Energy xxx (2016) 1–9

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Impacts of electricity grid tariffs on flexible use of electricity to heat generation

Jon Gustav Kirkerud*, Erik Trømborg, Torjus Folsland Bolkesjø

Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, Norway

A R T I C L E I N F O

Article history:
Received 1 December 2015
Received in revised form
13 June 2016
Accepted 18 June 2016
Available online xxx

Keywords:
District heating
Power-to-heat
Variable renewable energy integration
Mixed integer model
Grid rent

A B S T R A C T

District heating plants having both electric boilers and alternative fuel options could hold a key in providing flexibility needed for cost efficient integration of variable renewable power. The electricity grid tariff is an important component of the electricity costs of electric boilers, and these tariffs may promote or hamper flexible use of power-to-heat. In this paper, a mixed integer cost minimization model that schedules the operation of different boilers in a district heating plant is developed and applied to analyze the impact of different tariff structures on flexibility provided by electric boilers. The results confirm that the structure of electric grid tariffs significantly influences the flexibility provided and the annual shares of electric boiler use, caused by differences in grid tariff structures, vary from 2% to 17%. Novel tariff structures with time-varying elements increase utilization electricity in low price periods and improve the profitability of power-to-heat as a flexibility solution. The study clearly demonstrates that system effects should be considered when grid tariffs for flexible electric boilers are designed and that novel tariff designs should be more widely adapted.

1. Introduction

New variable renewable energy (VRE) sources are increasing their share in worldwide electricity generation as a result of a need to decrease fossil-based power generation, while maintaining energy security. It is well known that high VRE shares cause challenges in load regulation, since the VRE supply cannot be regulated and storage of electricity has high costs. A recent review study [1] concludes that increased integration of thermal and electric systems (P2H) is promising for provision of flexibility needed for renewable power integration. District heating plants (DHP) with several fuel options can provide such flexibility if electricity is used for heating in periods with high power supply and low demand and other sources such as biomass is used when demand is high relative to supply. P2H in DHP has a large potential; for example in the Nordic region the DH generation is around 130 TWh, which correspond to about 30% of the size of the Nordic electricity market [2]. Electric boilers (EB) and heat pumps (HP) are mature P2H technologies available in the market. EB is in general more suited for flexibility purposes than HPs since the HPs have the economic characteristics of a base load technology — high investment costs and low operational costs [3]. The benefits of using EB in DHP for VRE integration has been addressed in several previous studies [4] strongly recommends using electricity and heat market interaction for increased energy system flexibility [5] studies the consequences of introducing these technologies into central cities in the Nordic energy market and concludes that it benefits the integration of wind power and saves fuel costs for heat producers. Also, [6], concludes that electric boilers provide substantial flexibility, especially for VRE, and that HPs combined with heat storage is a good solution to integrate baseload. Cities or municipalities can use P2H strategies to increase their share of renewable energy, according to [7].

To fully exploit the flexibility potential from P2H, prices must be efficient and time varying [8]. The retail price of electricity relative to other fuels determine when and how the electric boiler is used in a DHP. This cost consists of three components: wholesale electricity price, transmission costs (grid rent) and taxes. Taxes are usually low for industrial customers [9]. Wholesale electricity costs is usually the largest part and is normally charged based on the hourly wholesale price of electricity. In competitive markets, the hourly wholesale price provides efficient price signals conveying the short-term marginal cost of electricity generation. Transmission cost is the second largest cost component of an EB and comprises

* Corresponding author. P.O. Box 5003, NO-1432 Ås, Norway.
E-mail address: jon.gustav.kirkerud@nmbu.no (J.G. Kirkerud).

http://dx.doi.org/10.1016/j.energy.2016.06.147
0360-5442/

according to [9] 20–50% of total electricity costs in European countries. An increase in VRE deployment can cause this cost to further increase as these sources are often located far from load centers [10]. District system operators (DSOs) cover allowed costs, determined by electricity market regulators, through grid tariffs. However, time variation of tariffs are often neglected, as tariffs must be carefully designed and consider the interest of the DSO, the consumers and economic efficiency. This conflict of interest partly cause substantial variations in the actual tariff structure between countries and between DSOs. Consequently, conditions for flexible use of P2H vary widely and is seldom optimal.

