ASHESI

ASHESI UNIVERSITY COLLEGE

DETERMINING THE BEST LOAD SCHEDULING ALGORITHM FOR A HOME WITH ELECTRICITY SUPPLY FROM GRID AND SOLAR

SENIOR CAPSTONE PROJECT

B.Sc. Electrical and Electronics Engineering

Portia Awuah

2020

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SENIOR CAPSTONE PROJECT

Capstone Project submitted to the Department of Electrical and Electronics Engineering, Ashesi University College in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronics Engineering.

Portia Awuah

2020

DECLARATION

I hereby declare that this capstone project is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that preparation and presentation of this senior capstone project were supervised in accordance with the guidelines on supervision of senior capstone project laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Acknowledgements

To my supervisor and Dr. Maher Azaza, whose encouragement and academic advice helped me undertake this project.

Abstract

Improving energy efficiency is becoming increasingly critical to reduce the energy consumption and to solve the environmental crisis. The following capstone report describes a mixed-integer linear programming optimization algorithm to minimize the peak demand at the micro grid level and to reduce the cost function in a smart home environment. The optimization methods takes into account the time varying electricity price and the varying energy demand peaks to determine the most suitable time to use home appliances. The algorithms are further used to compare the energy cost reduction results with and without the use of renewable resources and more precisely photovoltaic modules. In addition, the sizing of a photovoltaic system is implemented to achieve further efficient energy optimization and appliance scheduling. Finally, a cost benefit analysis is performed on all the scheduling algorithms to determine which is the most cost effective.

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Chapter 1: Introduction

The ever-increasing world population has resulted in a high demand for energy. With issues of global warming and pollution from fossil-based energy supplies, [1] solar energy, amongst other renewable energy sources have been well embraced and integrated into society. Residential PV installations have helped reduce the number of grid-energy dependents over the past years. However, unutilized excess solar energy produced as peak hours raise a cause for alarm for energy wattage [2].

Successful residential solar-grid energy sharing relies greatly on effective use of energy in homes and management of constraints associated with pushing energy unto the grid through master planning and short-term look-ahead scheduling. My primary research interest is investigating the how best homes could maximize their solar consumption from their residential PV Installations; reducing the amount of excess solar energy fed unto the grid and reducing the dependency on too much battery storage. The second part of the project would analyze the electricity tariffs trends for the day, to determine the best time to sell solar energy unto the national grid for maximum profit.

1.1 Background

For a country like Ghana, where the utilities provided by the government are not enough for everyone, it is important that, residential PV installations are embraced to reduce the number of grid energy dependents and also to reduce the cost of electricity for homeowners. However, for homeowners, allowing energy produced from PV installations to be pushed unto the grid is without generating any revenue from it [3] is a loss for the homeowner.

1.1.1 Objectives of the Project Work

The long-term goal of the research is to develop a formalized energy selling structure from PV installation in homes to grid at times the tariffs are high so homes can maximize profit. The objective of the current study is to provide a comprehensive review of literatures and industry practices in relation to energy consumption in homes using effective load scheduling. Particularly, the study has the following sub-objectives.

1. The first part of the research would investigate grid losses, voltage security, and grid infrastructure burden which may result from the integration of solar energy unto the grid using data and modelling in MATLAB. Overload in transformers and overvoltage in buses would be amongst the burden of the grid infrastructure to be considered.
2. Reactive power (power factor, different generation models and constant Q) control tests would be conducted to find the ideal values of voltage, power factor amongst others at which solar energy can be integrated into the grid.

1.1.2 Expected Outcomes of the Project Work

The expected outcome is to be able to create a great load scheduling model for a home to maximize self-solar consumption. Secondly, at the end of this research, it is expected that,

1. Home users would know the best time to sell excess solar energy unto the grid to maximize profits.
2. These outcomes will help grid operators reduce the grid losses and enable controllability, and thereby not only reduce the quantity of excess energy pushed on grid line; but would also reduce the dependency on too many battery storages.
3. If the research supports the various hypotheses, it would form a basis for my future research into the optimum factors to consider when feeding excess energy unto the grid.

1.2 Motivation of Project Topic

This project is inspired from findings from previous studies that, the integration of solar power unto the grid can cause increased power loss and voltage rise [4], hence, this project seeks to maximize the use of solar energy in homes and pushing little unto the grid would reduce the power losses.

1.3 Research Methodology to be Used

The primary research method for this study is literature review and modeling with MATLAB.

a. This study will first model a home and all loads in it in MATLAB. Based on solar irradiation graphs and peak hours of sunlight, a structured load scheduling would be implemented.
b. In the second stage of this study, existing tariff rates at different times of the day would be modeled against the energy production in the from the PV home installation.
c. Secondly, appropriate times during the day, at which high returns for selling energy unto the grid would be recorded.
d. Then, the load in the house would be scheduled to operate at different times of the day. A graph of scheduled load would be plotted with a graph of unscheduled load, to prove the better option.

