Appliance Scheduling for Optimal Load Management in Smart Home Integrated with Renewable Energy by Using Whale Optimization Algorithm

Hussein Swalehe*, Pius Victor Chombo, and Boonruang Marungsri

Abstract— *One of the essential factor for the better operation of an electrical power system is load demand. Normally, higher load demand leads to instability and insufficient power supply. To make an electrical power system stable and sufficient, a good correlation between demand and supply should exist. A survey conducted during 2011 indicated that residential sector is consuming 18% of total energy. Also, the demand was seen to increase rapidly close to and sometimes beyond the supply. Hence, this paper focuses on appliance scheduling for cost reduction and peak load reduction by increasing demand-side response in the smart home integrated with renewable energy. A load management algorithm is developed in MATLAB which reduces both cost and peak load consumption by managing the operation according to utility controls and consumer preferences. The optimization problem was solved by using Whale Optimization Algorithm (WOA) technique. The simulation results depicted a reduction of up to 40% in electric bill when scheduling electrical appliances without renewable energy source; and up to 53% when renewable energy is considered with respect to Time-of-Use (TOU) pricing. The reduction in electric bill indicated the cutback of load demand from the specific user which can serve during severe peak demand. On the other hand, WOA can be adopted for appliance scheduling in the household, reduction of electric bill as well as cutback of peak demand from the demand side.*

Keywords— **Load Management; Demand response; Smart home; Time-of-Use (TOU) pricing; Whale Optimization Algorithm (WOA).**

1. INTRODUCTION

In the electrical power system, load demand plays an important role of maintaining the stability of the system. A good proportionality between demand (consumption) and supply (generation) should hold in order to avoid generation disturbances which later introduces negative effects in technical, economic and social areas [1]. The rapid rise of energy needs has made electric utility companies to expand generation plants with respects to peak demand rather than average power in order to meet the consumer's demand [2]. This approach, unfortunately, renders power systems highly underutilized and customers' consumption patterns increasingly irresponsible. Additionally, it has driven utility companies to make huge long-term investments in new generation power plants which are mostly and typically based on traditional (conventional) energy sources. Such power plants – in addition to being capital intensive – lead to increased Greenhouse Gases (GHG) emissions that greatly affect the earth's temperature, changes in weather, sea level, and land use patterns [3]. Efficient utilization and special consideration of the optimal plant generation capabilities must be employed in order to improve the under-performing available generating plants without building new power plants [4] - [5]. Nowadays, load management has been accepted worldwide as the simplest, safest and cheapest technique that provide a better correlation between generation and load by performing load management practices on demand side loads through demand reduction or reshaping the load profile.

Usually, load management practice aims to shift the load from on-peak period to off-peak period so as to reshape the load profile which in-turn reduces the total cost of electricity. Through energy management-based researches, an electrical engineer can cut costs of power system operation through utilization of optimal available generation capacity. A survey conducted during 2011 indicated that 18% of total energy is being consumed by residential sector [6]. Due to this reason, this paper target on scheduling home appliances (HAs) in the smart home integrated with renewable energy. Smart home (SH) appliances are connected to home area network (HAN) to coordinate power usage demanded the home under control. Load management is an essential key factor in smart grid (SG) for scheduling home appliances (HAs) in the smart home. A modern technology, with sophisticated metering infrastructure, can allow a two-way transmission of information between the utility company and the consumer through metering unit to enable a smooth aggressive load deviation. Regarding this direction, demand-response (DR) programs give incentives to significant costumers, generally in terms of money, to minimize their energy use during on-peak periods [6]. Demand Response appear at a very fast timescale, approximately real-time, it results to a stable

Hussein Swalehe is with the School of Electrical Engineering, Institute of Engineering, Suranaree University of Technology, Muang District, Nakhon Ratchasima, 30000, Thailand.

Pius V. Chombo is with the Department of Electrical Engineering, Dar es salaam Institute of Technology (DIT), P.O.BOX 2958, Dar es salaam, Tanzania.

B. Marungsri is with the School of Electrical Engineering, Institute of Engineering, Suranaree University of Technology, Muang District, Nakhon Ratchasima, 30000, Thailand.

* Corresponding author: Hussein Swalehe; E-mail: hussein.swalehe66@gmail.com.

and sufficient power grid system and importantly minimizes electric cost and CO2 emissions [7].

Smart grid, in the growing power system technology, is currently considered as an upcoming solution to the most of the existing power systems. It comes in different names such as smart power grid or intelligent grid [2] to take over an old, disorganized and defenseless existing power system. An efficient performance of smart grid depends on the advanced technologies in electrical power, control, communication, information theory, bi-directional flows of electrical power and information which promotes an advanced and modern power system with cost-effective, safety and security. In smart grid, advanced energy-metering infrastructure (AMI) and energy monitoring are performed over a number of smart meters and sensors equipped all the way in smart homes. The part of communication as well as networking technologies ensure real time data collection and transmission to and fro both sides. In smart grid (SG) system, the load management is an essential factor to control energy management system. Through load management strategies in smart grid (SG), reduction of peak load during the peak period and control pricing of electricity unity can be achieved through customer participation in the smart home [8]-[14]. The usage of photovoltaic system causes a reduction of electric bill and the peak demand at home. Moreover, excessive generated energy can be added to the smart grid from the smart home [15]-[17]. A recent and well performing technique, Whale Optimization Algorithm (WOA) is employed for optimizing scheduling of appliances. Its high exploration and convergence behaviors toward solution in different iterations makes it unique in problem solving against other conventional techniques.

