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Decision tree aided planning and energy balancing of planned community microgrids

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HIGHLIGHTS

- Application of microgrid concepts on planned community energy systems.
- Decision tree tool for energy balancing & storage planning appraisal in microgrids.
- Test implementation for parallelizing the algorithm using distributed controllers.

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ABSTRACT

Planned Communities (PCs) present a unique opportunity for deployment of intelligent control of demand-side distributed energy resources (DER) and storage, which may be organized in Microgrids (MGs). MGs require balancing for maintaining safe and resilient operation. This paper discusses the implications of using MG concepts for planning and control of energy systems within PCs. A novel tool is presented, based on decision trees (DTs), with two potential applications: (i) planning of energy storage systems within such MGs and (ii) controlling energy resources for energy balancing within a PC MG. The energy storage planning and energy balancing methodology is validated through sensitivity case studies, demonstrating its effectiveness. A test implementation is presented, utilizing distributed controller hardware to execute the energy balancing algorithm in real-time.

1. Introduction

The microgrid (MG) paradigm is a Smart Grid application aims at facilitating more efficient management of loads and increased penetration of renewable generation in distribution networks [1]. Despite extensive trial applications, there has been no actual commercial deployment of the MG paradigm, but mostly retrofitting realizations [2–4], largely due to complex regulatory frameworks [4–6].

The planned community (PC) residential approach, such as “New Towns” in Hong Kong, has been gaining ground as a means of decongesting the overcrowded city centres. A PC constitutes a cell of energy consumption with various types of loads. Renewable Energy Sources (RES) or Distributed Energy Resources (DER), such as Distributed Generators (DG), Energy Storage and Controllable Loads, may be included in the PC energy portfolio. Management of all electrical resources and actors of a PC can be facilitated and optimized through approaches developed for MG [4]. The fact that the electrical network within the PC is in the ownership of the developer (i.e. private wires), makes the MG approach applicable at all levels of control and monitoring. Thus, PC MG present a unique opportunity to implement MG approaches from the network design phase, in contrast to the retrofitting applications deployed so far [6–9], which is the first contribution of this paper.

The PC may also be required to be connected to the medium voltage (or higher) and be served as an industrial customer or similar, due to its size. Hence, the PC MG can be defined as a prosumer – a possible participant in energy and/or ancillary services markets. A basic requirement in order to utilize the financial benefits of market participation is a concise daily and hourly operational energy balancing framework, such as the one developed in this work, which is the second and main contribution of this paper.

MGs can be operated either interconnected to the grid or as autonomous island systems [2,3]. Technical issues are associated

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with MG operation, in both modes [4]. These justify the need for advanced control methodologies, which take into account multiple variables, considerations and constraints. Two main control philosophies have been mainly applied to the MG paradigm: central and distributed. The advantages and disadvantages of each philosophy are outlined below [4]:

- The Central control strategy tends to be optimal due to its wider scope and is based on traditional power system management and control. However, communication infrastructure requirements are high, while loss of information may lead to loss of optimality or asset controllability. Advanced algorithms have been utilized, such as Heuristic Optimisation techniques (Genetic Algorithms and Ant Colony Optimization [4,10], Agent-based Potential Function method [11] and Virtual Power Plant approaches [12].
- The Distributed control strategy is less demanding in infrastructure and caters for DER autonomy. However, it can be sub-optimal, complex DER communication and management protocols are required. Intelligent agents have been mostly proposed for such control, comprising multiple distributed controllers, coordinating towards a common goal [4,13,14]; field trials of such approaches have proven their feasibility [15]. To a lesser degree techniques utilizing exclusively local information have also been discussed [16].

The density of stochastic residential loads, and possibly intermittent RES-based generation, introduces stochastic characteristics to the power balance in a PC MG [17–20]. These stochastic effects influence the economic scheduling of the reserves to be procured [21,22]. In addition, forecasting methods have accuracy limits, which may lead to deviations from day-ahead dispatching, introducing further uncertainty. Hence, the internal load and generation deviations from the expected values should be handled in an hour-ahead scheduling horizon (usual scheduling period in PSs [23] based on very short-term forecasting.

The uncertainty of the loads and uncontrollable energy resources is a significant challenge for current energy balancing methods. Deviations, even from short-term forecasts, are always a possibility and it was shown in previous work by the authors that existing balancing methodologies such as intelligent control or centralized optimization methods cannot prevent that from happening [13].

