Minimizing the Cost of Solar PV-Connected Smart Home Electricity by Strategical Control

Sushil Kumar Bhoi, Deptt. of Electrical Engg., Govt. College of Engineering, kalahandi, Bhawanipatna, India
Jayanta Kumar Panigrahi, Deptt. of Electrical Engg., Govt. College of Engineering, kalahandi, Bhawanipatna, India

Abstract

The technology known as "smart home" has been around for more than a decade, and its primary purpose is to bring the idea of networking devices and equipment within the home. A higher quality of life may be achieved via the integration of technology and services through home networking, as stated by the Smart Homes Association, which is the most accurate description of smart home technology. A great number of the tools that are used in computer systems are likewise capable of being included into smart home programs. An effective improvement in energy consumption is required due to the environmental problem and the exponential rise in energy demand. The grasshopper optimization algorithm (GOA), which minimizes the cost function in a smart home setting and lowers the microgrid's peak demand, is described in the apex report that follows. The optimal time to operate household appliances in accordance with time of use (TOU) power tariff is determined using the suggested optimization approach. Every household appliance has a distinct peak energy consumption. The findings are further compared using the suggested approach with and without the usage of photovoltaic (PV) modules. Ultimately, the outcomes demonstrate how effective the grasshopper optimization algorithm (GOA) is at reducing daily power costs and achieving the best scheduling for household appliances.

Keywords: Smart home, Energy consumption, Scheduling, Photovoltaic (PV) Grasshopper optimization algorithm (GOA)

1 Introduction

A smart house is one that makes intelligent use of energy management techniques and communication technologies to operate its equipment more economically. Thus, researchers are currently paying greater attention to the management of smart household equipment. All household appliances should function as "smart" or more automated in order to accomplish this aim. [1,2]. To handle problems like the exponential rise in energy consumption and the grave worry about the effects on the environment, sophisticated optimization models are needed. By scheduling household appliances appropriately, it is possible to manage energy efficiency at the microgrid level and optimize energy resources. Appliance scheduling plans can be further improved by including a solar photovoltaic (PV).

Numerous strategies based on time-of-use pricing have been put forth to lower energy bills [3], [4]. TOU prices fluctuate throughout the day based on supply and demand [5]. Four household appliance schedules are created in [6], and the outcomes of two optimization strategies are contrasted. The outcome allows for the verification of the suggested single objective optimization method's supercity. In order to represent appliances for a single home, the mixed integer linear problem is expressed in the convex programming framework in [7]. The writers examine cost-cutting strategies while taking consumer unhappiness into account. An hourly energy schedule for pool pumps, heaters, electric vehicles, and water heaters is provided in [8]. The best schedule for the appliances under consideration is found using particle swarm optimization as an optimization method. Nayak etal. performed a technoeconomic analysis for a grid-connected PV-BESS system with the objective of obtaining minimum annual operating costs for three different cases, i.e. a system without BESS, with BESS and without peak load shaving, and with both BESS and peak load shaving. The integration of PV-BESS units has the advantage of demand charge management, renewable energy time shift, and capacity farming [9].

(a) Using the cutting-edge grasshopper optimization algorithm (GOA) optimization technique to determine the best appliance scheduling schedule in order to reduce household power costs [10].

(b) Showcase the appliance schedule for your home on two designated days each year: May 15th for summer and December 15th for winter.

(c) Illustrates the financial advantage from using PV excess energy to get the ideal operating window for household equipment.

In Section 2 the system modeling is described. In Section 3 problem formulation is defined, whereas Section 4 describes GOA. Section 5 shows the results and analysis for the proposed problem. Finally, the Section 6 gives the conclusion.

2. System Model

2.1 Energy Consumption Modes of Home Appliances

In smart home environment, use of energy should be done wisely to reduce energy consumption cost. So, we have to use smart appliances i.e. power consumption time of that appliance can be scheduled to a preferred working period to get low consumption cost. To get more benefit, an optimal scheduling is required, so that usages of appliances can be done at low electricity price hours.

