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Micro-generation dispatch in a smart residential multi-carrier energy system considering demand forecast error

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ABSTRACT

This paper deals with a residential hybrid thermal/electrical grid-connected home energy system incorporating real data for the load demand. A day-ahead scheduling (DAS) algorithm for dispatching different resources has been developed in previous studies to determine the optimal operation scheduling for the distributed energy resources at each time interval so that the operational cost of a smart house is minimized. However, demand of houses may be changed in each hour and cannot be exactly predicted one day ahead. System complexity caused by nonlinear dynamics of the fuel cell, as a combined heat and power device, and battery charging and discharging time make it difficult to find the optimal operating point of the system by using the optimization algorithms quickly in online applications. In this paper, the demand forecast error is studied and a near-optimal dispatch strategy by using artificial neural network (ANN) is proposed for the residential energy system when the demand changes are known one hour ahead with respect to the predicted day-ahead values. The day-ahead and hour-ahead optimizations are combined and ANN training inputs are adjusted according to the problem such that the economic dispatch of different energy resources can be achieved by the proposed method compared with previous studies. Using the model of the fuel cell extracted from experimental measurement and real data for the load demand makes the results more applicable in real residential energy systems.

1. Introduction

During the last decade, developments in the smart grid [1,2] and distributed generation [3,4] have attracted great attention all over the world. Considering that energy is needed in different forms in most applications [5,6], the diffusion of distributed generation in electrical power networks in the future will also facilitate the installation of micro-CHP (mCHP) systems, which have a primarily dispersive nature and which will probably replace traditional heating systems because of incentive schemes implemented by regulatory authorities [7].

Electrical and thermal demands in a home energy system can be met by cogeneration systems [8,9]. The CHP system is a major part of the integrated energy system, which has been advanced technologically in recent years. Due to effect of the CHP system in the operational cost of smart homes, the installation of these systems is increased. There are many current projects that use mCHP FCs in residential applications, for example, the Ene-farm project in Japan and the Lolland Hydrogen Community in Denmark. According to Innovation Research & Development (IRD), a FC manufacturer in Denmark, the conversion efficiency of a hydrogen fueled mCHP based on PEMFC is 47% electrical and 47% thermal i.e. 94% combined efficiency. The use of CHP systems for residential loads will be increased if the economic operation of the integrated energy system is studied well. Advantages of the using heat and power in a system have been investigated in [10].

In aspect of CHP applications in the energy systems, many studies have been carried out in optimization of CHP system operation. In some papers, the optimization has been carried out from the generation unit's owner point of view and the economic dispatch of the CHP plant has been investigated [11,12]. In other words, in this category the household's perspective is not taken into consideration. Some works have studied industrial applications [13]. Their results cannot be applied to the smart residential energy system because there are some devices in industrial application, which are not generally used in home application such as wind turbine, micro-turbine and heat storage tanks [14,15]. In the third category, e.g. [13,16] concentrate on demand response and risk analysis and the cost optimization is not performed. Therefore, according to increasing installation of CHP systems in smart homes

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Nomenclature

Acronyms and Notations

DAS	day-ahead scheduling
HAA	hour-ahead adjustment
CHP	combined heat and power
CCHP	combined cooling, heat and power
FC	fuel cell
PEMFC	proton exchange membrane fuel cell
HSS	hyper-spherical search
MCS	Monte Carlo simulation
T	time interval length
ANN	artificial neural network
PIANN	partial information artificial neural network
W	available energy in battery
ET	normalized price of electricity tariff
ROV	rate of output variation of fuel cell
C_{FC}	fuel cell total cost
C_G	grid total cost of
C_B	battery total cost of
C_F	furnace total cost of
P_{hFC}	heat power generated by fuel cell
P_{eFC}	electrical power generated by fuel cell
P_F	heat power generated by furnace
P_G	power purchased by home from grid
P_B	output power of battery
P_{eL}	electrical load demand
P_{hL}	thermal load power
η	efficiency
TER	thermal to electrical ratio of fuel cell
$P_\bullet$	generated power by different energy resources
PLR	generated electric power to capacity ratio of fuel cell
U	electrical demand uncertainty with respect to its predicted value
i	number of time intervals that appear as subscript of the variables, indicating the value of that variable at the i-th interval
D	appears as the superscript of the variables showing that they are determined based on DAS
ch	appears as the superscript of the variables showing that the device is in charging mode
dch	appears as the superscript of the variables showing that the device is in discharging mode
H	appears as the superscript of the variables showing that they are determined based on HAA
c	appears as the superscript of the variables showing that they are calculated based on complete information
p	appears as the superscript of the variables showing that they are calculated based on partial information
base	appears as the superscript of the variables showing that they are the cost per kW h