1.4 Facilities to be used for the research

1. This research would be built from

a. The Home Lab of the Future Energy Center in Mälardalen University and

b. The Research Building of Ashesi University.

2. Data of energy tariff variations throughout the day would be obtained from the Electricity Company of Ghana, for the second part; the energy selling model.

1.5 Scope of Work

This research is focused on investigating that, scheduling a household load would optimize solar power consumption in a standalone residential PV installation.

The project will be divided into three main parts.

1. The first part is modelling the power consumption of unscheduled load in the home.
2. The second part is to schedule the use of electric appliances in the home considering the photovoltaic system.
3. The results from the two parts will be used to compare the impact of scheduling load in a home.
4. The last part will be about the right time of the day to sell excess power from the residential power installation to the grid for maximum profit, considering the tariffs at different time of the day.

Chapter 2 Literature Study

This chapter introduces the concepts of literature that is in line to the subject of optimizing solar consumption in PV residential solar installations, using load scheduling. It describes the concept of solar energy optimization, load scheduling, household loads and related study of electricity tariff variations across different times of the day. It will show the concept of energy maximization and attempt to explain integration of load scheduling, against unscheduled load in a standalone residential PV installation

2.1 Literature Review

A lot of previous capstone projects have concentrated on energy optimization in smart homes and the utilization of sustainable power source power, which has laid the foundation for this research project. The latest one on energy optimization in homes was by "Salim El Kohen" on "Constant Electricity Pricing Based on Utility Maximization for Smart Homes". It planned for actualizing a quadratic calculation to limit the power value considering the on-peak and off-peak periods and price fluctuation. Another part of his undertaking was to amplify the utility function, which depicts the degree of fulfillment and satisfaction of the end client with respect to the services given by the power provider [6]. Another intriguing task acknowledged by "Fatima Ezzahra Barnicha" on "Checking and Control of Appliances Using an Arduino Based Network in the Context of a Micro-framework" concentrated on giving the clients their energy utilization and energy saving measures [7]. The expressed objective was to all the more likely deal with the utilization of renewables in a keen home condition and screen the vitality utilization of the home apparatuses utilizing an Arduino. The analysis showed that the management system improves the energy efficiency, but its high cost makes it difficult to actualize it in a Ghanaian context. At long last, the undertaking acknowledged by "Sofia Ait Bellah" on "An Arduino Based Wireless System" consolidates a similar observing and control components utilizing an Arduino yet incorporates into expansion stacking calculations [8]. It planned for actualizing another home vitality the board framework made out of many savvy plugs and a door to advance the utilization of vitality.

In his article on ‘Optimal scheduling of smart homes energy consumption in Conjunction with solar energy resources’, Rafkaoui explained that in order to optimize energy consumption in a home with solar installation, the power consumption pattern of time shiftable home loads has to be controlled. Note that Rafkaoui defines a time shiftable appliance as one ‘that its power consumption time can be shifted to a preferred working period’. [9].

2.2 Solar Energy Optimization

Self-consumption is one of the most effective ways target the greatest benefit out of a residential photovoltaic (PV) installation. When a residential entity consumes the generated PV electricity instantaneously as it is being produced, energy bills are reduced. And by acting as both the producer and the consumer, the ‘prosumer ‘can move toward greater future independence from the grid and electricity rate variations.

Of course, achieving the largest drop in demand for electricity from the grid requires coordinating household energy use with the periods of greatest availability of PV-generated electricity. But because residential energy, use is atypically greatest in the morning and evening, whereas energy availability peaks at midday, this requires load management, as discussed in a previous blog post on self-consumption.

The difference in solar irradiation, across different times of the day would result in difference in the output of the residential PV module. As a result, wattage-heavy loads can be scheduled to perform at peak hours of sunshine [10]. To do this, the load profiles should be considered as well as the priority of the load. Putting Ghana in context, a household load like the air conditioner is of high priority at peak sunlight hours, while the lamp may not be needed because of natural light in the home.

2.3 Load Scheduling

Load scheduling is one form of load management action that allows companies to save energy by minimizing their demand [11]. In order to have an efficient load schedule operation, the energy manager or business should conduct power logging and record all sessions to measure the usage of energy over a specific time. This enables the consumer to identify large loads that may be operating concurrently. The loads are mostly classified using three parameters, the first criteria is according to voltage; the other one according to load duty to show whether loads are standby, continuous, or intermittent. And lastly according to load criticality abased on whether they are normal loads, essential loads or critical loads. The collected information is then used to calculate the individual and overall operating, design and peak power at continuous, intermittent, and standby load duty.

