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DEMAND-SIDE MANAGEMENT FOR ENERGY PRODUCTION USING MICRO COMBINED HEAT AND POWER SYSTEM – A REVIEW

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ABSTRACT

World development increased dramatically ever since the Industrial Revolution, in particular after second world war (WWII), which drove the rise of energy consumption. Thus, energy consumption in the World has been growing continuously in the past 50 years. Using micro Combined Heat and Power (mCHP) allows energy scheduling and demand-side management depending on different variables which will benefit users and suppliers. Different researches have been conducted due to increasing interest from researchers to increase and optimise the advantages of energy scheduling. In addition to the mCHP system, optimisation process also includes distributed energy sources (solar panels) with electricity storage. On the demand side, various devices with different load profiles which can be controlled over time can be considered. This study therefore, being a desktop based one, sought to review the energy demand-side management as it applies to the use of mCHP in residential settings.

Keywords: Residential, Reliability, Flexibility, Optimization, Stirling-engine.

INTRODUCTION

Residential micro combine heat and power (CHP) systems are becoming popular in terms of heat and power generation in the world especially in the European continent (Maxim, 2014). The United Kingdom's government in particular supports mCHP technology due to its flexibility, reliability, safety simple operation and environmental suitability (Berelli et al. 2012). Micro CHP systems give advantage of energy scheduling and demand management depending on different variables which will benefit end users, manufacturers and suppliers. Various researches have been worked out due to continuing interest from researchers to increase and optimise the advantages of energy schedule and demand management. In addition to the CHP system, optimisation process also includes distributed energy sources (solar panels) with electricity storage. On the demand side, various devices with different load profiles which can be controlled over time can be considered (Kopanus et al. 2013). This particular study thus, focuses on the review from the available literature information of the energy production and demand side management using micro combine heat and power technologies in residential applications.

Energy Production

Energy is a key component that determines the economic growth and development of rich country across the Global. This has culminated in a situation of booming global energy requirement, and this, in turn, has brought about pressure on energy production and supply side because most of the developed and some upcoming countries are critically energy-dependent, which is a testimony that energy is an essential criterion in the economic growth and development of every society (Pirlogea and Cicea, 2012).Most of the conventional fossil-derived technologies and methods of energy generation and subsequent utilization have tremendous negative consequences which have demonstrated their inappropriateness and environmentally unfriendly nature. This has led energy based researchers to have started focussing on the sustainable systems of energy generation and consumption (Maxim, 2014) with emphasis on technological, economic, environmental, and social aspects of the energy (Santoyo-Castelazo and Azapagic, 2014).

It is very clear nowadays that the energy production trend is shifting to decentralised system which offers more benefits of energy efficiency and low-carbon foot print when compared with the centralised one. According to the energy systems engineering view, micro-generation system of energy production is a splendid alternative which could have a great role to play in the expansion of future sustainable systems of energy generations. Cogeneration system is undisputedly the most satisfying and reliable micro-generation technology, it is linked with the combined generation of heat energy and electricity in small-scale units which can be fixed in the building where the energy is designed to be consumed. And one key advantages of cogeneration systems is they can have total efficiency of up to 90% as against the 40-50% efficiency of electricity production alone (Pirlogea and Cicea, 2012).

Moreover, cogeneration networks could result into lower transmission and distribution cost and losses (Kopanus et al. 2013).

