Load Scheduling Algorithm Design for Smart Home Energy Management System

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***Abstract*- In a world of diminishing energy stores and heightening economic crises, it is imperative to develop systems that diminish our dependence on non-renewable resources. There is a growing trend of Smart Home Energy Management Systems (SHE) which use smart switches to actively monitor the energy consumption by each load, the power available and other factors to switch between renewable resources and the main power grid. An extensive literature survey was conducted and results of various approaches were consolidated and analyzed. The approach detailed is a combination of the merits of all the most popular approaches. The methodology proposed hopes to carry out demand response management on both the grid power and solar power in unison. The problem was split in two: scheduling assuming only solar power is available and scheduling assuming only grid power is available. The two halves are then merged together to have the most efficient utilization of the resources available. Further, after analysing the simulation results, the validity of such a solution is presented while adhering to various real world variables.**

Keywords—Grid Power, Load Prioritization, Load Scheduling. Renewable Energy, Solar Energy, Time of Day Based Pricing

I. INTRODUCTION

Power supplied by the main grid, although reliable, is expensive and is powered by non-renewable fossil fuels. The prices are only going to escalate, the pollution more intolerable and supply even more scarce in the next few years. The best solution is to ease off our dependency on fossil fuels and start incorporating renewables such as solar and wind power into our energy grid.

Since the technology to power our homes solely on renewables is still in its infancy, we propose a hybrid of both technologies to optimize energy utilization and costs of energy. The proposed solution involves a solar panel, an energy storage device to store the power generated by the panel and an algorithm to switch between solar power and the grid. The system would maximize the usage of solar power and minimize usage of the grid, while not compromising user comfort.

Several studies have been carried out in this area, notably in the optimal usage of solar power and also the most economical usage of loads, given the variable slab rates throughout the day. Thus, the problem has been analyzed on two fronts:

1. Load Scheduling when the house is running solely on the power grid for the most economical usage.
2. Load Scheduling when the house is running solely on solar power for optimal usage of the limited power available.

The approach presented below hopes to bridge the gap in the current research by providing a real time solution using sensors and power consumption information obtained from the loads. By dividing the project into solar and grid and then merging the two later, it is possible to provide optimized solutions to both halves, which further results in a better solution.

II. LITERATURE SURVEY OVERVIEW

The following are the resources that contributed significantly to our inspiration and guided us to the results that we achieved. In [1], the author lays down the various parameters that such a system typically considers for its computation. It also offers a method to model each load according to the type of load and its usage hours.

Cost optimization problems for smart energy utilization in residential grids have been addressed in [2], which combines several partial models into a single monolithic cost optimization model, thus enabling it to analyze scenarios which can be implemented practically and allows energy trading in micro grid which introduces a cost fairness problem. Reference [3] proposes a load scheduling algorithm to optimize cost and energy consumption for the domestic scenario. The approach targets smart grids which utilize renewable energy sources which include two-way communication and energy dispatch and forecasts pricing with inclining block rates from energy retailers, data about energy generation from renewable sources, and future jobs to come to a conclusion about buying and selling energy whilst fulfilling its basic duties.

The authors in [4] offer a scheme to manage the energy consumed by loads in a residential establishment using Demand Response. This paper aims to maximize energy saving and minimize costs by using an offline load scheduling algorithm which shifts loads to off-peak hours and hours with lower electricity cost to reduce peak demand.

In [5], an intelligent cloud home energy management system (iCHEMS), considering issues such as intermittent energy generation has been proposed. By assigning priority dynamically to appliances according to its type and its current status, the use of household appliances can be scheduled by accounting for the availability of renewable energy, thus reducing the average total power consumption by up to 7.3%

A highly detailed heuristic Mixed Integer Linear Programming (MILP) model for prediction of load consumption has been detailed in [6]. The model focuses on user comfort and the proposed Energy Box (eBox) takes in parameters like forecasted profiles of energy consumption, temperature and, possibly, power provided by the renewable source. Predictions about the renewable power output are made through weather forecasting like the previous approach.