2.3.1 Purpose of Load Scheduling

The objective of household load scheduling is to improve its energy and cost efficiency subject to given consumers' comfort constraints. Towards this end, renewable source availability prediction and day-ahead electricity market price forecasting are considered and dynamic priority allocation and scheduling for appliances with consumers' comfort constraints is proposed in this section [12]. In addition, to effectively schedule appliances according to real-time weather and electricity market price changes, an algorithm for real-time household load scheduling is also proposed in this section.

2.3.2 Advantages of Load Scheduling

1. Gives a good estimate of electrical load during the normal and the peak loading

2. Allows the design to include provisions for additional load or at least advise building owners of requirements to accommodate any extra load or expansion

3. By understanding the load, and when peak consumption is likely to occur, it is possible to implement an informed power management scheme that ensures that the load is average most of the time and eliminate cases of alternating between very low and very high peak consumption periods.

4. With proper management, it not only brings down the electricity bill charged at the peak times, but also benefits the generating company who now can generate less energy.

5. It enables the design to cater for future loads.

2.4 Strategies for Load Management in a Home

A. Renewable source availability prediction

The main advantages of using renewable energy sources are the inexhaustible resources of the primary energy and the elimination of harmful emissions. However, unlike traditional fossil fuel power plants, energy production from PV, is generally fluctuating and the continuously growing number of renewable sources starts compromising the stability of the electrical grid [13]. Based on the information provided by the hour-by-hour weather forecast, which can be easily obtained from a weather forecast website, prediction of the output of the solar panels can easily be made since it is directly related to the weather. For example, a steady output from a solar energy system can be obtained by studying the forecast of the solar irradiation in the next several hours. Based on the historical statistical data, more practical data of the energy output from renewable sources can be obtained and considered in the household load scheduling.

B. Day-ahead electricity market price forecasting

Electricity has been turned into a traded commodity nowadays, which is sold and bought at market prices. Therefore, electricity market price forecasting is essential for market participants in both daily operation and long-term planning analyses, such as designing bidding strategies and making investment decisions [14]. Especially, in the short term, consumers need electricity price forecasts to optimally schedule their household loads.

In recent years, several techniques have been applied to short-term electricity market price forecasting and forecast accuracy improvement (e.g., [13] and [15]). Also, the economic impact of price forecast inaccuracies on forecast users has been analyzed in [16]. Based on the price forecast, home appliances can be scheduled in a cost-efficient way.

C. Dynamic priority allocation and scheduling

In our proposed scheme, priority is dynamically allocated according to the corresponding status of appliances that can be scheduled, i.e., appliances with periodic nonreal-time energy consumption mode and appliances with nonperiodic nonrealtime energy consumption mode. Appliances with real-time energy consumption mode, since they cannot be scheduled and must run immediately, do not need priority allocation.

D. Real-time household load scheduling

The real-time weather and electricity market prices usually deviate from the corresponding forecasting. To effectively schedule appliances according to the real-time output of renewable sources and the electricity market price changes, an algorithm for real-time household load scheduling is proposed in this subsection [13]. Different types of home appliances and renewable sources are connected to the energy management unit (EMU) via a home-area wireless sensor network. Sensor data and control commands are exchanged among them to realize the appliances' priority and renewable sources' real-time output update and to implement the energy scheduling and management. To obtain weather forecast information and real-time electricity market prices, the EMU also connects to the Internet and the grid operator, respectively. It periodically updates weather forecast information and real-time electricity market prices and receives sensor data from appliances and renewable sources to update the appliances' priority status and real-time output of renewable sources. If the corresponding status changes, the EMU executes the appliances' energy scheduling and management process and controls appliances according to the changes. That is, after the appliances' energy scheduling and management process, the EMU implements the appliance energy control process (i.e., turning on or off the corresponding appliances), if necessary [15]. Otherwise, the EMU returns to the idle state directly and controls the appliances based on the time schedule.

2.4.1 Household Loads

In order to optimize energy consumption in a home with solar installation, the power consumption pattern of time shiftable home loads must be controlled. In view of this, a list of household appliances with their Wattage per hour consumption is drawn below. From which decision about their scheduling would be made. [17]

Table 1 Data was obtained from Household Load data site, Research Gate [15]

Electrical Load	No. of units	Operating hours per day	Wattage per unit used	Wh/day
Lights	6	12	15	180
Ceiling fan	2	10	100	1000
Washing machine	1	1	375	375
Computer	1	4	225	900
Refrigerator	1	9	600	5400
Microwave	1	0.5	1300	650
TV	1	14	300	4200
Laundry	1	0.5	1000	500

Total = 13205 Wh/day

2.4.2 Classification and 'Schedulability' of Household Loads

According to the article, 'Real-time Household Load Priority Scheduling Algorithm based on Prediction of Renewable Source Availability', the loads in a home is classified in these 3 categories [18].

