat pump controller board and paired to local Wi-Fi[1], with no requirements for complex wiring or network reconfiguration. An application programming interface (API) for MELCloud is used to send measurement requests and control actions from the REACT platform to individual heat pump devices. A cloud adaptor software component was developed for issuing the API calls and translating received messages to the REACT CDM format. Control actions available in MELCloud include forced domestic hot water (DHW) heating for air-to-water (ATW) heat pumps and temperature or fan speed adjustments for air-to-air (ATA) heat pumps. MELCloud also allows access to real-time operating status and energy data for individual heat pump systems.

1 Wi-Fi is a registered trademark of Wi-Fi Alliance.

3.2 Smart Grid Ready

Smart Grid Ready (or "SG Ready") is a label that indicates specific devices, including heat pumps, that meet certain technical standards for operation in smart grid environments. Since 2016, Mitsubishi Electric have incorporated an SG Ready interface into Ecodan ATW heat pumps. The interface enables the heat pump operating state to be switched by an external signal, to boost or limit power consumption. SG Ready is used in limited cases in the REACT demonstration, for heat pump systems that include a supplementary thermal store for space heating, in addition to a DHW cylinder. SG Ready provides a means for direct integration with a PV or battery system, where the heat pump activation signal can be provided by a digital output or relay on the inverter device. This enables autonomous operation for PV self-consumption, in which the heat pump is operated to charge the thermal store when the electrical battery is fully charged.

4. REACT Energy Optimization

The energy optimization performed within the REACT platform is based on an Energy Hub approach, whereby each building is represented as a prosumer node, i.e., an entity that both produces and consumes energy [3]. For each prosumer node, a central energy converter device (e.g., a PV inverter or battery system inverter) is the local point for managing all energy flows in the building between the grid and the local storage, generation and electrical loads. Battery systems are useful for collectively shaping the load profile at the grid level, by operating at controllable charging or discharging rates or fixed set points for grid import or export. Meanwhile, heat pumps and smart appliances can be operated flexibly to increase or decrease household energy consumption at certain times of the day.

The REACT optimization methodology is performed at two levels. At the single-prosumer level, the Energy Hub optimization is implemented as a mixed-integer linear programming (MILP) model. A time-horizon of 24 hours is typically applied, in line with the day-ahead energy pricing and forecasting inputs. The optimization objective is to minimize operational costs to the end-user, within constraints that are implemented based on a selected Energy Hub control mode: e.g., constant battery operation, constant grid interaction, consumption peak shaving or reverse peak shaving. The output is a schedule of setpoints and optimal consumption curves for each node, which is stored in the database. At the distribution system level, grid capacity management (GCM) techniques are applied to optimize power flow across the network while avoiding voltage violations. This two-level approach allows the REACT solution to provide both grid-level services and savings to the end-user under a diverse range of operating conditions and grid configurations.

5. Demonstration Cases

The REACT solution was piloted at three European demonstration sites located on offshore islands: the Irish island of Inishmore, the Italian island of San Pietro and the Spanish island of La Graciosa. Each site consists of a cluster of 20-30 public and private buildings. The participating buildings have rooftop solar-PV installations, providing a total distributed generation capacity of 100-120 kW per demonstration site. Each site also has a distributed array of battery energy storage systems including lithium-ion, lead-carbon and sodium nickel-chloride technologies, with storage capacities between 4-16 kWh per building. At the Irish demonstration site, Mitsubishi Electric Ecodan ATW heat pumps are used to provide space heating and hot water for residential and small office buildings, with installed system capacities ranging from 8 kW to 24 kW (thermal). At the Italian demonstration site, the M-series ATA product range is used for residential air conditioning, with system capacities between 2-10 kW (thermal). Other state-of-the-art technologies include vehicle-to-grid (V2G) electric vehicle charging and a power-to-hydrogen (P2H) storage facility.

The demonstrations were designed around realistic use cases, with business models that can be adapted for large-scale replication. Battery system use-case objectives included minimizing grid import, minimizing grid export or managing reactive power. Heat pump use cases were designed to target load shifting using thermal storage. While previous studies have shown that heat pumps with thermal storage can be highly effective for reducing carbon emissions and energy costs at the single-household level [(4)], REACT also considers the influence that coordinated control of multiple heat pump systems can have on energy demand at the community level. Taking the Irish island as a case study, a future electrification of heat scenario was investigated where 200 dwellings (approximately two-thirds of all homes on the island) are heated with air-to-water heat pumps [(5)]. A simulation model was used to evaluate novel control strategies based on flexible charging of DHW storage cylinders using the range of control functions available in MELCloud. Through coordinated use of the forced DHW heating function, it was predicted that a 23% reduction in daily maximum electrical load or an 18% reduction in curtailment of renewable energy could be achieved.

A further indirect form of load shifting using heat pumps can also be targeted through adjustments to space heating and cooling setpoints. Towards this aim, building simulation modules were developed in REACT based on reduced-order physical models of the demonstration site buildings, with machine-learning methods to calibrate the model properties and determine user preferences based on data collected in the REACT platform [(6)]. For each forecast period, heating and cooling set point schedules were determined by an algorithm to match optimized power consumption profiles within the bounds of thermal comfort.

6. Future Outlook

In Europe, the framework for demand-side response at the household level is taking shape. In 2023, the European Commission Joint Research Centre is designing a Code of Conduct (CoC) for Energy Smart Appliances (ESA), which defines requirements for data sharing and interoperability [(7)]. The CoC will describe mandatory and optional functions for different types of ESA, including HVAC systems, that may include use cases such as energy monitoring, flexible start time and incentive-based management of power consumption. Manufacturers that sign up to the code of conduct will be required to make their devices interoperable by adopting an open standard of communication that complies with the Smart Applications Reference (SAREF) ontology [(8)]. Meanwhile, the British Standards Institute have published a publicly available specification on ESAs for the UK, that provides a reference architecture for implicit and explicit demand response services with defined interfaces between the electricity grid, energy management devices and smart appliances [(9)]. To demonstrate the core principles, the UK government has funded several trial projects with HVAC and EV manufacturers as part of the Interoperable Demand Side Response programme [(10)].

For offshore islands and remote microgrids, the introduction of advanced RES and smart-grid technologies must be complemented with efforts to promote community engagement and provide improved access to technical support and maintenance infrastructure [(11)]. Demonstration projects like REACT are important for developing know-how and practical experience for local installers and technicians, while also exploring new ideas about how maintenance of RES and storage equipment can be managed at the community level. In the future, remote diagnostic capabilities of cloud monitoring services such as MELCloud can also support major advances in the efficiency of service and maintenance provision for remote locations.

Acknowledgement

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