The power consumption of the i^{th} appliance in a time slot $t \in T = \{1, \ldots ,24\}$ can be defined as :

$$P_i(t) = (P_i(1), P_i(2), \ldots\ldots, P_i(24)) \in R^{24}, \; for\; i \in H \;\&\; t \in T \quad (1)$$

where, H is the home appliances set defined as $H= \{1,2,3, \ldots ,m\}$,m is the number of home appliances.

Here, five home appliances are considered . Appliances and their power Consumption patterns are shown in Table 1. As per the consumption of energy the electricity price is also varying during a day. Here hourly electricity price for two days which are chosen as 15th May for summer season and 15th December for winter season are considered as shown in Fig.1.

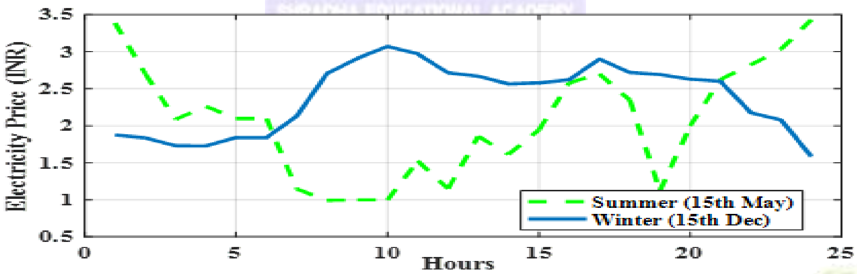


Fig. 1. Hourly electricity price

Table 1. Appliances and Power Consumption Patterns.

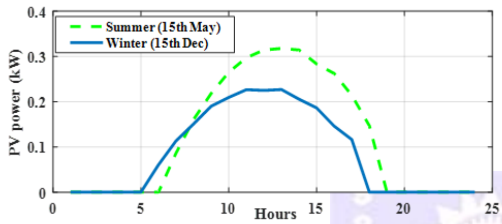
Appliances	Daily Power	Energy consumption Patterns
Induction Cooker	1100 W	Preferred hours: 7am-9am: 300Wh,10am: 200Wh
Washing Machine	500 W	Preferred hours: 12pm: 500Wh
Iron	400 W	Preferred hours: 9am: 500Wh, 1pm: 300Wh
Dishwasher	400 W	Preferred hour: 12pm-2pm: 400W
Heater -2	800 W	Preferred hour: 9am: 500Wh, 2pm: 300Wh

2.2 Modelling of PV

MPPT and an inverter is connected to the output terminals of the PV arrays at the time of PV output power calculation. Global horizontal irradiance (GHI) ($E_{ir}(t)$) and the real time temperature (*Tem*) [11] are used for calculation of PV output.
where, *d* (= 89%) is the power de-rating coefficient by shading, cable and switching losses

$$P_{PV}(t) = d \times \eta_{PV} \times \eta_{inv} \times P_{PV}^{rated} \times \frac{E_{ir}(t)}{E_{ir}^{std}} \times [1 + \beta(Tem(t) - Tem_{std})] \quad (2)$$

and dust accumulation on the array, η_{PV} (= 15%) is the PV efficiency, η_{inv} (= 97%) is the inverter efficiency, P_{PV}^{rated} (= 5 kW) is the rated PV power output, E_{ir}^{std} & T_{std} are the GHI and the temperature at standard test conditions respectively and β is the temperature coefficient of the PV cell. The PV module power output & real time temperature for two days as 15th May for summer season and 15th December for winter season are shown in Fig. 2 & Fig.3 respectively.



