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A new heuristically optimized Home Energy Management controller for smart grid

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ABSTRACT

Recently, Home Energy Management (HEM) controllers have been widely used for residential load management in a smart grid. Generally, residential load management aims to reduce the electricity bills and also curtail the Peak-to-Average Ratio (PAR). In this paper, we design a HEM controller on the basis of four heuristic algorithms: Bacterial Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA), Binary Particle Swarm Optimization (BPSO), and Wind Driven Optimization (WDO). Moreover, we proposed a hybrid algorithm which is Genetic BPSO (GBPSO). All the selected algorithms are tested with the consideration of essential home appliances in Real Time Pricing (RTP) environment. Simulation results show that each algorithm in the HEM controller reduces the electricity cost and curtails the PAR. GA based HEM controller performs relatively better in term of PAR reduction; it curtails approximately 34% PAR. Similarly, BPSO based HEM controller performs relatively better in term of cost reduction, as it reduces approximately 36% cost. Moreover, GBPSO based HEM controller performs better than the other algorithms based HEM controllers in terms of both cost reduction and PAR curtailment.

1. Introduction

The ever increasing energy demand has created problems like blackout, load shedding, voltage instability, frequency drop, etc. As a solution, two approaches are nowadays in practice: (i) increasing the generation capacity, and (ii) managing the load according to existing power generation capacity through Home Energy Management (HEM) system (Saha et al., 2014). The earlier approach majorly depends on the installation of new power generation substations. In the later approach, Demand Side Management (DSM) programs are utilized which aim to manage the load according to existing generation capacity through scheduling techniques. In fact, the scheduling techniques are optimization algorithms for managing the load between on-peak hours and off-peak hours while taking into account user and utility requirements. Substantial research efforts have been made to investigate the scheduling problem in the residential sector (refer to Fig. 1 for a pictorial view of the residential area based smart grid). For example, Bozchalui, Hashmi, Hassen, Canizares, and Bhattacharya (2012) used Mixed Integer Linear Programming (MILP) to schedule residential appliances. They integrate Photovoltaic (PV), storage, lighting, heating and air conditioning systems. Case study results show a reduction in cost and Peak-to-Average Ratio (PAR), however, system complexity is increased. In Roh and Lee (2016), Mixed Integer Non-Linear Programming (MINLP) is used to schedule appliances belonging to multiple classes. Similarly, in Gholian, Mohsenian-Rad, and Hua (2016) and Tsui and Chan (2012) MILP and MINLP are used for appliance scheduling to reduce the electricity cost. In Chana (2013), Bacterial Foraging Optimization Algorithm (BFOA) is implemented for resource scheduling problem in grid computing aiming at electricity cost minimization. MINLP and Genetic Algorithm (GA) are used in Fernandes et al. (2011) for controlling home appliances. Zhao, Lee, Shin, and Song (2013) use GA for scheduling in residential appliances subject to electricity cost reduction. In Pedrasa, Spooner, and MacGill (2009), Binary Particle Swarm Optimization (BPSO) is used for scheduling interruptible load. Their simulation results verify the effectiveness of BPSO in terms of electricity bill reduction and energy profile stability. Similarly, Zhou, Chen, Xu, and Zhang (2014) studied load shifting techniques in HEM system by using Particle Swarm Optimization (PSO). Cost and energy

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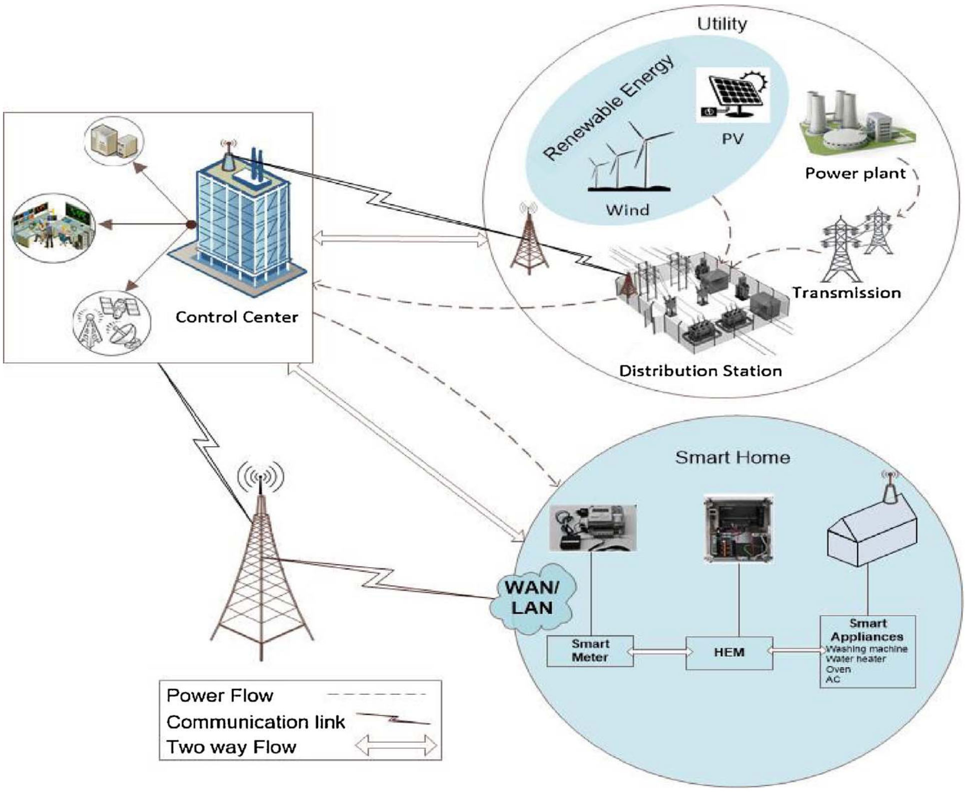