2. THE SMART HOME (SH)

"Smart Home is the term normally used to define a household that uses a home controller to integrate the residence's various home automation systems" [18]. Smart Home is the computerized controls in homes and appliances that can be set up to respond to signals from the energy provider to reduce their energy use at times when the power grid is unstable from high peak load demand, or even to shift some of their power use (energy consumption) to times when power is available at a lower cost. Customer involvement is the one among the critical attribute of the SH. The involvement of the customer is facilitated by a smart meter, which also connects the smart home (SH) and Smart Grid (SG). Besides the gathering of data for electric utility companies, smart meters perform crucial roles for both customers and the grid to which they are connected to. They act as controllers over consumer's appliances. With the upcoming technologies of SH, each home appliance will be provided an ability to transfer information and monitored by the smart meter with the use of in-home networking system. Current developed appliances are equipped with application softwares and interfaces to provide an easy use to costumers. The programmed instructions can then be viewed to costumers through displays. The SH control can further give customers extra opportunities, such as energy saving, loss reduction, cost saving, and reduced carbon emission.

The concept of future SH is displayed in Fig. 1 where a small renewable generation and energy storage system are equipped to make a future SH working as a small connected micro-grid (MG) [19]-[27]. Moreover, the use of hybrid DC/AC system can be added to support the future SH with the use of both DC power and AC power supply. Therefore, with the future SH, a reliable power supply will be available with an addition of automation, user preferences, and low emissions and cost-effective. The higher penetration of renewable energy into the smart home results in a minimization of electric bill, peak demand of the household and export of extra energy to the smart grid in times when renewable energy generation is more than the demand of the household [15]-[17].

Smart Appliances

"The term 'Smart Appliance' with respect to the smart grid refers to a modernization of the electricity usage system of a home appliance so that it monitors, protects and automatically adjusts its operation to the needs of its owner" [28]. Some of the key features noted by [28] include the following:

- The capability to alter the requirement for electrical energy exploitation.
- To give alerts to end-users to shift to a convenient time with available cheaper prices.
- To provide an automatic reduction of usage based on the consumers pre-established guidelines.
- To maintain stability of the system.
- Consumer is able to reverse all pre-programmed sets of instructions.
- To develop the energy consumption profile from total home energy consumption approach to utilize the data to its best profit.

The two main reasons for a consumer accepting to adopt smart appliances are an economic gain to the consumer and environmental reasons, but the latter is among only a small percentage of consumers who are environmentally conscious or environmental advocators. Most consumers will readily accept to shift to smart appliances for economic gains rather than environmental gains [29]. To trigger consumers to buy smart appliances, [29] suggested a promotion of attractive tariff from utility to customers with an addition of other incentives.

All smart appliances are classified as receivers, and the means of controlling them are through transmitters such as the 'remote control or keypad' [18]. For instance, if an appliance is needed to be switched ON or OFF, the transmitter (the remote), should transmit a signal to the receiver (appliance) in the form of a code which may include an attention to the intended system, giving a unit number of the respective equipment and the instructions that contains a set of actions to be performed [18].

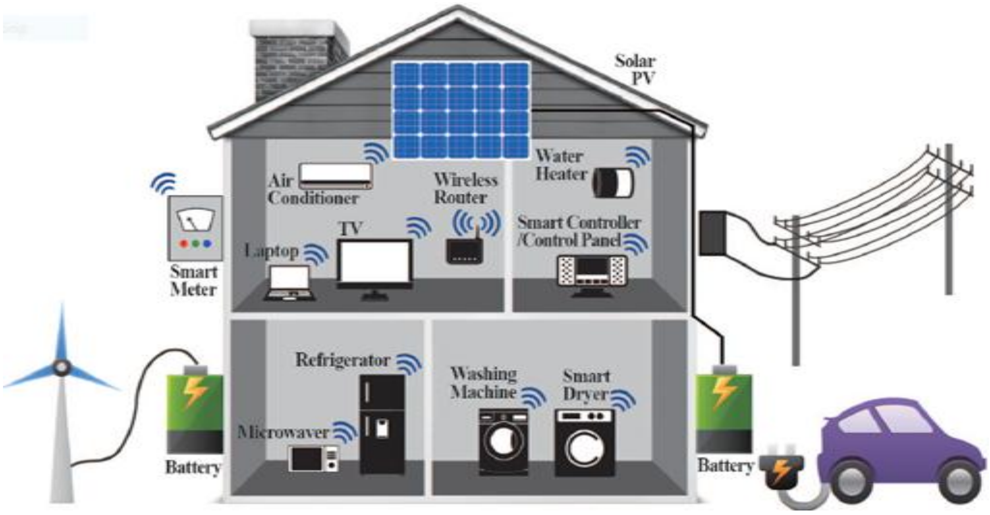

Fig.1 The concept of future smart home (SH)

3. LOAD MANAGEMENT (LM)

Paracha and Doulai (1998) [30] described load management as a set of goals aimed to manage, control or monitor the utilization of electical energy of various customers either by switching ON or OFF directly from the grid through grid operator during peak period or indirectly (demand response) from customer participation to reshape the load profile. This action helps the grid to gain stability between supply and demand and to make the best operation of its existing capacities in generation and transmission systems[4], [31].

Strategies for Load Management on Demand Side

There exist several strategies applicable for load management on demand side such as valley filling, peak clipping, and load shifting. Others are strategic conservation, strategic load growth, and flexible load shape. The operation of these strategies is shown on Fig. 2.

