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Optimization of distributed energy resources in an industrial microgrid

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Abstract

This paper introduces a model of an industrial microgrid with distributed energy resources (DERs). The model is applied to an existing manufacturing facility in Ireland. The test facility is connected to the main electricity grid but also has onsite generating units; a wind turbine and a combined heat and power (CHP) unit. The model generates a facility load forecast using historical data. A scenario analysis is then performed to investigate the effect of operating DERs, including demand response (DR), on carbon emissions and energy costs in an industrial microgrid. An energy storage component is then introduced and the viability of installing this technology is investigated.

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Keywords: Distributed energy resources; Indutrial microgrid; Load forecast; Green manufacturing; Energy management

1. Introduction

In 2015, industrial facilities accounted for 39.3% of electricity demand in Ireland, the largest share by sector, and one fifth of total energy demand [1]. In the past, the electricity demand of industrial facilities has been met by large-scale central power plants, and distributed via transmission and distribution systems, which often lead to losses [2]. This, along with the growing pressure to increase production of electricity from renewable sources, has led to a push to integrate distributed energy resources (DERs) into electricity supply [3]. As industrial facilities invest in DERs, these sites become industrial microgrids, whose operational objectives are expanded to energy efficiency, emission control and the use of alternative energy resources, and an investigation into the resulting benefits is the motivation for this study [4].

The Consortium for Electric Reliability Technology Solutions (CERTS) defines a microgrid as the aggregation of loads and sources operating as a single systems, that provides both power and heat [5]. Microgrids are utilized in a range of settings. Campus microgrids are often deployed on college campuses, prisons or military bases, allowing for central control and ensuring a level of service when disconnected from the main grid. Microgrids are also installed on islands or in remote areas where a connection to the grid is not viable. Industrial microgrids are being developed with an increase in DERs installed onsite.

DERs are energy resources that are typically located at the user's sites where the energy is used [5]. They consist of small, modular power sources, storage technologies and controllable loads [6]. The power sources can be dispatchable, such as onsite combined heat and power (CHP) unit, or they can be non-dispatchable, such as solar cells and wind turbines. Non-dispatchable power sources are of an intermittent nature and fluctuate in their output, due to their dependence on weather conditions [6]. The peak load of a facility can occur when the energy yield from an intermittent source is low. Energy storage technologies can aid in reducing the energy imbalance between supply and demand by storing energy and delivering it at a later time. Controllable loads are loads (electrical and thermal) that can be adjusted or reduced at critical times and for which the demand can be scheduled among a set of pre-defined operating points [7]. Controllable loads respond to a control signal and achieve a step change in power consumption, which can be based on a pricing signal, or a disturbance in power supply [8].

This paper introduces a model of a grid connected industrial microgrid with distributed energy resources installed onsite. The test facility is a large manufacturing plant in the south of

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Ireland. An overview of the facility is given in Fig. 1. The microgrid system is comprised of (a) the electricity load for the industrial facility, which is controllable via demand response (DR), (b) a 3MW wind turbine, providing intermittent power, (c) a controllable 405kW CHP unit, and (d) a 150kW lithium ion battery for energy storage (this is not currently installed at the facility but is included here as analysis on it's possible contribution is performed).

External to the facility is the incoming power from the electricity grid. Energy flow at the point of common coupling (PCC), the point where the on-site network meets the grid, is bi-directional. When an excess of electricity is produced by the DERs on-site, it is exported to the grid and revenue is earned by the facility. The remainder of the paper is laid out as follows: Section 2 of this paper describes the related literature in this field. Section 3 outlines the model framework and methodology for this investigation. Section 4 details the results of the model and concluding remarks are included in Section 5.