An interesting approach using the predicted maximum demand has been explored in [7]. The paper focuses exclusively on the demand response of loads in a micro-grid and a scheduling algorithm to minimize costs. The concept of demand response was also explored in [8]. The prioritization algorithm considers the various appliances to be switched on at any time instant and its priorities and schedules the loads accordingly, thus reducing the tariff. An alternative approach to real time price based dynamic response management has been explored in [9], with a stochastic as well as a robust optimization method. Just like in [8], both approaches are formulated as mixed-integer linear programming (MILP) problems.

A decentralized approach for resource allocation was proposed in [10]. The approach was to utilize the thermal energy generated by "hybrid" appliances to allocate the available resources optimally using a multi agent system which can perform optimal supply and demand matching (SDM) of available energy sources and appliances, as well as to suppress the net remaining exchange over time.

Finally, in [11], we get a sense of the future of Smart Grid in terms of the possible methodology to achieve said goals. By applying demand response initiatives, it is possible to reduce the annual peak demand by 8.5% or more.

From the extensive literature survey, the key takeaways include the various stochastic and robust methods to optimize grid energy while pandering to slab rates provided by the government, various approaches to classify and prioritize appliances and a few methods to switch between renewables and the grid power. However, most of the current research does not provide a reasonable method of integration.

III. LOAD CLASSIFICATION FOR HOMES POWERED SOLELY BY GRID SUPPLY

A. Introduction

The shift from centralized production and load management to decentralized production calls for intelligent systems to be employed for efficient management of power being consumed at the consumer end.

B. Load Scheduling and Prioritization.

The task of Load Prioritization and Scheduling for household appliances in a residential setup which gets its power supply primarily from the grid can be divided into the following steps.

1. Classifications of Appliances
2. Load Prioritization based on above classification and external parameters such as
    a. Weather conditions
    b. Seasons
    c. User activity Pattern
3. Load Scheduling algorithm based on the priority determined above.

TABLE I
CLASSIFICATION OF APPLIANCES

Classification Of Appliances		
Non Schedulable	***Schedulable, Periodic TOD Dependent usage***	***Schedulable, Non Periodic Independent of TOD***
Lights, fans, TV, Desktop Computers, Kitchen Appliances	Embedded Battery Appliances - Laptops Thermally Controlled Air Conditioners	Washing Machine, Dishwasher, Water Pump, Pool Pump

TABLE II
TYPICAL USAGE HOURS OF APPLIANCES

Sl no	**Classification Of Appliances**		
	Example of Device	***Type***	***Typical usage Hours***
1.	Lights, fans	Non Schedulable	6pm-6am
2.	Washing Machine	Schedulable, Non Periodic	2pm-5pm
3.	Desktop Computer	Non Schedulable	9am-5pm
4.	Water Heater	Schedulable, Periodic	7am-9am 7pm-9pm

C. Classification of Appliances

For grid usage the classification of loads is as shown in Table I and typical usage hours of the appliances is given in Table II.

1) Non Controllable/ Non Schedulable Appliances

1. Real Time Power Consumption
2. Directly related to consumer behavior
3. Needs to operate as and when the consumer demands and should remain energized throughout the consumption period.
4. Cannot be scheduled.
5. Assigned Highest Priority

2) Controllable/ Schedulable Appliances

1. Non real time consumption of power.
2. Tasks are time bound, but can be completed within set time limit at any time of the day.
3. Appliances can have embedded battery
4. Can be scheduled.

Controllable/Schedulable Appliances are further classified as:

1. ***Periodic Usage*** – Consumption of energy by these devices is periodic and is prone to fluctuation eg. Air conditioners, refrigerators, battery embedded devices.
2. ***Non Periodic Usage*** – Energy consumption of these appliances are non-periodic with no particular time to be operational. Also, they must complete their operation within a stipulated time frame.

IV. LOAD CLASSIFICATION FOR HOMES POWERED SOLELY BY SOLAR POWER

For usage on solar power, loads are classified as follows:
Loads are classified as follows:
Schedulability is whether or not the device can be used at any point in the day.
Interruptibility is whether the operation can be stopped during its operation

1. Schedulable:

Non-Interruptible

Interruptible

2. Non -Schedulable:

Non-Interruptible

Interruptible

Usage of loads running solely on solar power are subject to multiple constraints. These include:

1. The intensity and availability of solar power
2. Distribution of intensity of solar radiation over the day
3. The capacity of the energy storage device used in conjunction with the solar cells
4. The power consumption and usage of all the loads in the system.