The descriptions of the above-mentioned strategies are given below:

- Peak clipping- this minimizes utility loads in case of peak demand periods and reconnect during off-peak.
- Valley filling- building loads during off-peak period
- Load shifting- transferring of loads from on-peak period to off-peak periods and vice versa
- Strategic load growth- increase customer usage resulting in sales increment beyond valley filling
- Flexible load shape- incentive contracts and tariffs (i.e, RTP, TOU, etc) with possibilities to shift consumer's equipment from on-peak period to off-peak period

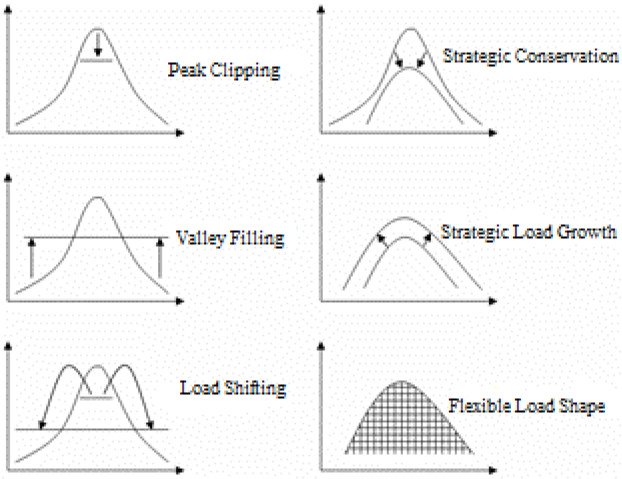

Fig.2 Load control strategies [32].

Among of the above-mentioned strategies, load shifting strategy is highly preferred and opted for scheduling since it gives a chance for a load to be reconsidered when removed during on-peak period. With this strategy, the reduced load is scheduled-in again in off-peak period.

Load Management Measures

Normally, the classification of load management measures falls into two classes which are direct load control (DLC) and indirect load control (ILC). The first class, DLC, secures the technological standards (AMI) applicable in smart grid as well as smart homes (like sensors and smart meters positioned at each customer to be monitored) that enable the grid operator to turn OFF the equipment during on-peak period and turn ON during off-peak period.

The second class, ILC, is positioned on either statute or economic policies. Based on this class, certain tariffs and pricing mechanisms are set to motivate customers to reduce their demands during on-peak periods. These are:

Time-of-use(TOU) tariff

This tariff is applied to direct the billing system on periods of cheaper prices (off-peak) and expensive prices (peak). With the successfully invented TOU billing system, both the utility and the consumer benefit.

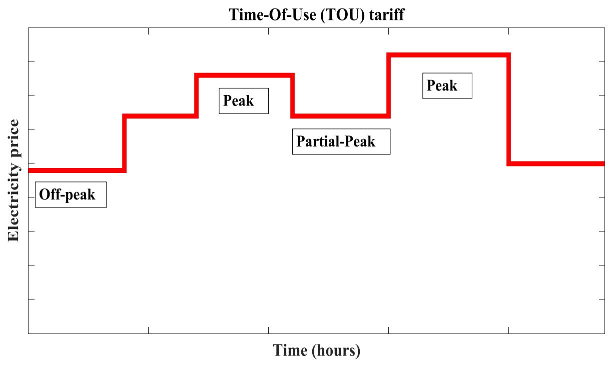

Fig.3. Time of use pricing.

Interruptible load tariff (ILT)

In Interruptible load tariff (ILT), consumer signs an incentive contract from the utility company to turn OFF the appliances during on-peak period or during emergence. And most of the time, this incentive contract is in the form of monetary reward to encourage the consumer to minimize their demand timely when required by the utility.

Tariff with load demand component (TLDC)

With (TLDC), end-user is requested to manage the load demand at a lower level due to a part of electricity bill build upon the highest documented hourly load demand price.

Real-time pricing (RTP)

This tariff associates the end-user's rate with the large-scale market rate. It is sometimes known as dynamic billing system. The principal characteristics are that the timing and costs are not set in advance [33].

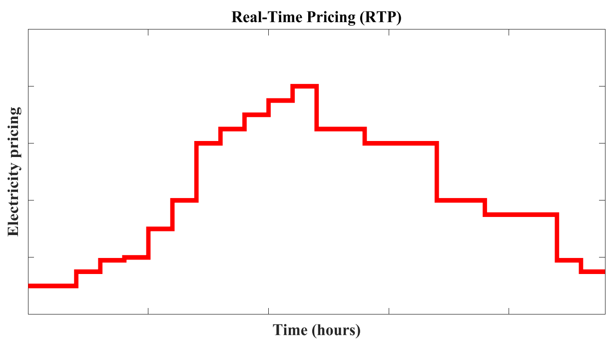

Fig.4. Real-time pricing.

Critical peak pricing (CPP)

This incorporates the principal characteristics of both TOU and RTP tariffs. It accounts a unique, extended price on chosen days with accelerated demand indicator, aimed to reduce the load in critical levels. Usually, an upcoming signal is given to end-users to let on them to make voluntary energy minimization when CPP days are called.

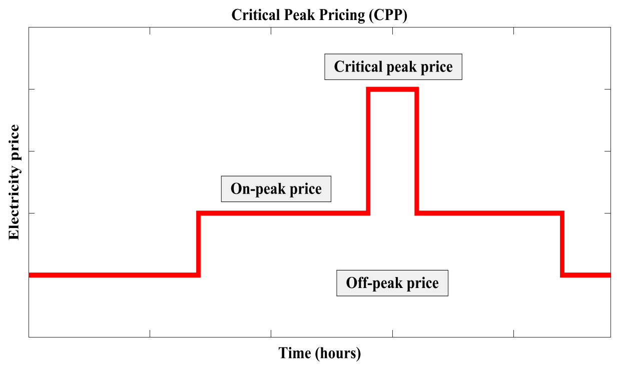

Fig.5. Critical peak pricing.

Demand-side bidding (DSB)

In Demand-side bidding, the costumer is given an opportunity to choose the best time to get-involved and measures required during real-time and upcoming spot markets

Based on [34], DSB allows customer to be refunded at the real-time market price for disconnecting loads, when requested by the market operator, in a same way that power plants are remunerated to supply.

4. DEMAND RESPONSE (DR)

Demand response (DR) is the process of minimizing load at times when either contingency happens which intimidates the balance between supply and demand or market conditions happen that raise production cost.