Micro Combine Heat and Power (m-CHP)

Micro combine heat and power (m-CHP) or micro-cogeneration is an evolving system that has the ability of producing both electricity and heat with good energy efficiency and low environmental effects, m-CHP is robust enough to satisfy plentiful energy and social policy objectives. These objectives are such as; enhanced decentralisation of energy production and supply, improved energy security, reduced emissions of greenhouse gas associated with energy production and supply, reduced energy cost and losses during electricity transmission and distribution. Micro combined heat and power systems is capable of minimising energy requirements of the residential sector for domestic hot water need, space heating and electricity (Maryam et al. 2013). Of recent years, micro combined heat and power systems that efficiently produce heat and power have received meaningful attention, and they have also brought an explicit segment of market in both residential and other applications due to their ability of fast and efficient change of electrical load to increase or decrease the thermal productivity (Berelli et al. 2012; Shaneb et al. 2011; and Wang et al 2011). The small power output usually less than 5kW of electricity, the flexibility, simplicity, and portability of micro combined heat and power systems are the reasons they are now found installed in millions of residential settings, especially in places where there is a huge marketability's of heating fuels (Berelli et al. 2012; & Andreason and Kaer, 2001). The mCHP have globally been accepted as the most convincing alternative to traditional power and heat production systems due to it efficient energy saving and environmental conservation (D'Accacia et al. 2001; Bernotat and Sandberg, 2004; Alanne and Saari, 2004). Generally, small-scale combined heat and power conceptually signify the combined generation of heat and power with an electrical power output of less than 100kW, while micro combined heat and power are used to refer to small-scale combined heat and power where the electricity output is smaller than 15kW (Dong and Riffat, 2009).

Micro Combined Heat and Power Technologies

According to Walker and Cass (2016) micro-generation is a technology in which an energy is converted to a form that can be utilised for hot water applications, space heating, and electrical power applications. This technology has received acceptance in energy application sector, and many micro-generation technologies have so far been investigated by number of researchers (Jutunen and Hyysalo, 2015). mCHP has been proved by the International Energy Agency (IEA) as being one of the resilient and easiest multi generation approaches. There are multiple micro combined heat and power (m-CHP) technologies applicable to residential energy needs that are currently found in the market at commercial quantities, among which are those that operate based on Internal combustion Engine (ICE), micro Gas Turbine (mGT), Stirling Engine (ST), micro Rankine Cycle (mRC), Fuel Cells (FC), and Thermo-Photovoltaic (TPV) Generators (Meybodi and Behnia, 2011; Bianchi et al. 2009; Parente et al. 2012; Milkalsen et al. 2009; and Caresane et al. 2011). According to Bianchi et al. (2012), the combined heat and power technology based on the micro Gas Turbines are characterized by electrical power-to-thermal energy ratio values that are bit greater than Internal Combustion Engines and quite greater than Stirling Engines and micro Rankine Cycle. Micro Rankine Cycle and Stirling Engine technologies are characterized by the smallest efficiencies in terms of electrical power output (usually 20% and 5% respectively).

Micro Combined Heat and Power (m-CHP) in Residential Buildings

According to the international Energy Agency, energy savings can be enhanced by lowering the residential sector utilization of primary energy (IEA, 2011). In the United Kingdom, 45% of the total electrical energy consumption is believed to be accounted by the domestic sector, and this consumption is true in most of the developed countries and some upcoming countries across the Globe, that is why Engineers and Builders are being charged by the relevant authorities to come up with better building designs to accommodate the maximum energy savings through optimised building insulations (Sebastein et al. 2013; & Alexandros et al. 2013). Micro combined heat and power (m-CHP) systems have been found to be one of the efficient methods to achieving energy saving objectives. Residential energy demands for hot water applications, space heating and electricity are constantly varying with daily and seasonal rotations. The electricity and heating systems must meet the maximum demand of a house, but also must be robust, smart and flexible enough to control itself between minimum and maximum demand. The residential energy demand is a function of residential building size, building materials, location, and type occupancy (Alexandros et al. 2013; and Adam et al. 2015).The micro combined heat and power (m-CHP) prime movers that are usually utilised in residential settings applications are; the Stirling Engines (SI), Internal Combustion Engine (ICE), Micro gas Turbine (mGT), Fuel Cells (FC), Micro Rankine Cycles (MRC), and Thermo-Photovoltaic Generators (TPV), even though some of the above mentioned prime movers are still found in the market at the prototypes level (Sebastein et al. 2013).

