Journal of Cleaner Production 127 (2016) 352–362

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Energy management strategy for industries integrating small scale waste-to-energy and energy storage system under variable electricity pricing

Samantha Islam [a], S.G. Ponnambalam [a, *], Hon Loong Lam [b]

[a] Advanced Engineering Platform, School of Engineering, Monash University Malaysia, 46150 Bandar Sunway, Malaysia
[b] The University of Nottingham, Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form
5 April 2016
Accepted 7 April 2016
Available online 16 April 2016

Keywords:
Energy management
Waste-to-energy (WtE)
Energy storage
Variable electricity pricing

ABSTRACT

Energy is a basic need for different purposes in an industry and it incurs the highest cost in any production system. In order to reduce the energy cost, achieving energy efficiency with renewable fuel has no alternative. However, when the industry operates under variable electricity pricing, only energy efficiency cannot help cost saving. An energy management strategy for energy usage is also required. Waste-to-energy (WtE) can be an attractive solution for renewable energy source. Current research on small scale WtE paves the way of using WtE for energy efficiency into industries. The objective of this work is to propose a strategy to reduce the electricity bill for the industry under variable electricity pricing. In order to reduce the electricity bill, a fuzzy Inference System (FIS) based energy management strategy to produce electricity in low pricing period and utilize it in peak period is proposed by integrating small scale WtE and storage into industry system. Though this model is built for energy management, it indirectly works as a tool for waste management as well. The performance of the proposed model is tested with the data collected from a plastic container manufacturing industry. The cost analysis is shown to justify the higher establishment cost of WtE.

1. Introduction

Increasing energy costs, new environmental legislation, and concerns over energy security are driving efforts to increase industrial energy efficiency (Vikhorev et al., 2013). The industrial sector uses more energy than any other end-use sectors. For example, in Taiwan, industries are accounted for 53.8% of the nation's total energy use while Chinese industrial sector is causing as much as 70% of the country's total energy consumption (Lu et al., 2013). This worldwide industrial energy consumption is projected to grow by an average of 1.4% per year (Abdelaziz et al., 2011). The increased consumption of fuel results rapid increase in energy price and greenhouse gas emission. Therefore, enterprises are becoming attracted to keep alternative energy back up for industries. By applying renewable energy based systems in industries, the greenhouse emissions could be reduced significantly. Therefore, traditional energy supplies are shifting to renewable sources of energy and new strategies are being applied in industries.

Energy management strategy is getting important day by day due to the increased cost for energy supply and enhanced environmental awareness. Energy management is the strategy of meeting energy demand when and where it is needed. This can be achieved by optimizing energy usage by the systems in order to reduce the total production cost of these systems (Abdelaziz et al., 2011). It particularly contributes in attaining energy efficiency by the industries and mitigating environmental pollution.

Energy management becomes more important when the industry is consuming electricity under variable electricity pricing. Instead of paying for electricity at a flat tariff, variable pricing causes different rates charged depending on when the power is being used (peak, shoulder, off peak). This difference in pricing can change by the hour, day or month and depends on the customer demand concentration on each period. Usually high demand period are charged at high rate and vice versa. Industries plan their production according to their customer demand. Industries electricity requirement varies with their production plan and electricity price can be high at different time of the day. Therefore, electricity cost

* Corresponding author.
E-mail addresses: samantha.islam@monash.edu (S. Islam), sgponnambalam@monash.edu (S.G. Ponnambalam), honloong.lam@nottingham.edu.my (H.L. Lam).

http://dx.doi.org/10.1016/j.jclepro.2016.04.030
0959-6526/

gets even higher if industries requirement is high at peak period. Efficient energy management can help to balance the industry's energy demand either by shifting some demand from high pricing period to low pricing period or with back up energy source i.e.: renewable energy generator to supply energy at peak period or energy storage to store energy at low demand period and supply it in high demand period (Arteconi et al., 2013).

Energy management strategy based on renewable energy source and storage is quite common. Zhang et al. (2012) presented an energy management strategy for a super market using photo voltaic cell and storage. García et al. (2013) introduced an energy management system composed of wind turbine, PV cell, hydrogen sub system and battery. Hashimoto et al. (2005) discussed stand-alone wind-PV hybrid system with a backup battery that ensures the supply of electricity to a radio base station in an island. However, these commonly used renewable energy sources (solar, wind) are based on the weather condition and possess inherited intermittent nature, which hinders stable power supply (Duić, 2015).

These commonly used renewable energy sources (solar, wind etc.) have only one scope which is reducing emission. In contrast, waste as a source of renewable energy production can be highly preferable (Ali et al., 2012). It can also be considered from two perspectives, one is environmental waste management and other is energy management (Münster and Meibom, 2011). In 2014, U.S. Energy Information Administration (EIA) published a report on comparison among various renewable energy sources which put waste technology at the top due to its fairly steady nature and high calorific value. This study justifies the use of waste in energy production system. However, in spite of being a reliable source of energy, no study on energy management system based on WtE is found in literature.

