Applied Thermal Engineering 50 (2013) 523–535

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Modelling and simulation of a distributed power generation system with energy storage to meet dynamic household electricity demand

Yaodong Wang [a,*], Ferdian Ronilaya [b], Xiangping Chen [a], Anthony P. Roskilly [a]

[a] Sir Joseph Swan Centre for Energy Research, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom
[b] Electrical Engineering Department, The State Polytechnic of Malang, East Java, Indonesia

HIGHLIGHTS

- ► Simulation using Dymola software.
- ► Study of a distributed power generation system with energy storage.
- ► To meet the dynamic electricity demand of a household in the UK.
- ► Two designs are presented and compared.

ARTICLE INFO

Article history:
Received 30 January 2012
Accepted 9 August 2012
Available online 23 August 2012

Keywords:
Distributed power generation system
Electric energy storage
Dynamic simulation
Household

ABSTRACT

Electrical consumption in a household is not stable but changeable in one day throughout a whole year. The consumption depends on weather, seasons and users. This characteristic of demand makes it difficult to design and build a distributed power generation system to meet the demand for a household. For this reason, a stand-alone distributed power generation system (DPGS) needs to be carefully designed not only to meet the dynamic household electricity demand, but also to be economical. Hence, for a DPGS, it is essential to utilise electrical energy storage (EES) unit to store the excessive energy while power generation is running at off-peak time; and then the EES may supply the stored energy during the peak demand period. This study investigates a distributed power generation system with an electric energy storage unit to meet the dynamic electricity demand in a household. The system composes of one diesel-engine-generator (DG) running with biofuel; a fuel cell; integrated with an energy storage unit including a supercapacitor and a group of batteries. Models have been set up in Dymola software and two different system configurations are proposed and simulated. The characteristics of the integrated DPGS–EES system are presented and discussed. The results show that both configurations are working properly to meet the demand.

1. Introduction

Electricity is one of the most widely used forms of energy in our daily life. For the convenience of electricity supply, currently, centralised generation systems are widely used to provide national or international electricity supplies in the world. About one third of the primary energy consumed worldwide is used for electricity generation; 81.3% of the electricity is generated by non-renewable energy [1] and the average efficiency of electricity generation from coal is only 36% and that of gas is 48% in 2008 [2]; and about 23.5% of the electricity is used by residential sector globally [3]. That means around 6% of total carbon emissions of the world are from the electricity consumption of the households. For the OECD (Organization for Economic Co-operation and Development) countries, about 30% electricity is consumed by residential sector and this accounts for 12% of greenhouse gas emissions [3]. Therefore, in order to reduce the greenhouse gas emissions, it is important to utilise renewable energy for electricity generation and supply at high efficiency for the residential sector. However, renewable energy sources are mostly intermittent. This makes it impossible for the renewable energy systems to supply power constantly. This disadvantage can be overcome by combining more renewable energy sources together with non-renewable ones and/or with storage devices to form a hybrid distributed power generation system (DPGS) [4–7]. On the other hand, the residential electrical load is not constant, but variable and dynamic. It can be from a few hundred

* Corresponding author. Tel.: +44 191 246 4934.
E-mail address: y.d.wang@ncl.ac.uk (Y. Wang).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2012.08.014

watts during the night time to several kilowatts or more in the morning and evening [8–11]. This is a very special characteristic of household electricity consumption and it is very different from the other consumers. Therefore, it requires the DPGS systems used for household be able to supply enough power to meet the load demand persistently throughout the day, no matter it is the peak hours or the off-peak hours. Although it is technically possible to have a DPGS system for a house according to its maximum electrical load, this is not an economical solution since the time of electrical peak load is a few hours only for a house. Therefore, it is necessary to carry out a study to find out a solution of matching the capacity of the DPGS with the fluctuating domestic electrical power demand at a higher efficiency and lower cost. DPGS systems have been proposed and used to provide electrical power for remote area for many years [12–14]. They can be catalogued into: systems based on non-renewable resource with batteries; systems based on renewable resource (such as solar PV and wind turbine) with large battery banks for storage, and engine generator as a backup [12]; most recently, supercapacitors are being proposed for storage together with battery [14]. To allow the widespread application of solar PV and wind turbine technologies, there is a need for further R&D improvements in these two technologies that can reduce the cost of hybrid system [15]. The research publications found are mostly focus on the overall system performance to meet the overall demand of users. As for the detail dynamic response of a household size DPGS system to meet the dynamic load demand of the household, to our best knowledge, however, little work on the study in this area can be found in the open literatures. Aiming to develop a DPGS–EES system to meet the dynamic electrical demand at a high efficiency for a household, this work will conduct a systematic investigation of the performance of a hybrid distributed power generation system by computational simulation. Extending from our previous work [16], the load profile of a typical house in the UK will be selected and analysed; a DPGS and an EES will then be designed and integrated in two configurations. It is intended to find out some characteristics of the system from the case study and then the potential strategies for serving the user demand. Detailed simulations of the two DPGS–EES configurations will be carried out and the characteristics of the DPGS–EES systems will be explored.

