Pigeon Inspired Optimization and Bacterial Foraging Optimization for Home Energy Management

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Abstract. In this paper, we are dealing with Home Energy Management System (HEMS) using Bacterial Foraging Optimization (BFO) and Pigeon Inspired Optimization (PIO) techniques in a single home. Performance of Both techniques is evaluated through simulations in term of reduction in electricity cost, Peak to Average Ratio (PAR) by scheduling smart appliances. We have used Critical Peak Pricing (CPP) as a pricing signal and we have gained electricity cost reduction upto 40%.

Keywords: Smart grid · Home energy management · Pigeon inspired optimization · Bacterial foraging optimization.

1 Introduction

A Smart Grid (SG) as shown in Fig. 1 is an intelligent power network that integrates with advance information, control and communication technologies [1]. SG was introduced as it fulfill the demands of the consumers efficiently whereas, traditional grid was unable to fulfill these demands. Demand-side management (DSM) has been traditionally seen as a means of reducing peak electricity demand. In fact, by reducing the overall load on an electricity network, DSM has various beneficial effects, including lowering of electrical system emergencies, reducing the number of blackouts and increasing system reliability. Possible benefits can also include reducing dependency on expensive imports of fuel, reducing energy prices, and reducing harmful emissions to the environment. DSM has a major role to play in dealing with high investments in generation, transmission and distribution networks. Thus, DSM applied to electricity systems provides significant economic reliability and environmental benefits. CPP is designed to provide users with more accurate information regarding the cost of energy, so that they can make more informed decisions about how and when to use electricity. While, the price of electricity is higher during periods of high energy use called CPP events, the CPP rate offers lower prices during all other times.

L. Barolli et al. (eds.), *Advances on Broad-Band Wireless Computing, Communication and Applications*, Lecture Notes on Data Engineering and Communications Technologies 12,
https://doi.org/10.1007/978-3-319-69811-3_2

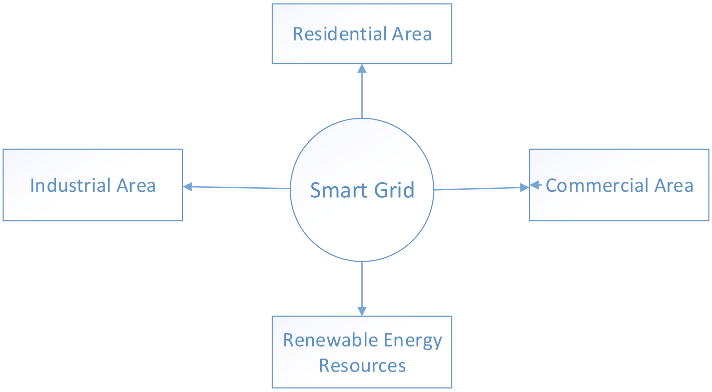

Fig. 1. Proposed system model in smart grid

This provides users with the opportunity to better assess and potentially reduce their overall energy costs. The objectives of this paper are to reduce the electricity cost, PAR and maximize the user-comfort. In order to minimize the electricity cost consumers have to pay a price of compromising their comfort, as there exists a tradeoff between cost and waiting time. In order to schedule shiftable load we implement PIO and BFO. The PIO algorithm is a novel swarm intelligence algorithm, proposed by Duan and Qiao in 2014 [2]. Authors were inspired by the behaviour of homing pigeons, as they can find their way back to their homes using three homing tools: magnetic field, sun, and landmarks. In basic PIO, map and compass operator are used based on magnetic field and sun. Main advantage of PIO is that it can accelerate the convergence speed. We utilize these techniques for finding optimal solution. BFO is a nature inspired optimization technique inspired by social behaviour of Esherichia coli (E.coli) bacterium. E.coli bacterium communicates with each other by sending signals. Two basic operations are performed during foraging: swim and tumble. Bacterium will swim if they meet favourable conditions and they send signals to other bacterium too. Bacterium will tumble if they meet unfavourable conditions. It has three basic steps: chemotaxis, reproduction, elimination dispersal. These steps are further defined in Subsect. 4.1.

The rest of the paper is organized as follows. In Sect. 2, related work is described, Sect. 3 explains problem statement, Sect. 4 describes proposed system, In Sect. 5, results and simulations are discussed, and in the last Sect. 6 paper is concluded.