The reasons for not considering WtE for energy management might be its higher establishment cost. Due to this higher cost, WtE was commonly being considered for municipal solid waste (MSW) in large scale capacity (Münster and Meibom, 2011). However, the question still remains as to why WtE plants are much more costly to build than coal-fired plants, even when the coal's calorific value is close to that of MSW (about 10 MJ/kg). With a view to reduce this higher set up cost, studies have been carried out regarding changing the technology of waste to energy conversion (Themelis and Reshadi, 2009; Mastellone et al., 2010). So, waste gasification takes the place of waste combustion where the requirement is a low capacity plant (Ellyin and Themelis, 2011; Nguyen et al., 2013). As a result, some small scale WtE plant comes into operation. Ellyin and Themelis (2011) examined the technical, economic, and environmental aspects of some small-scale WtE technologies currently operating around the world.

Many studies (Shareefdeen et al., 2015) have focused on municipal solid waste (MSW) as a potential feedstock, but appear to overlook the potential benefits of industrial waste. Waste is an inevitable byproduct in any industrial production. According to Schaub and Leonard (1996), in the food processing industries up to 30% of incoming raw materials becomes waste rather than a value-added product. In another study carried out by Caputo and Pelagagge (2001), a large paper plant in Italy produce a sludge output of about 52 t/day. Industries incur huge amount of cost for treatment and disposal of this waste. This huge cost instigates an alternate solution for this waste generated by industries. An analysis carried out by Lupa et al. (2011) shows the similarity between municipal waste and industrial waste for being used as an energy source. This study justifies the use of WtE as a waste treatment option for industries which is not only cost effective but also environmental friendly.

Usually industries depend on third party WtE Company for waste treatment or energy supply. When an industry depends on a third party WtE, it has to pay in two ways; one is for waste treatment and other is for electricity purchase. There are some other limitations too. They are – Firstly, the cost become bigger if waste generation is very frequent and electricity demand is fluctuating. Secondly, the transportation cost will be very high if there is no nearby WtE facility. Thirdly, the waste production and electricity consumption of an industry change with their own production plan. Going to a third party, lacks in control and cause disintegration and higher cost. Finally, a particular industry produces a particular type of waste all the time, they always need a single type of WtE to treat their waste. Nevertheless, in case of a third party, the primary challenge facing by these facilities is the heterogeneous nature of waste, which creates a widely varying chemical constituency of the energy generated from these processes. This variance affects the ability to efficiently extract energy. Consequently, it will increase the expenditure of the customer industries.

Few studies have been carried out where proposal is presented for building an onsite WtE in an industry to meet the purpose of their waste management (Villar et al., 2012). Caputo and Pelagagge (2001) conducted a technical and economic evaluation of an in house WtE plant in an Italian paper industry sludge disposal. Caputo et al. (2003) presented a technical and economic viability of combined treatment of two type waste generated from an olive oil industry in an onsite WtE facility. These studies only reveal the use of WtE as a solution for waste treatment which reduces the huge landfilling cost incurred by industries and generate some revenue on selling electricity. Only using as a source of waste management does not complete the role of WtE in an industry. Its produced energy can be used as an energy backup by the industry possessing it.

WtE accompanied by storage can be a wonderful solution for energy management for the industries' energy expenditure when the industry is operating under variable electricity pricing. At low pricing period, the energy produced from WtE is stored in storage and is supplied when the pricing period is high keeping the consumption lower for the supply from main grid. Fuzzy logic serves the best for guiding this kind of operating principle (García et al., 2013; Ciabattoni et al., 2014; Suganthi et al., 2015).

Based on the above discussion, it has been seen that variable electricity pricing is a constraint on industry's energy requirement. Without proper energy management, it may cost huge energy charge. To solve energy problem, many industries depend on third party WtE but it is not feasible and cost effective. Many previous studies are conducted on WtE based on municipal solid waste but the potential of industrial waste was overlooked. Some studies have come up with onsite small scale WtE as a solution for waste management in industries but its potential as an energy solution within industry was unnoticed. In this novel work, a fuzzy logic based energy management strategy is proposed which can save energy charge under variable electricity pricing by incorporating a small scale WtE with energy storage in industry.

The objective of this work is to reduce electricity bill in an industry. The strategy for this purpose is to produce and store energy in low pricing period and consume it in the high pricing period. The fuel required for energy production is waste produced by the industry itself. Therefore, the industry will become energy efficient. In order to perform this work, an economic waste model has been introduced for calculating the optimal capacity for WtE facility. The guiding rules for operating this system are designed according to the industry requirement and electricity pricing period. The fuzzy inference system is used for implementing the energy management strategy. The energy saved and the saving in electricity bill are estimated for a plastic container manufacturing industry and Matlab Fuzzy Inference system (FIS) tool is used for simulation. The cost analysis for proposed model is also presented to justify its validity.