2. The proposed distributed power generation system with electrical energy storage

2.1. Electrical power consumption of households and a typical load profile

It is known that the electrical load of a household is very dynamic [8–11], but there is no detail data available in the open literatures. Therefore, an investigation of electricity consumption in four typical houses on site in the UK was carried out by our research group. It was found that the consumption of electricity in the houses was mostly lower than 0.5 kW. The percentage was around 65–72% for a typical day (24 h). The consumption of electricity between 0.5 and 10 kW was around 33–25%. The consumption higher than 10 kW was less than 3.0%. The average power consumption is around 1.5 kW for 24 h in a typical day in winter [17]. These results gave us the fundamental data to design and configure a distributed electrical power system for the selected house. Based on the above findings and in order to find out the whether the DPGS–EES may meet the dynamic demand from the users, one typical result of electrical load profile in a house from the above study is selected as the study case, as shown in Fig. 1 [17]. From the figure, it can be seen that the electrical power consumption can be divided into two peak times and three off-peak times. That means the profile can be divided into five zones as follows:

- Zone 1: 00:00–06:00. The load in this zone is less than 500 W. The load in this zone may be caused by: Internet router, refrigerator, security lighting and standby TV set.
- Zone 2: 06:00–10.00. This is the first peak load period in the house during the day. The typical increased load in this zone may be caused by kettle, toaster, electric shower and oven.
- Zone 3: 10:00–16:30. The load in this zone is low. It is similar as that in Zone 1. There are some spiky power demands that may be caused by a kettle.
- Zone 4: 16:30–19:30. This is the second peak load period in the house during the day. Typical loads increased may be caused by kettle, oven, heaters, electronic devices and washing machine, etc.

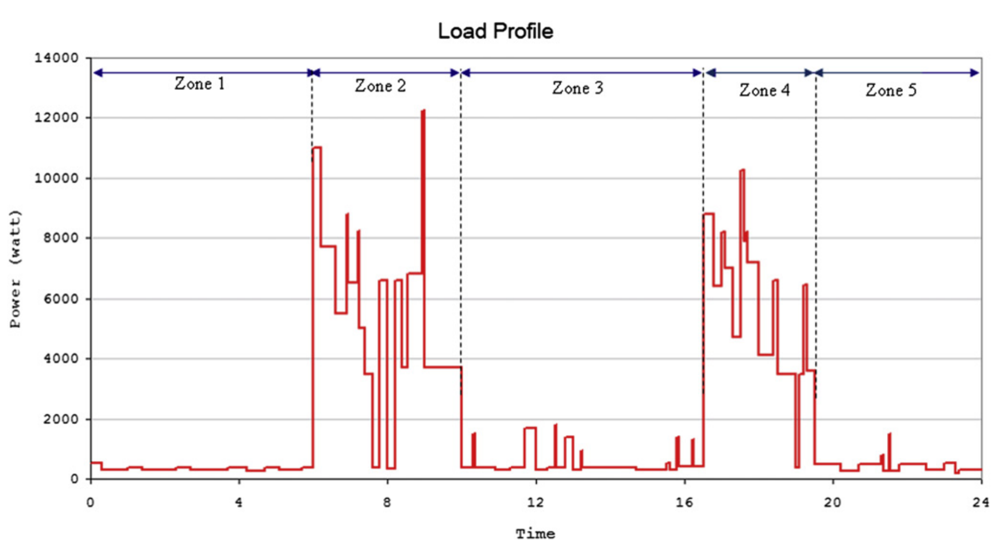

Fig. 1. Load profile of a typical UK household.