Three basic categories of DR automation are listed below [35]:

- Manual Demand Response- suggests manually switching OFF appliances.
- Semi-Automated Response- implicates the application of home energy management control systems for load shedding, where facilities staff initiates a preprogrammed load shedding strategy.
- Fully-Automated Demand Response- commence at a building the use of access card (programmable card) which is programmed to switch on or off the appliance the time you need to use or not and within a certain period of time it goes off.

Types of Load of the household and its Characteristics

The residential appliances can be categorized into different types as shown in Table 1.

Base Loads

Base load refers to the appliances that to be operated continuously throughout the day. Examples of this baseload are an air conditioner, electric heater, etc.

Non-shiftable Loads

These are appliances which must be turned ON immediately when it is needed, and their working period cannot be changed.

Shiftable Loads

These refer to the appliances which can complete their tasks within the preferred time intervals, e.g., washing machine, dishwater, etc. They can further be divided into two types namely interruptible and non-interruptible loads [36]-[37].

- Interruptible load-refers to the appliances that can be given a discrete time interval to complete its working cycle. E.g., water heater, refrigerator
- Non-interruptible load-refers to the appliance which is turned ON exactly once to complete its job.

Table 1. Load types and its Characteristics.

No	Category	Types of loads	Home appliance
1	Manageable	Shiftable	Washing Machine, Dish Washer
2	Manageable	Interruptible	Water heater, Refrigerator
3	Manageable	Weather Based	Air Conditioner, Electric Heater
4	Non-manageable	Auxiliary	TV, laptops, lights

Benefits of Load Management

LM and DR require an avoidable effort of costumer's prosperity and home-independence. Nevertheless, the execution of Load Management and Demand Response plan can lead to several benefits in terms of technical, economic, environmental and social benefits. Based on [38]-[40], the chief advantages of an electricity market are given as:

- Increased overall economic efficiency.
- Market power mitigation.
- Improved system reliability.
- Reduced price volatility (risk management).
- Minimization of average energy costs to all customers.
- Consumer service.
- Environmental impact.
- Minimizing the generation margin
- Modifying distribution network investment efficiency

5. OPTIMAL SCHEDULING OF SMART HOME ENERGY CONSUMPTION

Total load demand for appliances depends on how they are scheduled over the certain period of time. For example, if all appliances start at once, the coincident demand should be very high to surpass the maximum limits introduced by the electricity distributors and most of the time adversely affects in-home electrical system. Therefore, the appliance usage should be appropriately used one after another to maintain the peak demand to a minimum level as well as electric bill, yet the comfort is not sacrificed. To minimize the electric bill and make better use of its available generation from the utility, the energy consumption of the smart home environment must be minimized. Also, to reduce electric bill, the concept of in-home energy management system (HEMS) is proposed and implemented through an optimal scheduling of smart home appliances. A scheduled strategy is planned in such a way that energy usage of several appliances is arranged to match low price periods in a day. The main concept is to move the shiftable loads (high resistive and inductive loads) in residential house into off-peak periods with low-price rate. Although the maximum power for selection of appliances is not set, some of the probable appliances with shifted and high consumption nature are shown in Table 2.

Table 2. Appliances and Power Consumption Patterns.

Appliances	Daily Power	Energy Consumption Patterns
Heater 1	1100 W	Preferred hours: 7 a.m-9 a.m: 300 Wh, 10 a.m: 200 Wh
Washing Machine	500 W	Preferred hours: 12 p.m: 500 Wh
Iron	400 W	Preferred hours: 9 a.m: 500 Wh, 1 p.m: 300 Wh
Dish Washer	400 W	Preferred hours: 12 p.m-2 p.m: 400 Wh
Heater 2	800 W	Preferred hours: 9 a.m: 500 Wh, 2 p.m: 300 Wh

Problem Formulation

For this case, the load management problem is considered to be linear. It contains of a linear function subjected by linear constraints. The optimal solution of load management problem depends upon the solution of linear equations, defining optimal and secured operation of the home network. In general, a constrained load management problem can be given as shown below [41-42]:

$$\min = \left\{ f\left(x\right) \middle| x \in X \right\}$$
$$\text{Subject to } g\left(x\right) \geq 0$$
$$h\left(x\right) = 0$$

where: *f(x)* is the objective function, *g(x)* is the inequality constraint function, *h(x)* is the equality constraint function, *x* is the set of each decision variable.

Formulating Objective Function

The goal of the objective function of load management problem is to reduce the total electric bill by scheduling the appliance on the basis of one-day ahead of TOU tariffs. The total electric bill is given in (1):

$$\min\sum_{k=1}^{m} C^k \left(\sum_{i=1}^{N}\sum_{j=1}^{ni} P_{ij}^k X_{ij}^k \right) \tag{1}$$

where:

$$X_{ij}^k = \begin{cases} 1 \text{ if appliance is ON} \\ 0 \text{ if appliance is OFF} \end{cases} \tag{2}$$

If smart-grid (SG) is added, then the equation will be as follows:

$$\min\sum_{k=1}^{m}\sum_{i=1}^{N}\sum_{j=1}^{ni}\left(C^k P_{ij}^k X_{ij}^k \text{-} g^k G_{ij}^k X_{ij}^k\right) \tag{3}$$

If solar PV modules are added, then the equation will be as follows:

$$\min\sum_{k=1}^{m}\sum_{i=1}^{N}\sum_{j=1}^{ni}\left(C^k P_{ij}^k X_{ij}^k \text{-} g^k * r * PR * A * T_{ij}^k\right) \tag{4}$$

where: r is the solar panel efficiency, (0.16 used in simulation). The value of PR is 0.75 (used in simulation). The A variable is the area of the photovoltaic modules which is 4 m^2 and T is the hourly irradiation. g^k is the feed-in tariff.