2 Related Work

Many researchers are working on smart grids some of their work is discussed below. In [1], authors are dealing with the power scheduling problem for residential consumers in smart grid. Two type of electrical appliances are used.

Author gives residential consumers a strategy for power scheduling. It is applied as 3 operational modes, and only with third operational mode desired trade-off is achieved between discomfort and payment. 24 h time slot is used and DA pricing signal is used because it reduce the PAR. Authors are dealing with the problem of the reverse power flow in [3]. Approximate dynamic programming is used to schedule the operation of appliances. Relation between user and excess power generation is shown by game theoretic approach. Author also proposed the load control algorithm for demand side management. PAR is not considered. If the electricity supply is less then demand then MCP is increased. In paper [4], A SG heuristic algorithm based on energy management controller is proposed for a residential area. Five algorithms are used for scheduling the load from on peak hours to off peak hours using RTP. The objective of author here is to minimize the cost and PAR and maximize the user comfort. Their proposed technique is hybrid Genetic Wind-Driven (GWD) algorithm. GWD algorithm performs better than the other heuristic algorithms. User-comfort is compromised. For electricity trading author proposes Stackelberg game approach in [5]. RTP is used for optimal power generation and iterative algorithm is used. Authors are successful in reducing the peaks and balance the supply and demand load. This paper [4], deals with the situation of RTP when electricity price is low and most of the appliances are operating, due to which there is a possibility of blackout because of high demand. Author uses RTP with IBR to solve this problem. Nonlinear problem of optimization is solved by using Genetic Algorithm (GA). In Home Area Network (HAN), author introduces general architecture of Energy Management System (EMS). Author also proposes a technique to minimize electricity cost and PAR. In [6], authors are proposing a model based on GA Genetic-Demand Side Management (G-DSM) used to schedule appliances. Two types of appliances are used: delayable and non-delayable appliances. Proposed model is used to reduce PAR, energy cost and waiting time of appliances. Load shifting based strategy is used instead of load reduction to manage power consumption. To avoid load synchronization author uses IBR and total power consumption capacity limit. In [7], authors are using different heuristic algorithms to check the performance of Home Energy Management Controller (HEMC). Author uses GA, Binary Particle Swam Optimization (BPSO) and Ant Colony Optimization (ACO). ToU and IBR pricing tariffs are used to reduce peak formation. They also uses Renewable Energy Sources (RESs) to reduce load on utility and to balance supply and demand load. Authors solve the problem by using Multiple Knapsack Problem (MKP) and tackle randomness by using Monte carlo simulations. Main objective of this paper is to reduce electricity cost by maximizing user comfort. GA works more efficiently than other two techniques. In this [8] paper, the authors proposed a game theory based dynamic pricing strategy. Peak load is reduced by proposed technique and profit is increased. Proposed solution is for residential, commercial and industrial sectors. Half-hourly RTP, ToU and DN pricing is used and the proposed method is robust. In order to reduce user discomfort and enhanced appliance utility author proposed a Realistic Scheduling Mechanism (RSM) in [9]. BPSO is applied to schedule appliances in given time-slot. Equilibrium between appliance utility and cost effectiveness is achieved by using RTP and DA. Appliances utility has inverse relation with cost. Scheduled and non-scheduled load is analysed to prove the proposed scheme. ILP technique is proposed by author in [10]. This technique is used for home area load management. Goal is to reduce peak load to schedule daily load that will minimize energy consumption. This technique is better for residential area. Proposed technique is only suitable for fixed price scenario. In [11], authors are reducing and scheduling the energy usage in Home Energy Management System (HEMS). Author proposed BBSA to manage energy consumption in domestic sector. Real-time optimal schedule controller is used. In two cases this algorithm is used first in weekdays and second on weekends. User-comfort is considered and results are compared with BPSO however the proposed technique works better reducing the energy consumption keep user comfort in mind and maintain supply and demand load. In paper [12], authors are proposing Game-theoretic DSM for bill reduction and privacy-friendly DSM, it maintains the privacy of users. Two kind of appliances are used; fixed and shift-able. Minimized cost is achieved and privacy is considered.