and the importance of optimal scheduling, more detailed study in this area is needed.

The operation of CHP systems has not been studied in aspect of cost minimization, in some papers. For example, the economic operation of a FC-based CHP system has been studied in [17], in which four cases with different recovery heat dispatching rates have been compared. However, cost minimization has not been considered in [17]. In [18], an energy system analysis model, Energy PLAN, has been presented, which used to analyze integration of wind power into the electricity system and design suitable energy planning strategies.

DAS has been studied in several previous works. In [19], a stochastic programming framework for achieving optimal DAS of CHP-based MicroGrid (MG) including wind turbine, FC, boiler, grid and a battery, considering demand uncertainties, has been investigated. In [20], the optimal operating strategy for DAS has been determined in aspect of cost optimization and environmental emissions reduction of a MG, including a microturbine, a wind turbine, a photovoltaic array, a diesel generator, a FC, and a battery, for residential application by using genetic algorithm. In [21], the effect and cost of combining FC power plant and wind power, considering uncertainty of wind energy, for DAS have been investigated by using evolutionary programming. In [22], the electricity cost of DAS of a home has been studied by considering the demand behavior such as seasonality. In [23], automatic and optimal consumption of residential energy and its DAS has been achieved considering a trade-off between minimizing the costs and inconvenience in a home energy system. Achieving optimal DAS has been studied in [19–23], however, HAA has not been considered in them. DAS cannot be effective especially in the complex systems, including PEMFC and battery. Due to the uncertain nature of demand, DAS is not able to specify the optimal power scheduling strategy to meet the minimal operating costs. Any variation in load demand in a time interval not only affects hour ahead scheduling in that time interval, but also has effects on power generation scheduling in future hours. Therefore, the optimal operation of a system cannot be achieved by DAS. In residential application, hour-ahead scheduling is significant and should be studied to achieve optimal operational cost.

More accurate mathematical modeling of an energy system, leads to more accurate and practically results. There are several studies about FC-based CHP system without consideration of actual FC operation, and only a general view of input/output of FC has been considered. In [24], a hybrid multi-objective particle swarm optimization algorithm based on a chaotic local search mechanism and fuzzy has been proposed for optimal operation of a micro-grid, including micro-turbine, FC and battery to minimize operation and emission. In [25], adaptive modified firefly algorithm has been used to optimize proposed stochastic framework which investigated uncertainty effect on the operation of a micro-grids including wind turbine, photovoltaic and FC. In [26], design and simulation of an inverter topology has been studied to describe lifetime cost of a system, including FC, battery and grid. The relation among FC rating, load profile and capacity of battery has been investigated. In [27], multi-objective genetic algorithm has been used to investigate the performance of a micro-grid including a photovoltaic, wind turbine and a FC-based CHP, considering weather condition. In [28], the optimal operation cost of a system, including FC, photovoltaic and wind energy, as mixed-integer linear programming model, has been solved considering demand response by using GAMS software. In [29], the scheduling of a FC-based system has been optimized using a software, which is developed by Berkeley Lab. In all aforementioned papers [24–29], a simple model for FC has been considered for optimization of the system.

This paper is devoted to an economic study of a multi-carrier energy system, which is installed in a house. The thermal and electrical loads are energized by a PEMFC and a battery supplied by a natural gas resource and an electrical grid. The mathematic model of PEMFC for approximation of the relation between generated electrical power of FC and its efficiency and output thermal power is extracted from experimental curves expressed in [30].