The introduction of smart meters with real-time measurements, combined with the recent increase in deployment of variable renewables has actualized grid tariff designs that increase demand-side flexibility. Real-time measurements allow for tariffs designs that are more sophisticated. High VRE shares cause high short-run volatility of electricity prices and distributed VRE reduce utilization of the grid for some customers [11]. Different options and suggestions for changes in tariff design, from different viewpoints, have been discussed in the literature. Arguing from a DSO perspective [12], promotes an arrangement where customers pay for a subscription to a certain amount of power. Such tariffs secure a predictable income for DSOs [13]. discuss and simulate the effects of tariff structures on end-customer benefits and find that time varying pricing will be most beneficial [14] analyzed empirical data of hourly-metered consumption by residential customers in Sweden on tariffs and found that better tariff design could shift consumption from high demand hours to low demand hours. Finally [15], studies tariffs through simulations of flexible households and argues for flexible tariffs that increase with the hourly withdrawal of power from the grid. This reduces simultaneous peaks in demand caused by low price hours. Several studies focus on tariff designs to reduce the individual consumer's maximum consumption rather than the network's maximum consumption. In this study it is assumed that the latter is a more important driver of network costs for large scale consumers such as district heating plants. Also, many previous studies analyze the response to tariffs by consumers with a low degree of flexibility such as residential and services sector, whereas this study analyze large and very flexible consumers such as DHPs that can fully replace electricity consumption on short notice at a low cost. This type of consumers could hold a key in handling variable supply from VRE.

The objective of this study is to analyze how electricity grid tariff structures affect the use of electricity and hence the role of the heating sector as a flexibility provider. The study compare and evaluate alternative structures, representing a range of possible options, based on typical tariff design principles as well as the ability to enable flexible response of P2H to electricity prices. For this purpose, a new DHP mixed integer optimization model is developed. The model minimizes the operational costs and capture variations in electricity prices, start-up costs of different boilers in a heat only plant, as well as the characteristics of different grid tariffs.

2. Grid tariff design

2.1. Principles for tariff design

Picciariello [16] and Rodríguez Ortega [17] identify principles for tariff design, here summarized into three main groups:

- **System sustainability principles** state that tariffs should recover the allowed costs for the DSO. A tariff structure that secures a stable yearly income is usually preferred over one that vary greatly from year to year.
- **Economic efficiency principles** state that tariffs should give the right price signals for both consumers and DSOs so that the socio-economic surplus is maximized both in the short and long term. Tariffs should reflect each network user's contribution to network costs to achieve cost-causality. The equity principle means charging “each consumer the same amount for using the same good or service, independently of the electricity's use and of the customer's characteristics.”
- **Consumer protection principles** emphasize the need for transparency and stability in the tariff design method, and a simple and understandable tariff structure.

These principles contravene each other and a reasonable compromise must hence be found. Typically, consumer protection principles has been used as an argument against more economic efficient tariffs [18]. A design with high degree of time-varying pricing, to satisfy economic efficiency principles, can be difficult to communicate and understand meaning that the consumer protection principles is challenged. One possible approach, presented in [18], is to have both a default tariff structure that favors consumer protection principles and an optional tariff structure that pursue economic efficiency principles. Flexible consumers or consumers with load patterns that avoid peak hours will benefit from the optional tariff, while other consumers benefit from the default. This study asserts the need to find tariff schemes that sustain good tariff principles while still allowing for flexible use of P2H, thus a tariff with high degree of efficiency is desirable.

2.2. Time varying tariffs

The economics of tariff design is much discussed in the literature (e.g. Refs. [11,19,20]) The electrical transmission grid is a natural monopoly, as the capital costs (fixed costs) are high compared to the short-run marginal costs (SRMC) (variable costs), which are primarily costs to cover grid losses. Variable user charges should therefore be set low to ensure high grid utilization in hours where grid capacity is sufficient. However, the demand for transmission vary greatly over the course of a day and a year, and the grid must be dimensioned to meet expected peak demand. The long-run marginal costs (LRMC) of increasing transmission during peak situations include additional capital and operational costs of incremental capacity. The LRMC of increasing demand in off-peak situations is low in comparison as only SRMC of existing capacity id included. This gives a rationale for peak pricing which discriminate between consumption in off-peak and peak hours. In such a system, a low tariff - reflecting SRMC only – is given to consumers during off-peak hours, and a high price reflecting LRMC is given in peak hours.

The design of the grid tariff is usually structured into three main components:

- Fixed access charge (€/period)
- Energy charge (€/kWh/period)
- Demand or capacity charge (€/kW_{peak}/period)

The fixed charge is the cost of access to the grid regardless of the consumption and covers the residual costs.

The energy charge is a cost per kWh electricity consumed. At minimum, the energy charge should reflect the short-run marginal cost of transmission, i.e. the marginal cost of covering grid losses. To reflect time variation in loss factors and electricity prices, the charge may differentiate between seasons and peak/off-peak hours or be settled dynamically based on the electricity price. It can also be used to signal long term marginal costs through time-of-use or critical peak pricing structures [21].