System Constraints

These define the conditions for solving the objective function of the load management, they include the following constraints:

- Load phases of the appliance should fulfill their energy requirements.

$$\frac{1}{4}\left(\sum_{i=1}^{N}\sum_{j=1}^{ni} P_{ij}^k \right) = E_{ij} \quad \forall\{i,j\} \tag{5}$$

- Load safety factor.

$$\sum_{i=1}^{N}\sum_{j=1}^{ni} P_{ij}^k \le \beta^k \quad \forall\{k\} \tag{6}$$

where: i is the cutback appliance index, k is the slot time over a certain period of time, j is the is the phase load number index correlated within each appliance, ni is the phases load shiftable set of numbers correlated with every appliance i, N is the appliances cutback set numbers, m is the slot time maximum number present in a day, P^k_{ij} is the power consumption of each appliance i having load phase j at time slot k, C^k is the TOU tariff, X^k_{ij} binary decision variable with value 1 if i^{th} appliance is ON otherwise 0.

6. INTELLIGENT ALGORITHM

Whale Optimization Algorithm (WOA)

Seyedali and Andrew (2006) [43-45], proposed an innovative nature based meta-heuristic optimization technique known as Whale Optimization Algorithm (WOA) that models the general behaviors of humpback whales. Usually, whales are considered as talented animals in movement. The WOA is motivated by the special hunting characteristic of humpback whales [43]. In general, the humpback whales aim to hunt krills or small fishes near the sea area. They use a genuine technique called bubble net feeding. With this technique, they swim around the target and build up a peculiar bubble beside a circle or 9-shaped path [43].

Mathematically, WOA can be expressed into three categories as: *(a) Encircling prey, (b) Bubble net hunting method, and (c) Search the prey*.

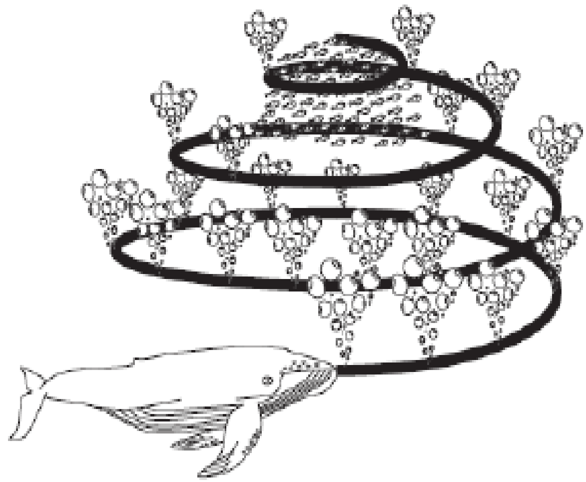

Fig.6. Bubble-net feeding behavior of humpback whale [43].

Encircling prey

WOA predicts the existent best candidate solution is the objective prey. Others try to update their positions toward best search agent. The behavior models are shown in (7)-(10) [43]:

$$\vec{X}(t+1) = \vec{X}*(t) \text{-} \vec{A} \times \vec{D} \tag{7}$$

$$\vec{D} = \left| \vec{C} \times \vec{X}*(t) \text{-} \vec{X}(t) \right| \tag{8}$$

$$\vec{A} = 2 \times \vec{a} \times \vec{r} \text{ - } \vec{a} \tag{9}$$

$$\vec{C} = 2 \times \vec{r} \tag{10}$$

where (7) show the best solution position and the position of the vector. The current iteration is expressed by *it*. $\vec{A}$, $\vec{C}$ are vectors coefficient. $\vec{a}$ decreased from 2 to 0 directly. $\vec{r}$ is a random vector [0, 1].

Bubble net hunting method

This one is classified into two categories as *Shrinking encircling prey* and *Spiral position updating.*

- *Shrinking encircling prey*

Here $\vec{A} \in [-a,a]$ whereby $\vec{A}$ is reduced from 2 to 0. Here the position is set down at random values in between [−1, 1]. The current position of $\vec{A}$ is achieved between original position and position of the current best agent.

- *Spiral position updating*

Helix-shaped movement spiral equation (11) is used to imitates.

$$\vec{X}(t+1) = \vec{D} \times e^{bl} \times \cos(2\pi l) + \vec{X}^* \tag{11}$$

In the two paths above, whales swim around the prey during hunting simultaneously. 50% probability is accounted for above two methods [41] to update whale's positions.

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \times \vec{D} & \text{if } p<0.5 \\ \vec{D}' \times e^{bl} \times \cos(2\pi l) + \vec{X}^* & \text{if } p<0.5 \end{cases} \tag{12}$$

where $D' = \left| \vec{X}^* - \vec{X}(t) \right|$ express the whale and the prey distance known as the best solution. *b* is constant, *l* ∈ [−1, 1]. *P* is random number [0, 1].

Search for prey

Instead of the best agent, randomly selected search agent updating is performed to obtain the global minima.

$$\vec{D} = \left| \vec{C} \times \vec{X}_{rand} - \vec{X} \right| \tag{13}$$

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} \times \vec{D} \tag{14}$$

$\vec{X}_{rand}$ are the current iteration random whales.

The input data to the proposed WOA is the number of appliances to be scheduled *n*, the population size of a whale *N*, and the maximum number of iterations it_{max}. The WOA beginning by producing *N* solutions from the random population in the search environment [0, 100], for every position the fitness function Fit_i is examined by using the above equation (1). Then the fitness function F_{best} with respect to its best whale position y_{best} are obtained. The values of *A* and *C* parameters are evaluated based on *a* parameter to diminish from 2 to 0, then the position of every whale is updated with respect to parameter *p*. The preceding procedures continued until the stoping criteria are achieved. The last and final step is to translate values into binary to represent the switching state of the appliances. The implementation of WOA is described by flowchart given in Fig 7.