3 Problem Statement

In SG, user-comfort maximization and optimization of energy consumption are difficult tasks. An efficient HEMS controller reduce electricity bills however PAR is still an issue. There are many contributions but their is still room for improvement. As we can see in Sect. 2, user-comfort is neglected while reducing electricity bills. There exists a trade off between these two parameters. In this paper, we considered two heuristic techniques: PIO and BFO to achieve our objectives. The objectives are to reduce electricity cost, PAR and maximize user-comfort by using CPP tariff. In our scenario appliances are divided into two categories: Non-interruptible and interruptible appliances.

4 Proposed System

In our proposed system, we are using BFO and PIO along with CPP pricing signal and 120 h time-slot. Single home is used where appliances are connected with Energy Management Controller (EMC). Smart meter is installed outside the home with EMC. The whole system is connected with smart grid as shown in Fig. 2 and used parameters are shown in Table 1. We are using two kind of appliances interruptible (e.g., Washing Machine) and non-interruptible (e.g., Electric Kettle).

Table 1. Parameters of proposed system model

Appliances	LOT	Power(KWh)
Ac1	5	1
Ac2	5	1
Ac3	10	1
Electric Radiator1	5	1.8
Electric Radiator2	10	1.8
Rice Cooker1	2	0.5
Rice Cooker2	2	0.5
Rice Cooker3	2	0.5
Water Heater	3	1.5
Dish Washer	2	0.6
Washing Machine	5	0.38
Humidifier1	10	0.05
Humidifier2	10	0.05
Cloth Dryer	5	0.8
Electric Kettle1	1	1.5
Electric Kettle2	1	1.5

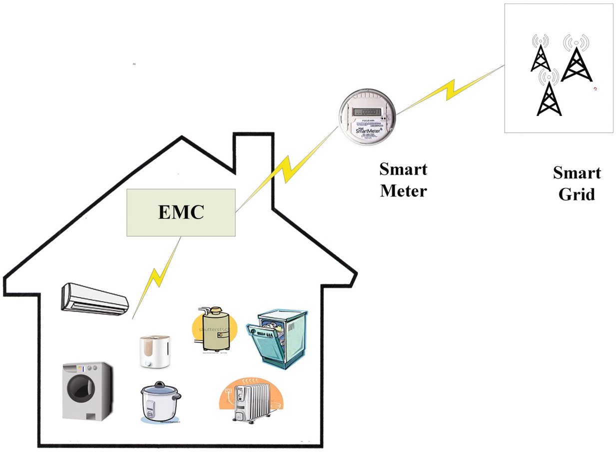

Fig. 2. Home energy management system

4.1 Algorithm

We are going to discuss two algorithms in this section. PIO is proposed by Duan and Qiao [12] and derived from homing pigeons. It can be described as follows: In Algorithm 1 all parameters are initialized and Population is randomly generated. Fitness of each appliance is calculated for finding the optimal solution after that map and compass operators are used to calculate X_i and V_i. All the appliances are sorted according to the fitness and half of the appliances are removed. X_i is calculated, X_g is the output.

In BFO Algorithm 2, there are three basic steps: chemotaxis, reproduction, elimination and dispersal step. In chemotaxis step, if bacterium meets favourable condition, it will continue to swim in that direction. If it meets unfavourable condition it will change its direction. Reproduction step it allow bacterium to reproduce and survive. In elimination dispersal step best one's are selected and previous were removed [4].

Algorithm 1. PIO Algorithm

Input: maximum iterations
Initialization: pigeonnum, D, map and compass factor, T1, T2, X_g
Specify LOT of appliances and power ratings
Randomly initialized the population
set initial path X_i and velocity V for each appliance
set X_p=X_i
calculate the fitness of individual appliances
find the optimal solution
map and compass operator
for $t = 1 \rightarrow T1$ **do**
    for $i = 1 \rightarrow pigeonnum$ **do**
        while X_i *is beyond the search range* **do**
            calculate X_i and V_i
        end
    end
    for *j=1 to D* **do**
        while X_P *is beyond the search range* **do**
            sort all the appliances according to their fitness values
            pigeonnum=pigeonnum/2
            keep half of the appliances with better fitness value and discard the other half
            X_c= average of the remaining appliances
            calculate X_i
        end
    end
    Output: X_g is output as the global optima of fitness function
end