2. Review of related literature

Modeling of the DERs in a microgrid provides insight into the operation of the grid and opportunities to optimize the control of the individual units and the grid itself. Quiggin et al. [9] used a linear programming approach to model a microgrid with a mix of renewable power sources, energy storage technologies and DR systems. The mixed-renewable microgrid operation resulted in a reduction of demand fluctuations and improved energy balance between supply and demand. Tazvinga et al. [10] used model predictive control techniques to control the power flow of a hybrid power supply system with DERs, providing a degree of robustness against uncertainties. Wang et al. [11] proposed a power supply and demand management scheme for a microgrid with DERs to minimize the electrical generation cost and to optimize the operating schedule considering uncertainties due to intermittent renewable sources. Zhang et al. [12] developed a distributed energy management system for microgrids with a high penetration of renewable energy, based on power scheduling. The optimization problem was solved to minimize the microgrid cost. In [13], Ding et al. proposed a mixed integer linear programming based energy management model for an industrial facility with DERs. Using day-ahead electricity prices, the model optimized the operation of the DERs in order to shift peak demand and resulted in lower energy costs for the facility. Moura and de Almeida [14] proposed a multi-objective optimization method incorporating DR to define the mix of DERs, maximize their contribution to peak load, while minimizing cost and intermittence. In [15], Mohammadi et al. used a genetic algorithm optimization method to determine the optimum mix of DERs on a grid connected microgrid participating in a hybrid electricity market. Hawkes and Leach [16] developed a linear programming cost minimization model for the design and unit commitment of a microgrid with DERs, and found that grid connected microgrids were more economical than networks without a strong grid connection.

Operation of DERs in a microgrid can be further enhanced through accurate load forecasting. Lee et al. [17] applied artificial neural networks to short-term load forecasting of day ahead hourly electric loads of a power system, with the inputs restricted to past loads and resulted in a forecasting error of 2%. In [18], Park et al. use weather data in addition to past loads as predictors, and utilize artificial neural networks to forecast load.

In order to efficiently schedule dispatchable power sources in a microgrid, it is critical to utilize accurate predictions of power output from non-dispatchable generators such as solar and wind. Lydia et al. [19] detailed a review of the different methodologies for modeling of wind turbine power curves, both parametric and non-parametric. The research found that models where the characteristic equations are based on the actual power curve of the turbine are most accurate. In [20], parametric and non-parametric models are developed and are solved using advanced algorithms. The differential evolution algorithm applied to a five-parameter logistic function represents the best parametric model and the neural networks

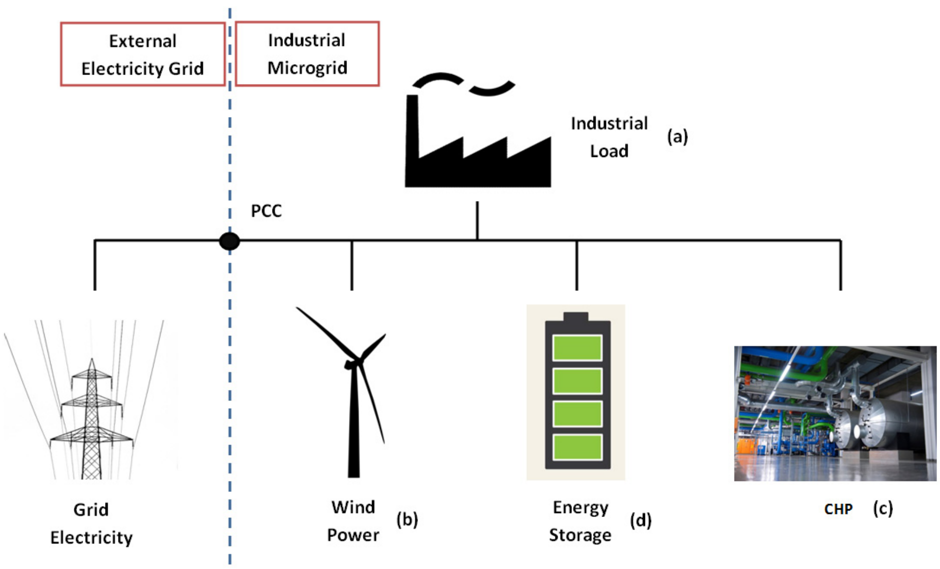

Fig. 1. Overview of test facility.