Algorithm: WOA Algorithm for Appliance Scheduling

```
Input: n: number of appliances, N: population size of
    whales, it_max: maximum number of iterations.
Output: y_best Optimal cost values.
Generate a population of N whales y_i, i = 1, 2, …, N
t = 1
for all y_i do // parallel techniques do
Calculate fitness function Fit_i for y_i from equation (1)
end for
Determine the best fitness function F_best and its
    position whale y_best.
repeat
    for For every Value of a decrease from 2 to 0 do
        for i = 1: N do
            Evaluate C and A using equation (10)
        and equation (9) respectively.
            p = rand
            if p ≥ 0.5 then
                Update the solution using equation (11)
            else
                if |A| ≥ 0.5 then
                Update the solution using equation (14)
                else
                Update the solution using equation (8)
                end if
            end if
        end for
    end for
    t = t + 1
until H < it_max
```

Fig.7. Pseudo-code of the WOA algorithm.

7. SIMULATION RESULTS AND DISCUSSION

Optimization of the Residential Electricity Bill (Cost) without Solar PV integration

The optimization of the appliance scheduling problem for cost reduction of the household for the 24-hours a day based on TOU tariff was performed by using a WOA technique. It was used to schedule five (5) different shiftable appliances (i.e., Heater1, washing machine, Iron, Dishwasher, and Heater2) each with different daily energy consumption as shown from Table 2 above. Preferred working hours for operating an appliance (equipment) was taken into account to ensure total constant power supply from either utility (grid).

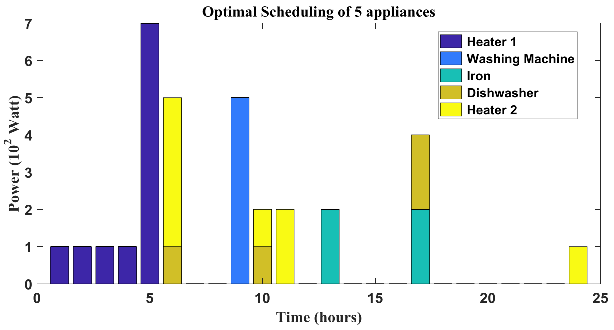

Fig.8. Optimal scheduling of appliances without Solar PV modules penetration.

The effectiveness and the efficiency of the WOA algorithm based on TOU tariff of the appliance scheduling problem for 24-hours a day was tested by comparing the electricity cost (bill) of the homes from the base case (i.e, before optimization) and after optimization. Table 3, give out the comparison of the simulation results of electricity bill (cost) of the household before WOA optimization and after WOA optimization with respect to TOU tariff. The optimization problem was done in MATLAB as seen from Fig 8 above. The simulation results shows that WOA minimizes electricity bill of the household at a large and can be adopted for load management in smart homes.

Table 3. Cost Comparison without PV Integration

TOU Tariff: Hourly Electricity Price Fluctuation		
Appliances	Bill before WOA ($)	Bill after WOA ($)
Heater 1	0.099	0.091
Washing Machine	0.055	0.041
Iron	0.032	0.031
Dish Washer	0.048	0.024
Heater 2	0.064	0.055
Total	0.298	0.242

Optimization of the Residential Electricity Bill (Cost) with Solar PV integration

In this case, the impact of penetrating renewable energy sources (Solar PV) in the smart home for electricity cost reduction was examined. The optimization was carried out in two different cases. First case was the base case (before optimization) and the second case was optimizing by WOA with integrating with renewable energy sources (WOA + solar PV) with respect to TOU tariff. Table 4, shows the comparison of the simulation results of electricity bill (cost) of the household before WOA optimization and after WOA with renewable energy source (solar PV) based on TOU tariff. Fig. 9 indicate the optimal scheduling of appliances with the integration of Solar PV modules.

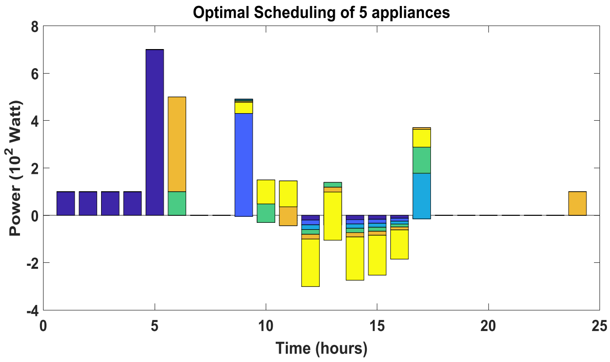

Fig.9. Optimal scheduling of appliances with the integration of Solar PV modules.

Table 4. Cost Comparison with PV Integration

TOU Tariff: Hourly Electricity Price Fluctuation		
Appliances	Before WOA ($)	WOA with solar PV ($)
Heater 1	0.099	0.073
Washing Machine	0.055	0.039
Iron	0.032	0.024
Dish Washer	0.048	0.021
Heater 2	0.064	0.039
Total	0.298	0.196

It can be shown from Table 4, that optimizing by WOA with solar PV (i.e., WOA + Solar PV) has major impact in case of minimizing the electricity cost than optimizing only with WOA. The extra energy from the solar PV that sold back to the grid in times when the PV generate more energy than the demand of the home was taken into consideration. The assumption made during simulation was that feed-in tariff (price of the energy sold back to the grid) equals to TOU tariff. A summary of the comparison of the Scheduling optimization of different cases is given from Table 5 below.

Table 5. Comparison of the Scheduling Optimization.

24-Hours Electricity Bill of the Appliances ($)	
Pricing	TOU tariff
Base Case ($)	0.298
WOA without PV ($)	0.243
WOA with PV ($)	0.196
WOA with PV and energy selling ($)	0.18

For validation, the results of WOA algorithm was compared with those of Mixed Integer Linear Programming (MILP). The procedures for performing MILP were described in [46] and results are shown in Table 6.

