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A powerful visualization technique for electricity supply and demand at industrial sites with combined heat and power and wind generation

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ABSTRACT

The combination of wind generation and combined heat and power (CHP) on an industrial site brings significant design and operational challenges. The stochastic nature of wind power affects the flows of electricity imported and exported to and from the site. Economies of scale favor larger wind turbines, but at the same time it is also desirable to minimize the amount of electricity exported from the site to avoid incurring increased network infrastructure usage charges. Therefore the optimum situation is to maximize the proportion of the site load served by on-site generation. This paper looks at a visualization technique for power flows on an industrial site, which can be used to size on-site generators. The technique is applied to a test case, demonstrating how a simple combined heat and power control scheme can support the integration of on-site wind power. The addition of such CHP control has a small impact on the CHP unit but can greatly increase the proportion of wind generation consumed on-site. This visualization technique allows the comparison of different generation mixes and control schemes in order to arrive at the optimal mix from a technical and economic viewpoint.

Contents

1. Introduction

Industrial facilities consumed 18.1% of Ireland's total energy demand in 2009 and represented 33% of the total Irish electricity usage [1]. Historically, such industrial sites have received the bulk of this energy via legacy gas and electricity networks, built around

Abbreviations: BESS, battery energy storage system; CHP, combined heat and power; DG, distributed generation; IRR, internal rate of return; MIC, maximum import capacity; PCC, point of common coupling; PV, photovoltaic; RAPS, renewable autoproduction simulator; SEM, [Irish] single electricity market

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centralized large-scale generation/production plants. The wide-scale deployment of distributed generation (DG) units, embedded within the network, and sometimes behind the meter, is challenging the centralized model and provides the motivation for this study [2,3].

Certain industrial electricity users may find DG to be a more economical and environmentally friendly method of supplying their energy needs when compared with traditional centralized utility scale power plant supply [3–5]. DG is placed close to the consumer and in some cases behind the utility meter. Consequently, industrial sites benefit from DG power in three main ways: (1) the ability to utilize heat from combined heat and power (CHP); (2) saving on transmission, distribution and connection charges; (3) fixing a proportion of future energy costs. Additional benefits may accrue from controlling and utilizing excess energy in the manufacturing process.

At present there is a wide range of different DG technologies available for industrial sites. Several studies have attempted to formulate schemes for optimizing the operation of microgrids with embedded DG [6–8]. Hawkes and Leach [7] found that grid-connected DG was generally more economically advantageous than microgrids with weak grid connection, and recommended that a more comprehensive treatment of the economics of renewables in DG environments be carried out. Srivastava et al. [9] used the HOMER model to demonstrate the potential economic benefit of incorporating storage devices into microgrids with diesel generation, but found no economic case for adding storage to microgrids with embedded wind generation. Mohammadi et al. [10] presented a genetic algorithm methodology for optimizing the mix of DG units on a grid-connected microgrid participating in a hybrid electricity market which included centralized unit commitment but also allowed limited bilateral trading of electricity. The DG portfolio included photovoltaics (PV), a fuel cell and a battery energy storage system (BESS). The increased flexibility of the hybrid market over the pool market slightly reduced the local economic benefits from DG. In another study of a microgrid with distributed PV and wind generation, a methodology based on mixed-integer linear programming was developed in order to determine the size of BESS in order to maximize the economic benefit under grid-connected and islanded operation [11]. However, it should be emphasized that the results of all such economic evaluations are highly dependent on local subsidy regimes for renewables.

Determining and presenting the optimum DG type, size and mix can be a difficult task for industrial or commercial sites [12–14]. Widely varying solutions can be arrived at for two similar or closely located sites. Changing aspects within the site load, such as minimum demand and the duration during which it occurs greatly, affect the optimal DG mix and unit size. Taking these options into account and determining the best solution for the site can be a difficult task, because large data sets have to be analyzed.

The best approach to complete the analysis is to build a computer simulation model. Numerous existing software models aim to simulate the integration of large-scale variable renewable generation into power systems (see [15,16] for detailed reviews). Tools such as RETScreen, developed by Natural Resources Canada, are aimed at pre-feasibility assessments of renewable energy projects, rather than optimal system design, and operate at coarse time resolutions [17]. Another set of models, such as HOMER [9], is capable of simulating microgrids with weak or non-existent grid connections, or community-scale DG systems [18–20]. A survey of over two decades of work on optimizing conventional CHP operations is presented in [21]. However, to date the problem of optimizing renewable generation in an industrial setting, typically (although not necessarily) with strong grid connection, has not been specifically addressed by any computer model. The Renewable AutoProduction Simulator (RAPS) model has been developed specifically to analyze the supply and demand of electricity on industrial sites and is described in this paper. The model is split into three main modules. The first module calculates the cost of supplying the industrial load from the network. The second module simulates the integration of wind power to jointly supply the site together with grid-supplied electricity. Different turbine types can be specified. Finally, the CHP module can simulate the operation of a range of CHP units. The CHP unit, if selected, is integrated into the remaining site demand with excess power being exported back to the electrical grid.

Increasing the proportion of DG power utilized on-site ensures that the generator receives a higher price for that power, because power exported to the grid will only receive the market export price of electricity, but power supplied directly to the on-site customer displaces the higher grid-supply price paid by the end user. The higher grid-supplied prices are due to additional charges, which are added to the wholesale market price. These extra charges are applied to pay for tax, market operation, supplier's margin and the transportation of electricity from the power station to the site.

The EU Gas and Electricity Directive requires Member States to open their energy markets for large users and distributors [21]. The directive was implemented in Ireland in 2006 with the development of the single electricity market (SEM). The SEM is a centralized wholesale electricity market in which all units of electricity must be bought and sold via a gross mandatory pool. Furthermore the price varies on the half hour as calculated by the market operator's optimization engine. The engine calculates the price by selecting the cheapest mix of generation units required to meet the full electrical demand on the island of Ireland over the full day. The market engine estimates the price a day ahead of actual dispatch and reconciles the price 4 days later. This price is made available to industrial electricity users.

Industrial users can decide to fix their electricity price with their supplier over a number of months. The supplier then takes on the risk associated with the price variability. Whether the supplier takes on the risk of the variable market price or the industry site self-supplies, the SEM price is the benchmark price, setting the cost of electricity for each half hour across the island of Ireland. Thus the RAPS model uses this half hour market price to calculate the cost of electricity for the site.

The importance of using the SEM price is its varying nature, giving it the ability to reflect the true cost of grid-supplied electricity each half-hour. There is a high correlation between supplies from different wind farms across the island. It is important to understand that there will be a correlation between the output from DG wind turbines and network-connected wind farms. Due to the so-called 'merit order effect', the wholesale price of electricity is reduced in systems with high wind penetration during periods of high wind generation [22]. Therefore, if on-site wind generation is to be simulated, it should be done using contemporaneous SEM price data and wind speed data. Furthermore the Irish government has specified a target of 40% renewable electricity by 2020, of which wind power is expected to supply a large proportion, forcing down the price of electricity even further during periods of high wind generation [23].

DG units convert different energy resources such as oil, gas, wind, biomass or solar into electricity, heat and motion [24]. To optimize the on-site DG mix it can be helpful to separate the units into two main categories: dispatchable and non-dispatchable sources [24]. Dispatchable DG sources are units which can be called upon to provide power and stability for the electrical system, e.g. CHP, demand side management or storage. A non-dispatchable source can be a slow-response or totally uncontrollable supply, e.g. wind or solar. An overview of an example of such a DG system is given in Fig. 1 showing the factory loads and different supply types.