Fig. 1. Abstract view of smart grid model.

minimization were the objectives of this study. A comparative study of PSO and Wind Driven Optimization (WDO) is conducted in Rasheed et al. (2015) to solve the problem of residential load management. The simulation results show that the performance of WDO is better than PSO in terms of user comfort and electricity cost reduction.

The mathematical techniques like MILP and MINLP are quite beneficial but at the cost of high computational complexity (Bozchalui et al., 2012; Fernandes et al., 2011). On the other hand, heuristic algorithms (e.g., GA, BPSO, and BFOA) are flexible for specified constraints, easy in terms of implementation and have low computational complexity (Maringer & Dietmar, 2006). In this paper, we use four heuristic algorithms; BFOA, GA, BPSO, and WDO to solve the load scheduling problem. We choose these algorithms due to their self-organization, self-optimization, self-protection, self-healing and decentralized control system (Maringer & Dietmar, 2006). These algorithms are tested with the simulative consideration of a HEM system in Real Time Pricing (RTP) environment. Simulation results show that each algorithm is capable of reducing cost and PAR in comparison to the unscheduled load, however, there is a trade-off between cost and PAR in each scheme (Table 11).

We propose a Genetic BPSO (GBPSO) algorithm to solve load management problem. This hybrid technique incorporates the functionalities of GA and BPSO to create new individuals (Naseem et al., 2016). In GBPSO, we modify the method of updating position by using genetic operators (crossover and mutation) to further improve the performance of BPSO. We follow all steps of BPSO to achieve better position vector, then we update position vector by applying crossover and mutation processes to further improve the results. Simulation results show that GBPSO outperforms other heuristic algorithms in terms of cost and PAR reductions (Tables 10 and 11).

The rest of the paper is organized as follows. Section 2 deals with the related work. System Model is presented in Section 3. Problem formulation and proposed solution are discussed in Section 4. In Section 5, simulation results are discussed in details. Section 6 concludes the paper.

2. Related work

In the literature, many DSM based load scheduling techniques are proposed to reduce the electricity bill and PAR. HEM system is an important feature in residential scheduling. For the development of HEM system, a substantial work has been done. For example, Bin et al. (2016) and Vardakas, Zorba, and Verikoukis (2015), present a brief survey of the design and essential functions of HEM system. They discuss configuration and implementation challenges, like the method of integrating renewable energy sources with the existing system in HEM environment. Moreover, an overview of existing literature regarding residential appliance scheduling is also discussed. Similarly, a detailed literature survey on residential energy management system is presented in Beaudin and Zareipour (2015). The main objectives of this study are to focus on modelling approaches and their effects on the development of HEM system. The authors also discuss the challenges, like load forecasting limitations, heterogeneity of residential appliances, computational complexity, etc., in the implementation of HEM system. Moreover, they give an intuition of scheduling techniques like mathematical, meta-heuristic and heuristic algorithms. Bin et al. (2016), Vardakas et al. (2015), Beaudin and Zareipour (2015) mention several problems in HEM system. To solve such problems, many mathematical and heuristic algorithms are presented. Some of the latest techniques are discussed below.

2.1. Mathematical modeling based optimization

The smart charging mechanism in Adika and Wang (2014) enhances the efficiency of energy storage systems and scheduling approaches in DSM under RTP scheme. An aggregator is introduced which optimally schedules the appliances and battery charging based on Day Ahead Pricing (DAP) scheme. The objective of this study is to benefit the consumer in terms of cost reduction and comfort maximization. To solve the optimization problem, Linear Programming (LP) has been used. The results show that with appropriate scheduling of storage