Table 6. Comparison of electric bills from MILP and WOA

24-Hours Electricity Bill of the Appliances ($)		
Pricing	TOU tariff	
	MILP	WOA
Base Case ($)	0.298	0.298
Optimization without PV ($)	0.263	0.243
Optimization with PV ($)	0.24	0.196
Optimization with PV and energy selling ($)	0.2	0.18

From Table 6, the results of electric bills from MILP and WOA in base case are seen to be the same. But for the case of optimization with and without PV, WOA gives better savings in electric bills compared to MILP. As seen in Table 6, the remained electric bill after optimization with PV and energy selling, WOA performs better than MILP in both cases.

8. CONCLUSION

Reducing the environmental impact such as increased Greenhouse Gases (GHG) emissions that greatly affect the earth's temperature, changes in weather, sea level, land use patterns and responding effectively and efficiently to the energy demand (cost and peak load reduction) is crucial towards achieving sustainability. WOA method was used to optimize and reduce the daily electricity cost through appliance scheduling. The scheduling optimization was implemented respectively with respect to Time-of-Use (TOU) billing method depending on the type of electricity price fluctuation. Moreover, the optimization was done in two different ways, i.e., optimization without solar PV and optimization integrating with solar PV. Simulation results depicted that optimizing the cutback of the electric appliances through WOA minimizes the cost up to 40% when no renewable energy is placed and by up to 53% when renewable energy is taken into account with respect to TOU pricing. Also, in terms of scheduling, WOA showed that it can be adopted for scheduling appliances in households for both electric bill and peak load reduction. The reduction in electric bill indicates the cutback of load demand from the specific user which can serve during severe peak demand. Moreover, the great saving of electric bills indicates a better performance of WOA.

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REFERENCES

[1] Davda, A. T., Desai, M. D. and Parekh, B. R. 2011. Integration of Renewable Distributed Generation in Distribution System for Loss Reduction: A Case Study. IEEE Trans. Power Deliv., vol. 3, No. 3.

[2] Goyal, S. and Shimi, S. L. 2017. Design of Nano Grid using Solar and Hydro System for Smart Homes. IEEE Trans. Power Deliv., vol. 5, Issue 5.

[3] Swathi, K., Balasubramanian, K., and Veluchamy, M.2016.Residential Load Management Optimization in Smart Grid. *International Journal for Trends in Engineering & Technology*, 13, pp. 48 - 53.

[4] Abaravicius, J. 2007. Demand Side Activities for Electric Load Reduction. ISRN LUTMDN/TMHP-04/7024-SE, Department of Heat and Power Engineering, Lund, University.

[5] Won, J. R., and Song, K. B. 2013. An Analysis of Power Demand Reduction Effects of Demand Response Systems in the Smart Grid Environment in Korea. *Journal of Electrical Engineering Technology (JEET)*, Vol 8(No. 6): 1296-1304.

[6] Salma, B. 2012. Design, Simulation, and Emulation of a Residential Load Management Algorithm Utilizing a Proposed Smart grid Environment for the Mena region. M.S. thesis, Department of Electrical engineering and Computer science., Cairo University., Egypt.

[7] Qayyum, F.A. 1998. Appliance Scheduling Optimization with Micro-grid in Smart Home Network. Department of Electrical and Computer Engineering., B.S., Sir Syed Engineering University, Karachi, Pakistan.

[8] Tammam, M. A., Aboelela, M. A. S., Moustafa, M. A. and Seif, A. E. A. 2013. A Multi-Objective Genetic Algorithm Based PID Controller for Load Frequency Control of Power Systems. *International Journal of Emerging Technology and Advanced Engineering*, Cairo., Egypt, 2013, pp. 463-467.

[9] Chao-Rong Chen, Ming-Jen Lan, Chi-Chen Huang, Ying-Yi Hong, and Steven H. Low. 2013. Demand Response Optimization for Smart Home Scheduling Using Genetic Algorithms. *IEEE International Conference on Systems, Man, and Cybernetics*, pp. 1461-1465.

[10] Chen, S. C., Tsui, K. M., Wu, H.C., Hou, Y., Wu, Y. C. and Wu, F. F. 2012. Load/Price Forecasting and Managing Demand Response for Smart Grids. *IEEE Signal Processing Magazine*, vol. 29, pp. 68-85.

[11] Black, J. W., and Tyagi, R. 2010. Potential Problems with Large-Scale Differential Pricing Programs. *IEEE PES Transmission. And Distribution Conference and Exposition*, pp. 1-5.

[12] Palensky, P. and Dietrich, D. 2011. Demand Side Management: Demand Response. Intelligent Energy Systems, and Smart Loads," *IEEE Trans. Industrial Informatics*, vol. 7, no. 3, pp. 381-388.

[13] Albadi, M. H., and EI-Saadany, E. F. 2008. A Summary of Demand Response in Electricity

Markets. Electric Power System Research, vol. 78, pp.1989–1996.

[14] Caves, D., Eakin, K. and Faruqui, A. 2000. Mitigating Price Spikes in Wholesale Markets through Market-Based Pricing in Retail Markets. The Elect. J., vol. 13, no. 3, pp. 13–23, Apr. 2000.

[15] Ackerman et al., 2001. Distributed generation: a definition. Electric Power Systems Research 57(195-204).

[16] Pepermans, G. 2005. Distributed generation: a definition, benefits, and issues. Energy Policy 33 (787-798).

[17] Twidell, J. 2003. Increasing Renewable Grid Generation using Sympathetic Loads and Tariffs. EU project Xpansion (draft in development at Nov. 6, 2003).

[18] Rosslin, J. R., and Tai-hoon, K. 2010. Applications, systems, and methods in smart home technology: a review. *International Journal of Advanced Science and Technology,* Vol. 15.