This paper presents a novel intra-day internal energy balancing methodology for addressing both substantial load increase (or loss of local DER power) and substantial load reduction (or increase of local DER power) within a PC MG. The major novelty of the proposed methodology is that it can accommodate uncertainty both within the expected confidence intervals of the forecasts [17–20] as also beyond them [22], since it always comes up with a merit-order dispatch list that can be used as fall back in case of deviations from the near global optimum position. The cost of each dispatch as well as network technical constraints are taken into account. That way techniques suggesting increased reserves, which affect negatively PS economics [24,22,25], or curtailment of stochastic RES, which limits penetration of emission-free DG units [15,25,26] are avoided. A DT is used to extract each of two dispatches (one of increasing and one of decreasing total active power output) out of a large set of possible dispatches, analytically generated through Monte Carlo simulations. The Monte Carlo simulations generate the Learning Set (LS) of the DT according to the constraints, limits and required power reduction, while the DT extracts the dispatch that represents the most profitable (in terms of cost) solution for the PC MG owner/operator. Ensuring profitability of the corrective measures as described, avoids complex pricing methods [15] which introduce considerations for penalties in the day-ahead scheduling, as also the consideration for employing costly storage topologies [21,27,28].

The methodology was also developed as a tool for energy storage planning, since it can assess the installation characteristics of energy storage systems that most economically serve PC MG energy balancing deviations. This is the third major contribution of this paper.

The DT methodology is inherently centralized, which does not offer the benefits related to distributed approaches, as described above [4,13]. The final contribution of this paper is a proposed technique to decentralize the DT methodology, utilizing local PC MG controllers. Thus, the developed system incorporates the benefits of the DT methodology, but also takes advantage of the flexibility, extensibility and resilience of distributed control systems [4,13].

In Section 2 further details on the PC MG concept are offered along with some comments on the energy balancing problem of PC MG. The DT as a machine learning tool and the complete outline of the suggested methodology are analysed in Section 3. Simulated results are presented in Section 4, of a realistic PC MG case study assessing the proposed methodology, both as a storage planning investment appraisal tool and as an energy balancing control technique. A test implementation of the suggested methodology is presented in Section 5, while Section 6 concludes this work.

2. Planned Communities as microgrid entities – definition and incentives

In previous work, the authors have identified the main challenges for a PC installation to be voltage deviations beyond standardized limits, over-loading of electrical equipment and asymmetrical use of storage availability [29]. Hence, management of the available assets is required. However, the viability of investment in MG approaches is unclear; i.e. an assessment of the business case for MG applications to PC projects has to be performed.

RES DG units, especially wind, tidal and photovoltaic generation, are characterized by lower Operational Expenses (OpEx) compared to conventional plants and constantly decreasing Capital Expenses (CapEx). Hence, incorporating RES generation in the PC, even without considering any kind of incentive, is by itself profitable for the end customers' energy consumption. On the other hand adding batteries to any installation, despite being a step towards improved resilience, can be particularly expensive, due to their relatively high CapEx and short lifecycle [30]. In the UK energy market, Short-Term Operating Reserve (STOR) can be aggregated from multiple actors [31]. Utilising a battery storage system in a PC as a STOR contributor will greatly reduce its actual cost per kWh, while linking it with RES will offer additional value, due to mitigation of RES intermittency. It is assumed that the PC MG operator would have an obligation to follow a specific hourly schedule, due to its participation in energy or ancillary services markets, or because it may be closely controlled by the local system operator. Thus, any deviation from the day-ahead schedule will have to be dealt with internally or through the imbalances market [32]. Covering deviations internally may require committing the available storage reserve capacity; hence if STOR is called upon the PC MG, there will be – at least – a missed opportunity cost. Hence, the size of the storage system needs to be determined during system planning, as it affects PC MG economics.

The uncertainty of RES and demand has been proven in the literature [17–20]. According to [17] the averaged root mean square (RMS) error over a year for various day-ahead forecasting methods spans between 2.9% and 3.7%. Nevertheless, the point error during peak times can be considerably higher (±15%). In this paper, steep load changes have been modelled according to [18]. Wind power shows the highest error rates regarding its day-ahead forecast, at