Loads are prioritized accordingly and are allocated power supplied from the solar cells (in the absence of which, loads consume power from the energy storage device used with the solar cells). In case of a dearth of renewable energy, the remaining loads are made to run on the grid.

V. Overview of Algorithms

D. Load running solely on Grid Power

1. Prioritization Algorithm

The Prioritization Algorithm runs every 30 mins to determine the priority order of the devices scheduled to be turned on in the next 30 mins. Figure 1 alongside gives an overview of the prioritization algorithm. Figure 2 and Figure 3 give a detailed flowchart of the sub priority prioritization algorithm.

1. All Non Schedulable appliances are assigned the HIGHEST PRIORITY (PRIORITY 1) and are run as and when the user generates an interrupt to use them.
2. Schedulable Appliances with Periodic usage are assigned PRIORITY 2.
3. Within a list of all Priority 2 appliances priority order is determined by the time span between current time and the expected usage time of the device. Shorter this time, the higher the priority of the appliance is. (Simple TOD dependent Devices)
4. For Thermally Controlled TOD – Priority is assigned based on the temperature difference between expected temperature and current temperature. The higher this temperature difference, the HIGHER is the Priority of the device.
5. For Embedded Battery Devices. Priority is assigned based on current percentage of charge in the device. Lower the percentage of charge higher is the Priority of the appliance.
6. PRIORITY 3 is assigned to Schedulable, Non-Periodic usage devices.

2. Scheduling Algorithm

Flowchart of the scheduling algorithm is shown in Figure 4 and comprises the following basic steps:

1. Devices are scheduled to operate based on the pricing of the slabs.
2. If slab price > fixed slab rate – Only PRIORITY 1 and PRIORITY 2 appliances which need to operate in the next 2 time slabs are scheduled to turn on.
3. If slab price = Fixed slab rate – P1 and P2 devices are turned on.
4. If slab price < fixed slab rate – P1, P2 and P3 devices are turned on.

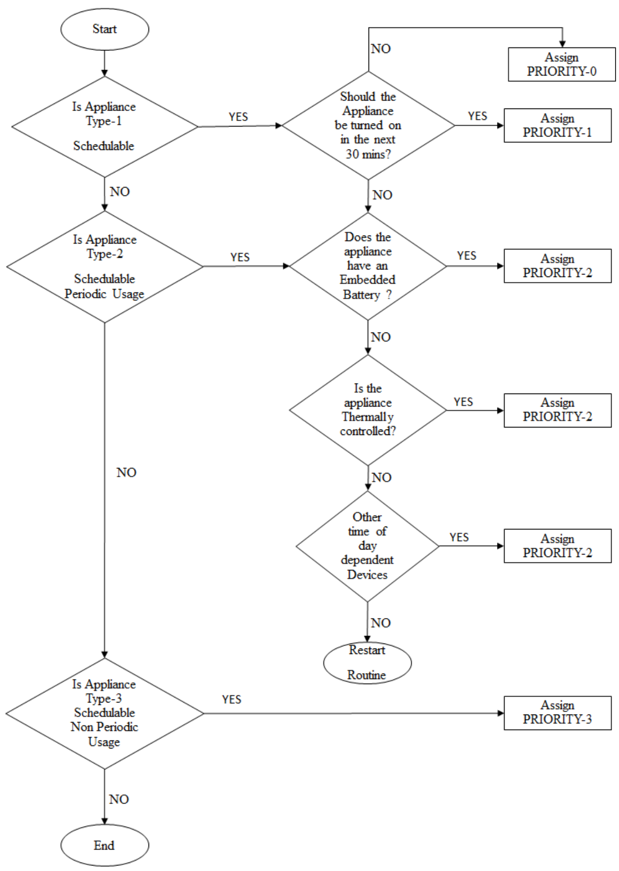

Fig. 1. Basic Prioritization Flow chart

E. Loads running solely on Renewable (Solar) Power

Parameters considered:

For each time step, the following parameters are taken into consideration:

1. Instantaneous power generated by the solar cells, P(W).
2. Available energy in the battery storage, E (J)
3. Threshold battery SoC (Minimum energy in the battery, below which, supply is switched off or switched to the grid. Assume 10% maximum capacity)
4. List of loads being turned on and their corresponding power consumption

Priority allocation:

1. All Non-Schedulable & Non-Interruptible devices are allocated priority 1
2. All Non-Schedulable & Interruptible devices are allocated priority 2
3. All Schedulable & Non-Interruptible devices are allocated priority 3
4. All Schedulable & Interruptible devices are allocated priority 4

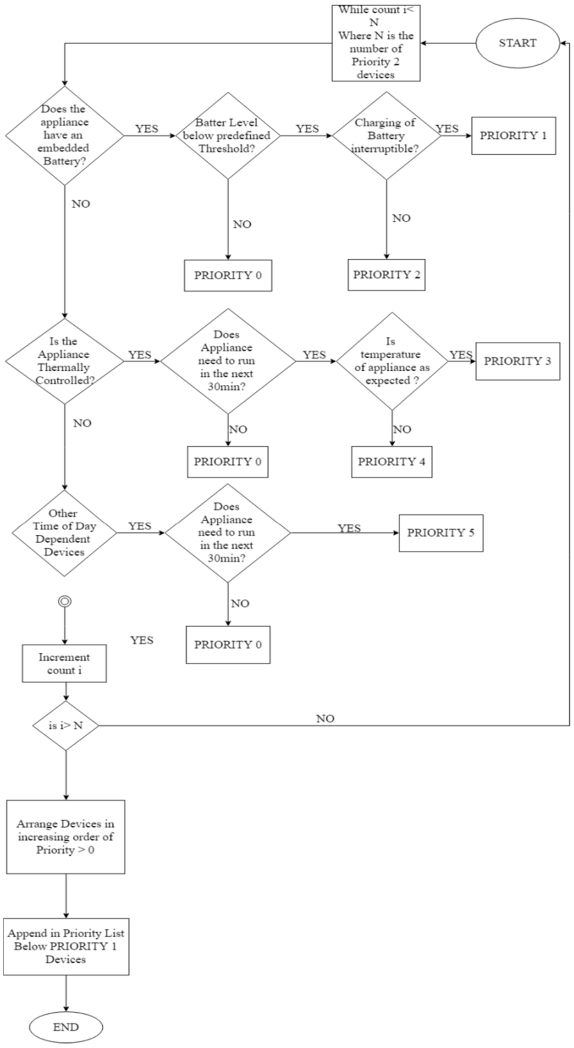

Fig. 2. Priority 2 Sub Priority Assignment Algorithm

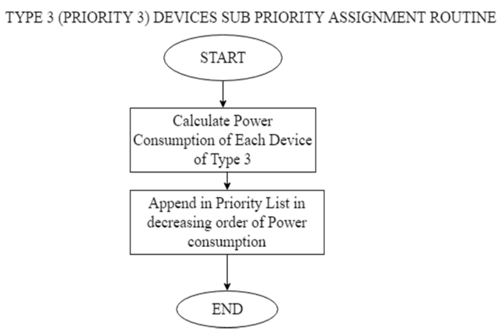

Fig. 3. Priority 3 Sub Priority Assignment Algorithm.

Within each category, the loads are arranged in descending order of power consumption, each load assigned a sub-priority. Devices consuming more power are given higher priority.