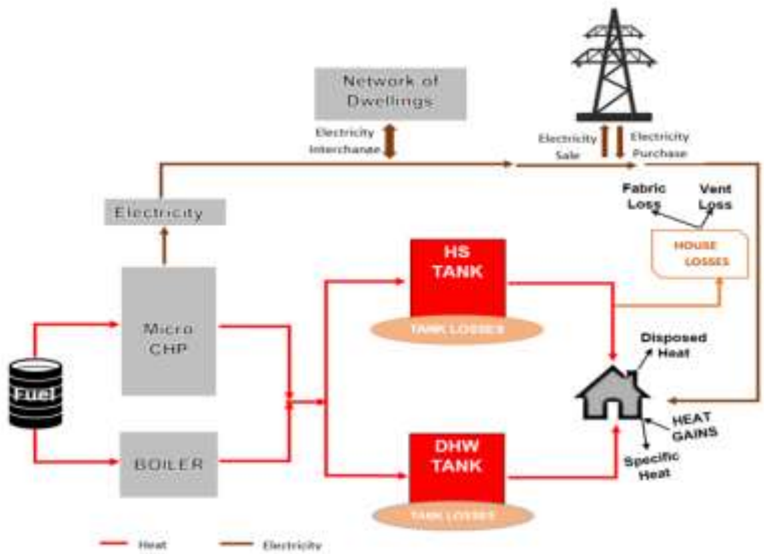

Figure 1: System of mCHP in a residential setting. Source (Ander, 2016)

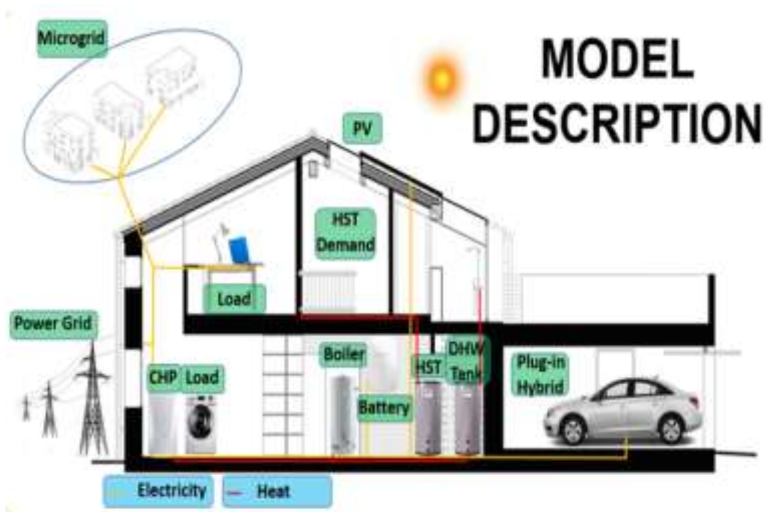

Figure 2: Energy structure of a given house in a micro-grid system. Source(Ander, 2016)

Figure 1 shows a system of mCHP in a residential setting which comprise of a network of dwellings, national grid to enable exchange of electricity to and fro, mCHP machines, house heat losses, domestic hot water tank, space heating tank and fuel tank to power the mCHP machines. Similarly, figure 2 depicts a group of houses, connected to one another electrically and then connected to the power grid in order to exchange electricity when needed. Each of the houses produce heat from the mCHP and the boiler and then store this heat in two separate tanks in order to meet the house heat demand. Moreover, the dwellings produce electricity from the combination of mCHP and the solar PV system. This electricity will be consumed by the electrical appliances available in each of the house, stored in batteries or shared to other houses within the network. When the electricity in the network of the houses cannot be used completely, then, this energy will be sold to the power grid (Ander, 2016).