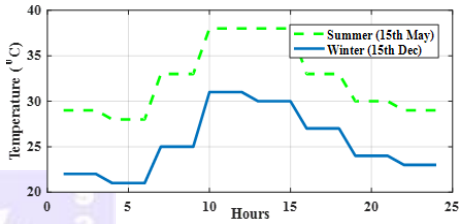


Fig. 2. PV Module Power Output

Fig. 3. Real time temperature

2.3 Smart home Advantages

It should come as no surprise that smart homes have the potential to simplify and broaden the scope of existence. Networking at home may also create a sense of calm and security. When you are away from home, whether you are at work or on vacation, the smart home will notify you of what is happening. Additionally, security systems may be designed to offer a significant amount of assistance in the event of an emergency. As an illustration, a person would not only be awoken by the warning of a fire alarm, but the smart house would also open doors, call the fire service, and illuminate the road to safety. Savings in energy efficiency are another benefit that comes with smart houses. It is possible for certain devices to go into a state of "sleep" and then wake up when they are given orders. This is because certain systems, such as Z-Wave and ZigBee, decrease the functioning of certain devices. When a person leaves a room, the lights are switched off automatically, and the temperature of the space may be adjusted according to who is there at any given time. This results in a reduction in the amount of money spent on electricity bills. One astute homeowner bragged that her monthly heating expenditure was around one-third lower than that of a typical home of the same size. Certain technologies are able to monitor the amount of energy that each appliance consumes and offer commands to reduce that amount.

2.4 Smart Technology and Power Consumption

All of the home appliances and electronic equipment are considered to be receivers, while the mechanisms by which the system is controlled, such as keypads and remote controllers, are considered transmitted. Should you choose to switch off a lamp that is located in a different room, the transmitter will send a message in the form of a numerical code that contains the following information: An alarm is sent to the system to inform it that it is giving a command. Additionally, an identifying unit number is assigned to the device that is supposed to receive the instruction. Finally, a code is provided that carries the actual command, such as "turn off." [12]. As power consumption by sensors and the equipment' s used for automation is very less that is not consider here for less power consuming devices. As well as the scheduling of the equipment' s used for automation can not possible so only the equipment' s which may be possible for scheduling is consider here.

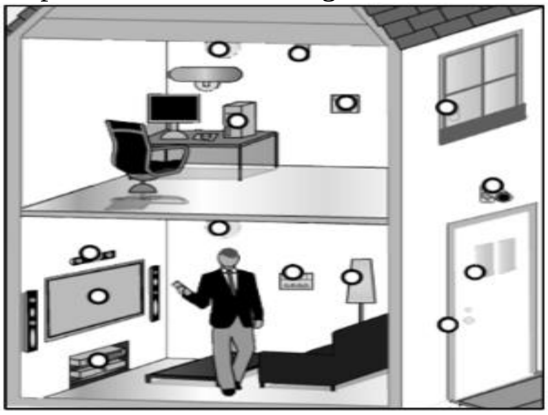


Figure 2. The dots represent devices that could be connected to your smart home network
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3. Problem Formulation

The problem of finding out the optimal scheduling for home appliances has the main objective of for minimizing the total electricity consumption cost in order to benefit the consumer within the framework of system operational constraints.

3.1 Objective Function

3.1.1 Minimization of electricity consumption cost

The objective function is defined as:

$$f_{obj} = \min\left(\sum_{t=1}^{24}\sum_{i=1}^{5} ec(t)(P_i(t) - P_{PV}(t))\right) \quad (3)$$

where, $ec(t)$ is the 24-hours electricity price.

3.2 System Operational Constraints

The constraints imposed to solve proposed problem are :

$$\sum_{i \in H} ec(t) \times P_i(t) \le L_i(t) \; \forall t \in T \quad (4)$$

$$P_i^{\min} \le P_i(t) \le P_i^{\max} \quad (5)$$

$$\pm P_{grid}(t) = P_i(t) - P_{PV}(t) \quad (6)$$

$$P_{PV}^{\min} \le P_{PV}(t) \le P_{PV}^{\max} \quad (7)$$

where, $L_i(t)$ highest electric consumption load at time t, $P_i^{\min}$ & $P_i^{\max}$ is the lower and upper bounds of appliance's power respectively, +ve and -ve sign are used for delivering & consuming power with the grid respectively, $\pm P_{grid}(t)$ is delivering & consuming power with the grid .