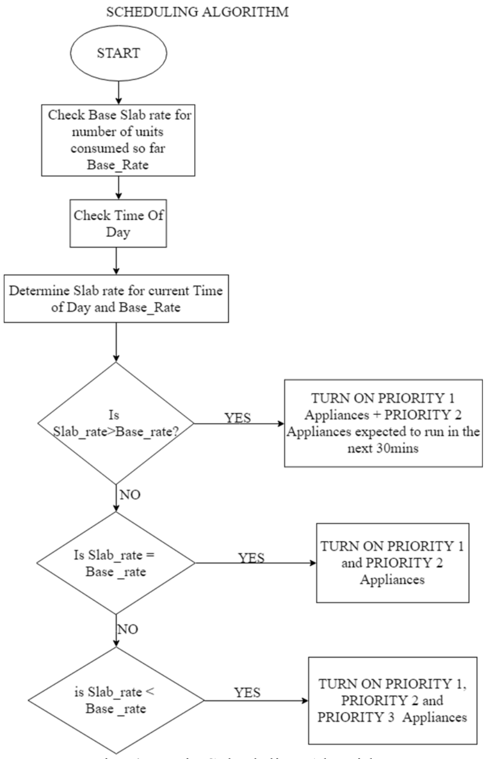

Fig. 4. Basic Scheduling Algorithm

If there are loads that are supposed to be running in a given time step, but solar power available (that generated by the solar panels and that available in the energy storage is insufficient), the remaining loads run on the grid power, using the prioritization algorithm outlined above. The switch is driven automatically by the central computer (Arduino in this case) and is done to ensure maximum comfort to the user and minimum usage of grid power.

The algorithm is not iterative, in the sense that it does not approach an optima after a few days, which would not be feasible. The cost function that we seek to minimise is the total energy consumed by all the loads, which is subject to the number of loads and the operating time set by the user. This could vary with different usage patterns and different loads. The algorithm seeks to minimise the energy consumed in each and every time step in real time, which makes it more flexible, less resource intensive and much more efficient than iterative approaches. With a simple priority based system, we also give the user to tweak the priority order as per his/her convenience.

VI. Simulation and Experimental Results

A simulation of the above algorithm was run on Proteus. The algorithm was compiled in the Arduino IDE and loaded into the Arduino package in Proteus.

Time steps of 30 mins each have been considered for easy analysis of the simulations without loss of generality. For real

world implementation, the time steps would be made to be much shorter in the order of 10 ms.
Table III shows the seven loads considered for the simulation. 48 time steps were chosen for 24 hours. This number can be varied accordingly. Figure 5 gives the detailed flowchart of Load Scheduling Algorithm implemented for integrated solar and grid homes.

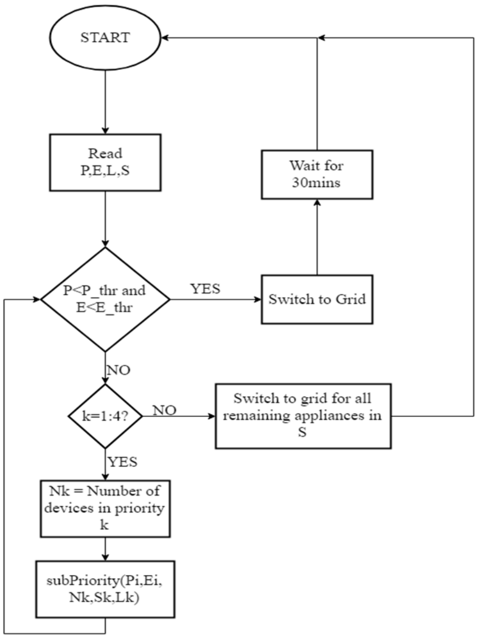

Fig. 5. Load Scheduling Algorithm Flowchart

TABLE III
LOADS IN SIMULATION

Load No.	*Device*	*Type*	*Power Rating*	*Typical Time of usage*
0	CFL Bulb	Schedulable Interruptible	60W	7pm- 5am
1	Hair Dryer	Schedulable Interruptible	1500W	7am-7:30am
2	Washing Machine	Schedulable Non-Interruptible	1000W	2pm-4pm
3	Dish Washer	Schedulable Non-Interruptible	1200W	9pm -11pm
4	Desktop Computer	Non Schedulable Interruptible	100W	9am -5pm
5	Water Heater	Non Schedulable Non Interruptible	3000W	5am- 8am, 6pm-9pm
6	Burglar Alarm	Non Schedulable Non Interruptible	40W	All Day