Algorithm 2. BFO Algorithm

```
1  Initialize population randomly
2  Calculate fitness of each bacterium (JLast)
3  Elimination and dispersal step
4  Reproduction step
5  Chemotaxis step
6  Calculate fitness of every bacterium
7  new position of bacterium
8  Fitness evaluation
9  Swimming step
10 if Ji < JLast then
11 |   Replace previous position with new position
12 |   else Assign random direction
13 end
14 Fitness evaluation
15 if i < Np then
16 |   if j < Nc then
17 |   |   Evaluate for selection
18 |   |   else Goto step 5
19 |   end
20 |   else Goto step 6
21 end
22 if K < Nr then
23 |   Select best one
24 |   Random elimination and dispersal step
25 |   Fitness evaluation
26 end
27 if J < Ne then
28 |   end
29 |   else Goto step 3
30 end
```

5 Results and Simulations

In order to compare the performance parameters: cost, PAR and waiting time of the appliances is calculated on the bases of 120 h time slot using BFO and PIO. Two types of appliances are used: interruptible and non-interruptible. CPP is used as a pricing signal to calculate the electricity bills. We are considering graphs of; PAR, cost, load and user-comfort or waiting time of an appliance (Fig. 3).

Figure 4 shows the hourly cost of scheduled and unscheduled appliances. In start the cost is high because of peak hours but it gradually decreases with the passage of time. The cost of scheduled appliances is less than that of unscheduled appliances. Figure 5 demonstrates that the PAR of scheduled appliances is less

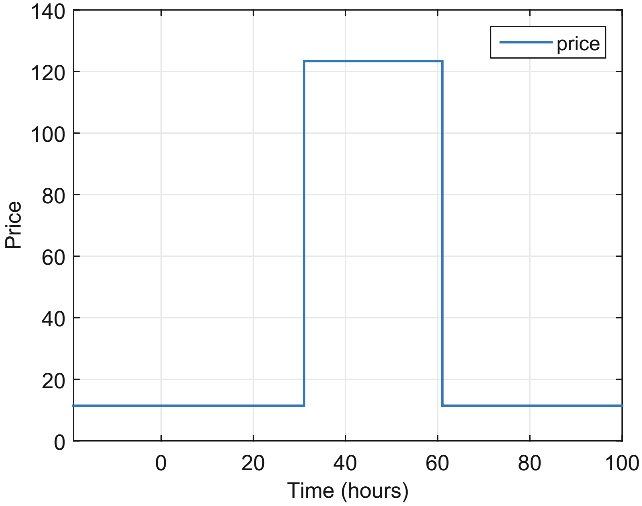

Fig. 3. Critical peak pricing signal

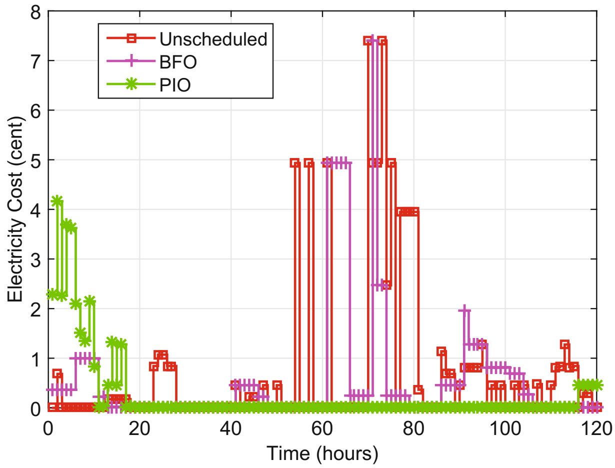

Fig. 4. Hourly cost of unscheduled, BFO and PIO

than that of the unscheduled appliances. The PAR of BFO is much less than PAR of unscheduled appliances. PAR is reduced by 3% by BFO. PAR of PIO is 18% less than unscheduled appliances. Result shows that our proposed technique effectively tackles the problem of peak reduction. Figure 6 explains the overall cost of scheduled and unscheduled appliances. The cost of scheduled appliances is less than that of unscheduled appliances. Cost is reduced 10% by BFO from unscheduled appliances and 30% by PIO from BFO. PIO cost is 40% less from unscheduled appliances. Total cost can be further reduced if consumer consume