Demand-Side Management (DSM)

To be efficient enough and to prevent grid problems, the energy production should be as close as possible to the energy demand. Maintaining balance between demand and supply is not an easy job, the main challenge is that of the penetration of intermittent energy sources such as solar and wind which will not necessarily match with the energy demand, due to their daily and seasonal variations (Strabac, 2008). In solving this problem, one of the approaches is to look at Demand-Side Management (DSM). This term, which appeared in the 1970s, has the objective of modifying consumer habits and reducing peak demands with distinctive measures (behavioural change, monetary incentives, real-time pricing, smart load controller, demand shifting, etc.). Finn and Fitzpatrick (2014) explain that DSM is an excellent solution because there are no losses due to energy conversion, compared to generation, transmission, and storage system.

On one hand, DSM techniques will have a lot of advantages to the end user by minimising the electricity bills and increasing the customer service quality. On another hand, these techniques will also have benefit for the energy suppliers and the grid managers with a lower cost of operation and maintenance, declining energy losses, decrease in equipment replacement and low generation and transmission inputs. Finally, DSM is a cost-effective solution that lowers fuel imports and environmental pollution by considering suitable and clean energy sources.

DSM Methods and Techniques

There are various techniques and methods for the demand-side management of an energy supply system, they are listed as follows:

a) Energy efficiency

This appears obvious, but energy efficiency in residential buildings is a major player in DSM. According to Palensky and Dietrich(2011)energy efficiency results in an immediate and permanent energy and emissions savings, and is often cost effective and easy to apply. But, to achieve a good energy efficiency, it requires direct involvement of the consumer as well as their behavioural and attitudinal changes. Insulation efficiency is now considered in all new buildings but still can as well be integrated into the already in order to lower heat requirements and thus energy bill.

Moreover, energy savings can be done by switching off unessential electrical loads (manually or automatically), using low consumption devices and efficient lights (LED) or replacing inefficient ventilation systems with better ones (Palensky and Dietrich, 2011).

b) Real-time pricing tariff

Real-time pricing tariff is mainly to encourage energy users to operate electrical appliances during the off-peak period. As described by (Strabac, 2008), this results in time-of-use rates where prices are higher during peaks periods and lower during off-peak periods. This is already the case in many countries across the world, with day and night tariff or seasonal price variation. But the old pricing system has no correspondence with the present market as it doesn't encourage the consumer to contribute to a more efficient system.

The solution considered is that electricity prices should follow as closely as possible the electricity production (hourly for example) by considering the amount of energy available and the type of energy sources involved on the production side (Strabac, 2008).These tariff measures would allow users to participate both in saving money and be more environmentally friendly, as renewable energy has very low running costs (Gelazanskas and Gamage, 2014).

c) Load management

There are multiple methods to vary the load demand shape and manage peak and off-peak periods (Logenthiran et al. 2012).

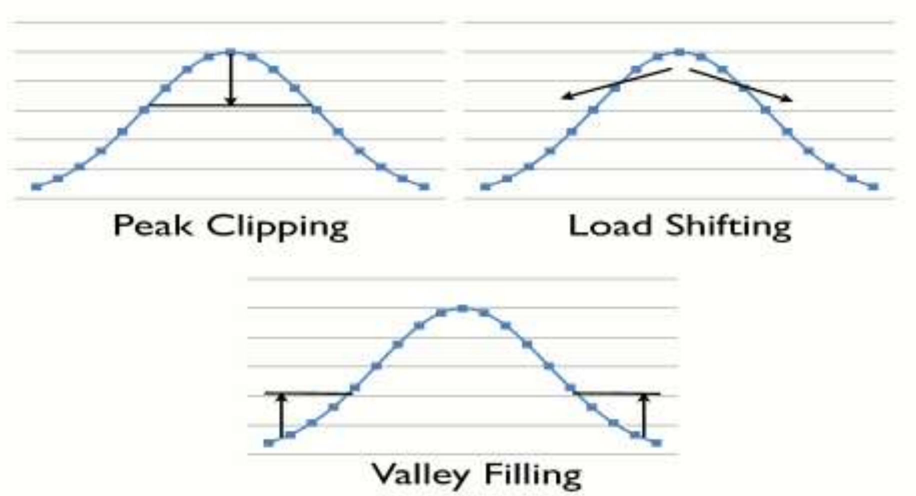

Figure 3: Load Levelling. Source (Gomez, 2015).