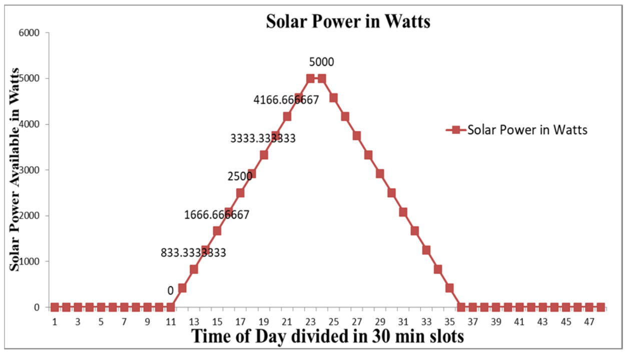

Fig. 6. Approx. model of solar intensity used for the simulation.

TABLE IV
TIME OF DAY BASED PRICING AT 0-30 UNITS SLAB FOR 325PS/UNIT

Time of Day (Hours)	*Additional Tariff (paise)*
6:00-10:00	+100
10:00-18:00	Flat Tariff
18:00-22:00	+100
22:00-6:00	-100

The following are a list of comparisons of energy consumed and monetary cost incurred in both cases, viz. using just the grid power and using the hybrid system proposed.
The reduced dependency on the grid has two immediate advantages:

1. There is a reduction in costs as a significant portion of the energy is being taken up by solar power. With no load scheduling mechanism, the number of units consumed per day is 31.16, whereas, using the implementation, 18.59 units are drawn from the grid, as shown in Figure 8. This leads to a saving of Rs 50/- per day for the consumer. It is estimated that the money saved will recover the cost of installation of the solar energy system within 2-3 years. Refer Figure 9.
2. Secondly, it reduces the dependency on grid supply during peak hours, benefiting the utility companies and avoiding grid overloads.

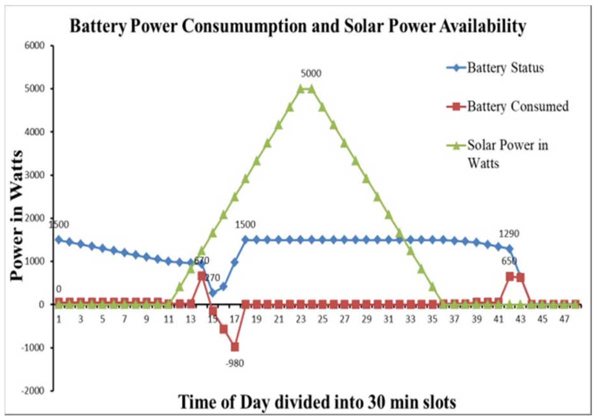

Fig. 7. Power Consumption on Solar Energy

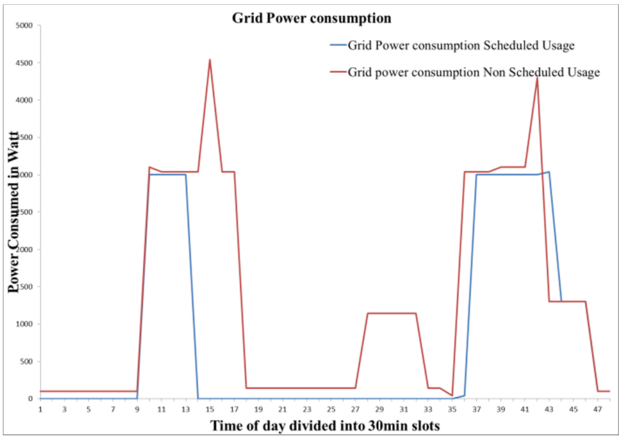

Fig. 8. Power consumption from Grid

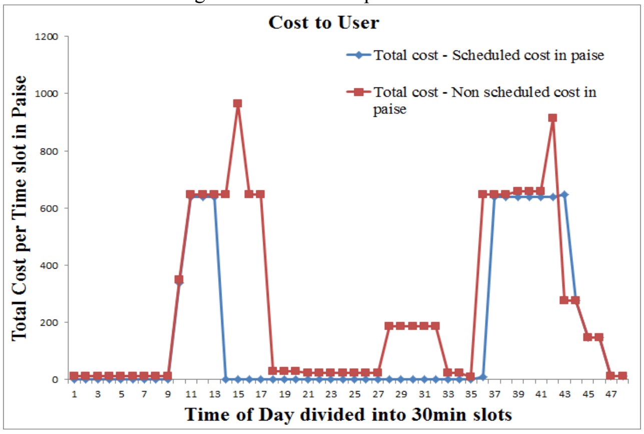

Fig. 9. Cost to Consumer.