4 Grass Hopper Optimization Algorithm (GOA)

The swarming behavior of grasshopper is simulated by the help of Grasshopper optimization algorithm. The position of grasshopper provides the solution of the optimization problem. X_n Indicates the of grass hopper at n^{th} location.

$$X_n = S_n + G_n + A_n$$

(8) where, S_n: social interaction, G_n : *gravity* forces on n^{th} grasshopper, and A_n : wind advection. The social interaction component of grasshopper can be visualized as:

$$S_n = \sum_{j=1, j\neq n}^{N} S(d_{np})\hat{d}_{np} \tag{9}$$

where, d_{np}: distance of n^{th} and p^{th} grasshopper. It can be calculated as $d_{np}=|x_p - x_n|$, *s:* strength of social forces, and $\hat{d}_{np} = \frac{x_p - x_n}{d_{np}}$ is the unit normal vector from n^{th} grass-hopper to the p^{th} grasshopper. Here the x_n and x_p are constants.

The function S is the social force, which can be formulated as

$$S(r) = fe^{\frac{-r}{l}} - e^{-r} \tag{10}$$

where, *f* shows the intensity of attraction and *l* is the attractive length scale. For large distances the function s, is unable to produce strong forces between the grasshoppers.

So to solve this problem the distance need to be mapped or normalized to

Now consider the 'G' in the equation (8)

$$G_n = -g\hat{e}_g \tag{11}$$

where, g is a constant for gravity and $\hat{e}_g$ is the unit vector in the direction to the center of earth. Further the A component in (8) can be realized as:

$$A_n = -u\hat{e}_w \tag{12}$$

where, *u* indicates the drift and $\hat{e}_w$ is a unit vector in the direction of wind.

Finally, we can write the equation (24) with all components as

$$x_i = \sum_{j=1, j\neq 1}^{N} s(|x_p - x_n|)\frac{x_p - x_n}{d_{np}} - g\hat{e}_g + u\hat{e}_w \tag{13}$$

where, N denotes the number of grasshoppers.

A stochastic algorithm needs to be performed for exploration and exploitation effectively to find an accurate approximation of the global optimum. Special parameters are used further to show exploration and exploitation of optimization.

$$x_i^d = c\left(\sum_{j=1, j\neq 1}^{N} c\frac{ub_d - lb_d}{2} s(|x_p - x_n|)\frac{x_p - x_n}{d_{np}}\right) + \hat{T}_d \tag{14}$$

where, ub_d is the maximum limit in the d^{th} dimension, lb_d indicates the minimum limit in the d^{th} direction. $S(r) = fe^{\frac{-r}{l}} - e^{-r}$, $\hat{T}_d$ shows d^{th} dimension in the target, and 'c' is a decaying coefficient which minimize the Comfort area, repulsion area, and attraction area. Here the gravity is not considered and for wind direction it is assumed to be towards the target i.e. $\hat{T}_d$ .The decrease in the attraction or repulsion among the grasshoppers is formulated by the inner 'c'. It is proportional to the number of cycles. The decrease in the search area is realized by the outer 'c'. We can update the ' c' by the help of the equation:

$$c = c_{mx} - l\frac{c_{mx} - c_{mn}}{L} \tag{15}$$

where, c_{mx} denotes the maximum value, c_{mn} denotes the minimum value, *l* denotes the current iteration, and *L* indicates the number of iterations.

5 Result & Analysis

Electricity consumption cost for each home appliances is given in Table 2. The analysis is done for two days of the year which are 15th May & 15th Dec respectively. Without optimization technique total cost is 2.98 INR whereas when GOA optimization is applied it reduces to 2.47 INR without PV integration. With integration PV, electricity consumption is

INTERNATIONAL ADVANCE JOURNAL OF ENGINEERING, SCIENCE AND MANAGEMENT (IAJESM)
July-December 2023, Submitted in October 2023, iajesm2014@gmail.com, ISSN -2393-8048
Multidisciplinary Indexed/Peer Reviewed Journal. SJIF Impact Factor 2023 =6.753

reduced to 2.20 INR & 2.33 INR for 15th May & 15th December respectively, which is more benefited to consumers.