Figure 3 shows peak clippings which are the direct load control technique where the load is lowered at peak times. This usually implies a loss of comfort. Valley filling constructs of the off-peak demand with storage capacity is shown. Finally, load shifting, which assumes to do clipping and filling at the same time is also shown. The load management considers flexible and deferrable load appliances by shifting them from peak to off-peak period. It doesn't reduce the average amount of energy consumed by the end users, but, combined with real-time pricing, it will lower the electricity bill and enhance the stability of the energy system (Galazanskas and Gamage, 2014).

d) Smart energy controllers and programmes

To apply DMS, energy controllers and programmes will have a greater role to play. This DSM technology is closely connected to the smart micro-grids as it will maintain the demand and supply of the network systems efficiently and automatically by using smart devices (Galazanskas and Gamage, 2014). As stated earlier, some appliances can be put on or off to follow the energy production and respond to price changes. The loads are integrated into a global communication infrastructure with smart and dynamic load management. The energy controllers are connected to complex algorithms with priorities and other rules (Palensky and Dietrich, 2011).

Strabac (2008) reported that simple controllers (thermostats) for air-conditioning and heating systems are very efficient enough to lower the electricity bill. These smart metering infrastructures can be expanded to reach other appliances in residential homes, such as the dishwasher, the washing-machine or the electric car charger, to maintain a balance between cost savings and comfort. Prediction agents have a key role to play, mostly in smart micro-grids with many renewable energy sources. In fact, the recurrence variations of the grid can be foreseen and managed by predicting the solar radiation or the wind speed, this will also allow the calculation of the power generated in advance and send it to energy controllers of the consumers (Kyriakarakos et al. 2013).

Challenges for DSM

In maintaining demand and supply balance and frequency stability, DSM must deal with multiple challenges and its implementation is increasingly complex. In fact, the growing population has a better access to electricity and electronic devices which resulted to continuing increase in electricity consumption. On the generation side, energy sources become more diversified, delocalised and often intermittent and unpredictable.

Strabac (2008) presumes the barriers that decelerate slow DSM development:

- Lack of knowledge and awareness regarding the quantification of costs, the value of demand controllability etc.
- Lack of information, communication, and technology infrastructure (control and communication systems, large scale metering replacement, sensor etc.)
- Increasing the complexity of the system operation (control of many parameters on demand and supply sides)
- Improper market structure (old existing network, optimisation to integrate storage and DSM technologies)
- No competitive markets (leading to traditional and inefficient tariff)
- Behavioural and attitudinal changes in terms of energy savings.
- Lack of incentives by the appropriate authorities to stimulate the consumer using energy efficiency appliances and DSM solutions.

Review on DSM

The objectives of DSM could be increasing the use of renewable energy sources, decreasing the monetary expenditure, lowering the power supplied from the main grid, or reducing the peak demand (Logenthiran et al. 2012). To achieve these objectives and improve the performance of the system, DSM will encourage users to reduce their power consumption and shift their loads to off-peak hours (Samadi et al. 2012).