VII. CONCLUSIONS

The following is a summary of the possible interpretations of the results of the simulation:

Scenario	***Grid Usage***	***Hybrid System Usage***	***Remarks***
Energy Efficiency	All the loads draw power from the main grid, thus incurring significant energy overheads	Some load is offloaded to solar energy. (Typical efficiency = 14%)	Hybrid system is more efficient due to load distribution. Results are more pronounced with smaller loads.
Monetary Expenditure	Subject to slab rates imposed	Offloading reduces monetary expenditure especially for lesser loads.	Hybrid system is more economical
Installation and maintenance Cost	Negligible	Currently expensive Recuperated in 2-3 years	The high installation and maintenance costs impede the utilization of this technology and is forecasted to reduce with time
Different loads	Can be used for any load	Typically used for loads which consume less power.	The number of loads that use the solar power depends on their power ratings.

Further advancements can be made to accommodate for climatic conditions in different parts of the world and also develop similar systems for commercial and industrial spaces such as schools and hospitals. A load scheduling system can be integrated with existing smart home architecture and to make homes self-sustainable and intelligent.

REFERENCES

[1] Wang, Chengshan, Yue Zhou, Bingqi Jiao, Yamin Wang, Wenjian Liu, and Dan Wang. "Robust optimization for load scheduling of a smart home with photovoltaic system." *Energy Conversion and Management* 102 (2015): 247-257.

[2] Alam, Muhammad Raisul, Marc St-Hilaire, and Thomas Kunz. "A unified residential energy cost optimization model for smart grid-significance and challenge." *arXiv preprint arXiv:1505.00844* (2015).

[3] Wang, Chengshan, Yue Zhou, Bingqi Jiao, Yamin Wang, Wenjian Liu, and Dan Wang. "Robust optimization for load scheduling of a smart home with photovoltaic system." *Energy Conversion and Management* 102 (2015): 247-257.

[4] Radhakrishnan, Asha, and M. P. Selvan. "Load scheduling for smart energy management in residential buildings with renewable sources." In *Power Systems Conference (NPSC), 2014 Eighteenth National*, pp. 1-6. IEEE, 2014.

[5] Byun, Jin Sung, Insung Hong, and Sehyun Park. "Intelligent cloud home energy management system using household appliance priority based scheduling based on prediction of renewable energy capability." *IEEE Transactions on Consumer Electronics* 58, no. 4 (2012).

[6] Agnetis, Alessandro, Gianluca de Pascale, Paolo Detti, and Antonio Vicino. "Load scheduling for household energy consumption optimization." *IEEE Transactions on Smart Grid*4, no. 4 (2013): 2364-2373.

[7] Ali, S. Q., S. D. Maqbool, TP Imthias Ahamed, and N. H. Malik. "Load scheduling with maximum demand and time of use pricing for microgrids." In *Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS), 2013 IEEE*, pp. 234-238. IEEE, 2013.

[8] Radhakrishnan, Asha, and M. P. Selvan. "Load scheduling for smart energy management in residential buildings with renewable sources." In *Power Systems Conference (NPSC), 2014 Eighteenth National*, pp. 1-6. IEEE, 201

[9] Chen, Zhi, Lei Wu, and Yong Fu. "Real-time price-based demand response management for residential appliances via stochastic optimization and robust optimization." *IEEE Transactions on Smart Grid* 3, no. 4 (2012): 1822-1831.

[10] Blaauwbroek, Niels, Phuong H. Nguyen, Mente J. Konsman, Huaizhou Shi, Ren IG Kamphuis, and Wil L. Kling. "Decentralized resource allocation and load scheduling for multicommodity smart energy systems." *IEEE Transactions on Sustainable Energy* 6, no. 4 (2015): 1506-1514.