Fig. 5 & Fig. 6 shows optimal scheduling of five home appliances. There is an effective reduction in electricity consumption cost, if all home appliances will operate as per this schedule. So proposed GOA optimization scheduling can tackle energy demand and can also reduce total electricity bill in a smart home environment effectively.

Fig. 7 & Fig. 8 shows optimal scheduling of five home appliances with integration of PV. The generated PV power output is used to supply the five home appliances first and rest portion of PV power output is to be fed back to the utility grid as surplus power which are shown a s negative power in the figures.

Table 2. Cost Comparison.

Home Appliances	Electricity onsumption cost (INR) (without optimization)	Electricity consumption cost (INR) (with optimization)	Electricity consumption cost INR) (with optimization & integration of PV)	
			15th May	15th Dec
Induction Cooker (Heater 1)	0.99	0.96	0.89	0.91
Washing Machine	0.55	0.46	0.44	0.45
Iron	0.32	0.27	0.19	0.20
Dishwasher	0.48	0.15	0.15	0.19
Heater 2	0.64	0.63	0.53	0.58
Total	2.98	2.47	2.20	2.33

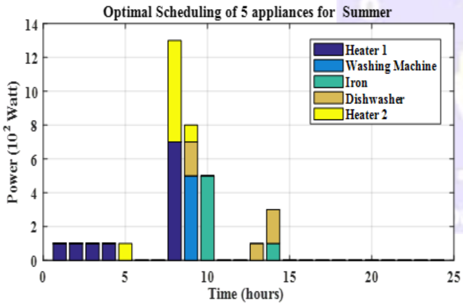

Fig. 5. Scheduling of 5 Appliances for 15th May without PV integration

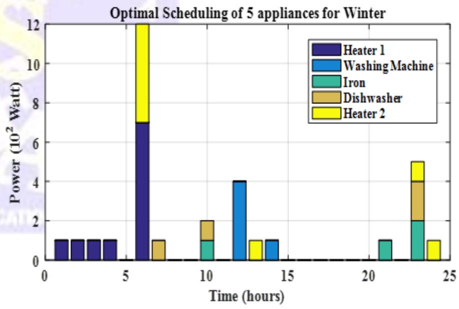

Fig. 6. Scheduling of 5 Appliances for 15th Dec without PV integration

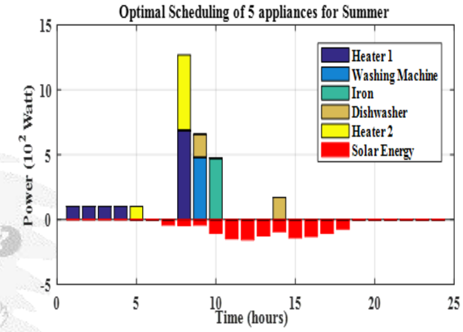

Fig. 7. Scheduling of 5 Appliances for 15th May with PV integration

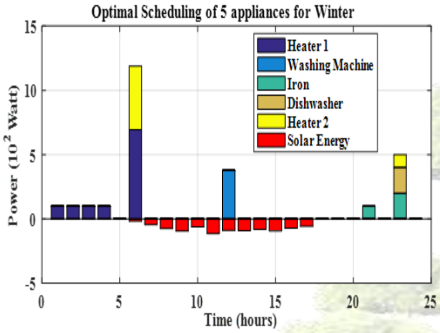

Fig. 8. Scheduling of 5 Appliances for 15th Dec with PV integration

6 Conclusion

Within the scope of this research, an innovative and effective GOA optimization approach is put into practice. When it comes to achieving optimal scheduling for smart home appliances, the solution that has been offered is more successful. In order to provide customers with a greater opportunity to make a profit, the proposed schedule is included in the integration of PV. The study is carried out on two days of the year, namely the 15th of May and the 15th of December, with their corresponding differences in the price of energy and the power production of photovoltaic systems.

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