[19] Abaravicius, J., Sernhed, K. and Pyrko, J. 2006. Analyzing Load Demand in Residential Houses. ISRN LUTMDN/TMHP-04/7024-SE, Department of Heat and Power Engineering, Lund, University.

[20] Abaravicius, J. 2007. Demand Side Activities for Electric Load Reduction. ISRN LUTMDN/TMHP-04/7024-SE, Department of Heat and Power Engineering, Lund, University.

[21] Barbose, G. and Goldman, C. 2004. A Survey of Utility Experience with Real Time Pricing. Lawrence Berkeley National Laboratory, LBNL-54238.

[22] Erol-Kantarci, M. and Mouftah, H. 2011. Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid. IEEE Transactions on Smart Grid, vol. 2, no. 2, pp. 314-325.

[23] IPART, 2002, Mechanism of promoting societal demand management. Independent Pricing and Regulatory Tribunal, New South Wales, ISBN 1 877049 11 5.

[24] Swedish Energy Agency. (2006). Energy in Sweden. ET2006-45.

[25] Tsui, K. and Chan, S. (2012). Demand Response Optimization for Smart Home Scheduling Under Real-Time Pricing. *IEEE Transactions on Smart Grid,* vol.3, no.4, pp. 1812-1821.

[26] Watson, D. 2005. New Developments in Demand Response. *Lecture at Pacific Energy Centre, Pacific Gas & Electric Company, San Fransisco,* May 23, 2005.

[27] Wilma, M., Suschek-Berger, J. and Tritthart, W. (2008). Consumer acceptance of smart appliances–smart domestic appliances in sustainable energy systems (Smart-A). obtained at smart-a.org/WP5_5_Consumer_acceptance_18_12_08.pdf, 2008.

[28] Association of Home Appliance Manufacturers, (2009). Smart grid white paper: the home appliance industry’s principles & requirements for achieving a widely accepted smart grid. *Association of Home Appliance Manufacturers, Washington,* DC, 2009.

[29] Wilma, M., Suschek-Berger, J. and Tritthart, W. 2008. Consumer acceptance of smart appliances–smart domestic appliances in sustainable energy systems (Smart-A). obtained at smart-a.org/WP5_5_Consumer_acceptance_18_12_08.pdf, 2008.

[30] Paracha, Z. and Doulai, P. (1998). Load Management Techniques and Methods in Electric Power System. IEEE Catalogue No: 98EX137, 1998.

[31] Abaravicius, J. (2004). Load Management in Residential Buildings Considering Techno-Economic and Environmental Aspects. Licentiate thesis. ISRN LUTMDN/TMHP-04/7024-SE, Department of Heat and Power Engineering, Lund, University, 2004.

[32] Gellings, C.W. and Chamberlain, J.H. 1993. Demand-side management: Concepts & Methods. The Fairmont Press, Inc, 1993.

[33] IEA, 2003, The power to choose. Demand Response in Liberalized Electricity Markets. *International Energy Agency,* ISBN 92-64-10503-4 2003.

[34] Piette, M. A. 2005. “PIR Demand Response Research Centre Overview. Partner Planning Committee Meeting, Presentation LBNL, Berkeley, 2005.

[35] Agnetis, A., Pascale, G., Detti, P. and Vicino, A. 2013. Load Scheduling for Household Energy Consumption Optimization. *IEEE Transactions on Smart Grid,* vol. 4, no.4, pp. 2364-2373, 2013.

[36] Bellarmine, G. (2000). Load Management Techniques. Electronic Engineering Technology, Florida A & M University.

[37] Chen, C., Wang, J., Heo, Y. and Kishore, S. 2013. MPC-Based Appliance Scheduling for Residential Building Energy Management Controller. *IEEE Transactions on Smart Grid*, vol. 4, no. 3, pp. 1401-1410, 2013.

[38] Ericson, T. 2007. Short-term electricity demand response. Doctorial thesis, Norwegian University of Science and Technology, ISBN 978-82-471-1156-7.

[39] Kiliccote, S. and Piette, M.A. 2005. Advanced Control Technologies and Strategies Linking Demand Response and Energy Efficiency. ICEBO 2005 Conference Paper, LBNL58179.

[40] PLMA, (2002). The principal of Regulatory Guidance. The Peak Load Management Alliance.

[41] Swalehe, H., Chombo, P. V., Minja, K. M., Mmary, E. R., Kimenyuka, N. M., Promvichai, N., Supanarapan, T., Leeton, U. And Marungsri, B.

2017. System Reconfiguration for Technical Power Loss Reduction in the Distribution Network by using Genetic Algorithm. *Conference: IEEJ P&ES - IEEE PES Thailand Joint Symposium 2017*, Thailand.

[42] Swalehe, H., and Marungsri, B. 2018. Intelligent Algorithm for Optimal Load Management in Smart Home Appliance Scheduling in Distribution System. *Conference: iEECON conference 2018*, Krabi, Thailand.

[43] Mirjalili, S. and Lewis, A. 2016. The Whale Optimization Algorithm. Advances in Engineering Software, pp 51-67, Vol 95.

[44] Dina Kara Prasad Reddy, P., Veera Reddy, V. C. and Gowri Manohar, T. 2017. Whale optimization algorithm for optimal sizing of renewable resources for loss reduction in distribution systems. Reddy et al. Renewables 4:3, 2017.

[45] Hu, H., Bai, Y. and Xu, T. 2016. A whale optimization algorithm with inertia weight. WSEAS TRANSACTIONS on COMPUTERS, pp 319-326, Vol 15, 2016.

[46] Rafkaoui, M. A., 2016. Optimal Scheduling of Smart Home Energy Consumption in Conjuction with Solar Energy Resources. pp 40-41, 2016.