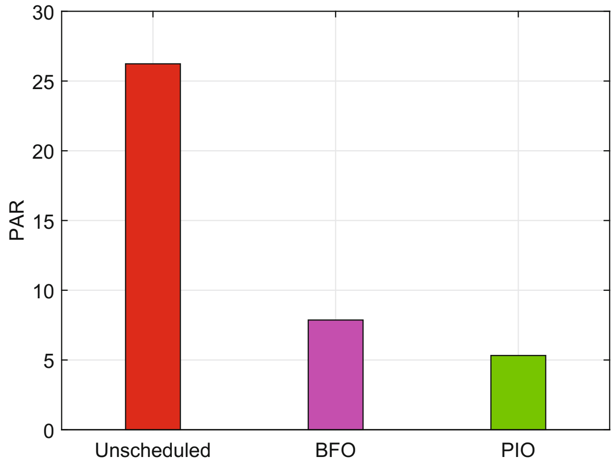

Fig. 5. Peak to average ratio of unscheduled, BFO and PIO

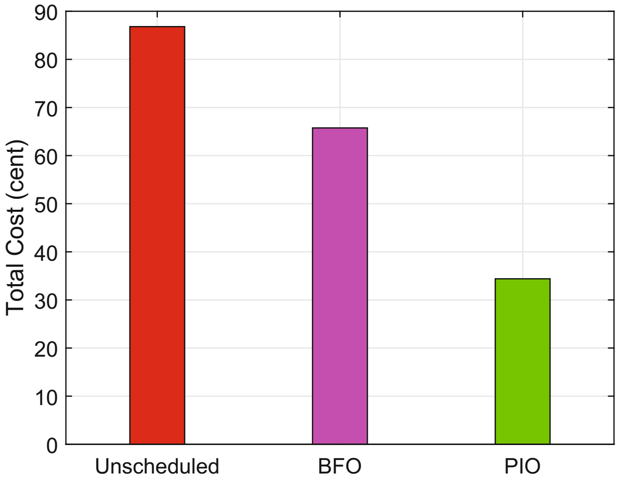

Fig. 6. Overall cost of unscheduled, BFO and PIO

energy in an intelligent way. Figure 7 shows the waiting time. Waiting time of PIO is 37% more than BFO because when cost decreases user-comfort increases as it is clear from Fig. 6 cost is decreased by 40% therefore consumers has to compromise their comfort as there exists a trade-off between waiting time and cost. Waiting time and user comfort are closely related to each other. The term waiting time means that how much user has to wait to use the appliance. From simulations it is clear that PIO outperforms BFO in terms of electricity cost.

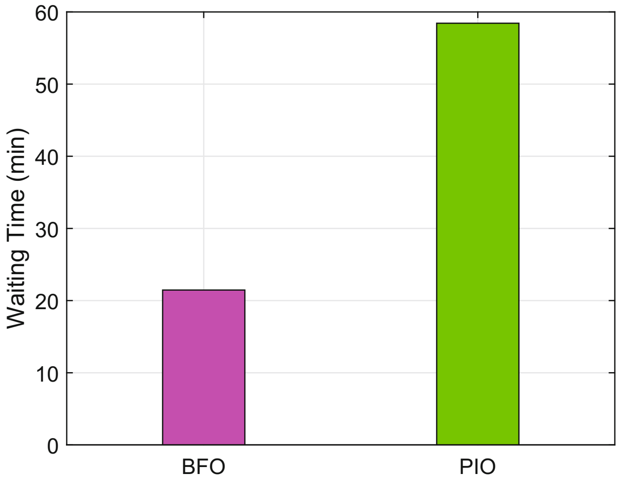

Fig. 7. Waiting time of BFO and PIO

6 Conclusion

In this paper, we have discussed BFO and PIO techniques in a single home with 16 different appliances. Comparison of both techniques is considered in terms of their performance. Performance is evaluated in terms of reduction in cost and PAR through simulations. Simulation results show that PIO is identified as the best technique as it performs well in reducing cost. PIO gives 37% more waiting time than BFO, it has 60% less cost by BFO and PAR is 3% less by BFO. It is concluded from results that there exists tradeoff between cost and waiting time of appliances. In future we will work on integration of renewable energy resources.

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http://www.springer.com/978-3-319-69810-6

Advances on Broad-Band Wireless Computing, Communication and Applications
Proceedings of the 12th International Conference on Broad-Band Wireless Computing, Communication and Applications (BWCCA-2017)
Barolli, L.; Xhafa, F.; Conesa, J. (Eds.)
2018, XLVIII, 865 p. 457 illus., Softcover
ISBN: 978-3-319-69810-6