Many researches were conducted using different methods and strategies to address one issue or the other regarding the DSM in energy production and utilisation. Some of these studies focused on the energy consumption profile, the day-ahead forecast, the controllable loads, or the variable price of electricity. Similarly, the configurations differ from one method to another, concerning the provider, the users, the loads, the energy prices, the energy sources, the storage devices, etc. (Logenthiran et al., 2012). In all the case, DSM methods have received good results concerning the reduction of the electricity bill and the average grid price. In a particular study, Logenthiran et al. (2012) concentrated on lowering the load consumption curve as close as possible to an objective load curve, by managing shift-able devices in a network including residential, commercial, and industrial areas. In the study, they obtained 5% reduction in the operating cost in the residential area using DSM measures. In another related study, Atzeni et al. (2012) used an optimised day-ahead strategy in a smart grid which considers equipment owned, energy prices energy sources, and storage devices. The users react to the grid energy prices fixed by the supply-side in the day-ahead, to lower the total expenditure for buying or producing the energy needed. With this approach, they achieved 12.6% reduction in average grid price and 16.3% reduction in total expenditure. In another case study, they changed the number of active users (users who participate in the optimisation process, reacting to the change in energy price by modifying their demand). For a percentage of 6%, 12% and 24% of active users, results are respectively 4.5%, 8.1% and 16.5% reduction in average grid prices. These results show the significance of participating in the DSM project to enhance the system of energy production and utilisation. Moreover, savings are higher for active users with storage and production equipment although it has benefits to all users in the network, encouraging demand-side users to embrace these solutions. The fact that energy storers charge their battery at the valley of energy cost and discharge it at peak hours allows more savings. However, increase the number of controllable devices will not necessarily yield better results. In fact, Logenthiran et al. (2014) showed that, even if the residential area has the zenithal number of controllable devices in terms of quantity and variety, the benefit in operating cost is lesser than expected, because residential area has low consumption devices compared to high consumption loads in commercial and industrial sectors.

Another essential aim of DSM measures, which mainly has profits to the energy provider, is to reduce peak demand to enhance the grid sustainability. To this end, the techniques and algorithms used have realised good results. In their case study with residential, commercial, and industrial areas, Logenthiran et al. (2012) have lowered peak load up to 18.3% in the residential area. In their work, Atzeni et al. (2012) have reported 13.8% reduction in peak to average ratio, and up to 17.1% with 24% of active users. Results depicts that the demand curve collapses during peak periods and raised during valley hours, to assume more and more flattened. But, as reported by Gelazanskas and Gamage (2014) the troublesome is to create even higher peaks in demand at a varuing time. In fact, in the case where load shifting follows real-time pricing, many shifted loads can be started at the same time when the price falls causing a new peak.

Finally, studies show that DSM has benefits to both provider and customers. It will increase the benefit for the provider and also increase the social welfare of the customers (Gelazanskas and Gamage, 2014). For example, the load demand model of Logenthiran et al. (2012), considers the lifestyle of the customer, to lower inconvenience on his comfort. It will consider that the coffee machine is usually operated in the morning and so it cannot be shifted now. In their system using ventilation, heating, and air conditioning, Logenthiran et al. (2012) have determined essential comfort ability settings for the houses, such as controlled of the inside temperature. But depending on the appliances concerned, the comfort cost can be much that is why priority rules must be defined. For example, Kyriakarakos et al.(2013) have characterised load types with preference. The lights have the highest preference, then the refrigeration systems and finally, the space heating/cooling and the rest of the electrical appliances. Following these rules, the DSM measures will have a restricted effect on the household comfort ability.

CONCLUSION

In conclusion, from the many relevant articles reviewed in this study, we came to realised the demand-side management of energy production using mCHP to have the following importance:

- Combining effective of thermal energy storage with the mCHP system which will suitably make the residential sector more decentralised in terms of heat energy systems.
- Enables effective and efficient demand management in order to reduce the cost of energy production and keep the environment less of greenhouse gas emissions.
- Actualising minimum energy cost, simple total energy production unit, primary energy savings and low pollution are the main tasks to make the mCHP market more attractive.
- Integrating poly-generation systems in residential settings will still be more attractive economically and environmental wise.
- DSM of paramount economic and social benefits to both the energy provider and consumer.

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