A. Appliances with real-time energy consumption mode,
B. Appliances with periodic nonreal-time energy consumption mode

C. Appliances with nonperiodic nonreal-time energy

A. Home appliances with real-time energy consumption mode

The energy consumption of this type of home appliance is directly related to consumer behavior, which means that after the consumer turns on this type of home appliance, energy will be consumed instantaneously and continuously until the appliance is shut down. This implies that, the cost of energy consumption of this type of home appliance is directly related to the time when the consumer turns it on and the duration of its usage [18].

B. Home appliances with periodic nonreal-time energy consumption mode

The energy consumption of this type of home appliance is periodical and fluctuant when it is in use. The refrigerator is an example. Energy is periodically consumed by the refrigerator to maintain the desired temperature. Generally, the desired temperature is defined by the upper and lower bounds and the refrigerator starts to consume energy when its temperature is higher than the upper bound until the temperature reaches the lower bound. However, it should be noted that this type of appliance is also related to consumer behavior because, the refrigerator consumes more energy when the user opens the refrigerator door often than when it is kept shut [18].

C. Home appliances with nonperiodic nonreal-time energy consumption mode

This type of home appliance consumes energy nonperiodically and does not have any running time limit. However, they may have a deadline to run, i.e., they must provide service before some certain conditions (time, capacity, throughput, etc.) apply. The pool pump, washing machine and dishwasher belong to this category [18]. In summary, the home appliance is categorized as follows and its ‘schedulability’ stated.

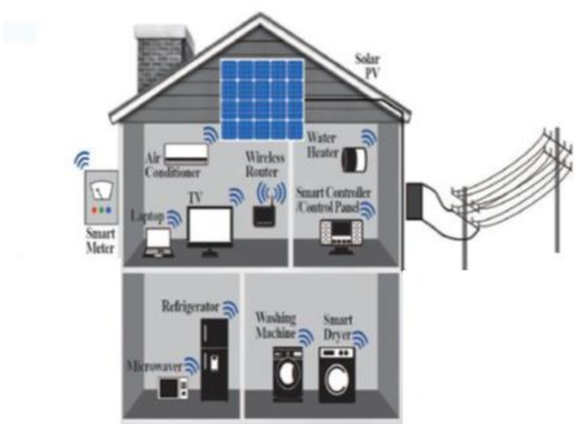
Home Appliance Categories

Category	**Energy Consumption**	**Eligible for Scheduling**	**Examples**
Appliances with real time energy consumption mode	Instantaneous and continuous	No	Refrigerator, Microwave ovens, desktop computers without battery, printers, lights, TV sets, DVD players.
Appliances with non-real time energy consumption mode	Periodic and flexible	Yes	Water and space heaters, air conditioners, laptop and other battery appliances.
Appliances with nonperiodic nonreal time energy consumption mode	Nonperiodic and flexible	Yes	Laundry machines and Dish washers.

Chapter 3 Design and System Requirements

In this chapter, a real-time household load priority scheduling algorithm based on prediction of renewable source availability and dynamic priority allocation and scheduling is proposed to optimize the consumption of solar energy in a home, without compromising the home user's comfort. Home appliances are classified into three categories, according to the Demand Response categorization for Load management. Then, a dynamic priority allocation and scheduling algorithm based on their different energy consumption modes and the electricity market price would be made. Then finally an algorithm for real-time household load scheduling would be proposed. The benefits and feasibility of the algorithm would be analyzed with a STEEPLE analysis by considering all the possible transitions between weather, price, and priority states and presenting all the foreseeable results when some of those factors change.

3.1 Model Home



My model home is a house with solar panels, which ideally, provide energy for all the home appliances during the day. In the evening, the home relies on the national grid for power.

On days with little sunshine, the grid acts as a backup for the home. The aim of the load scheduling is to ensure that

$$consumption - production = 0$$

However, on any rare occasion where there is excess energy produced, which cannot be consumed by the home appliances, the excess energy is fed unto the grid.

3.2 Load Profile for Major Household Appliances

In this paper, for the purpose of load profiles of appliances, a mid-size home is considered with the following major electricity consuming appliances. The home also has on-grid photo voltaic (PV) panels for electricity generation. Heating of water and home, if required, is done through oil or liquified petroleum gas (LPG) as it is practiced in many parts of Ghana. It is known that different appliances have definite times of completing their cycles. Appliances with major contribution in terms of energy consumptions such as dishwasher, washing machine with dryer, refrigerators, and air conditioners are considered in this model to study their demand response and optimize their operation over a period of time to minimize the total energy cost and level the load curve.

The Dishwasher

The dishwasher has three main operating cycles: wash, rinse and dry and it takes approximately 105 minutes to complete all the cycles on average. During the working of 1.75 hours of dish washer, load varies from maximum 1.2 kW to minimum 0.6 kW as shown in Figure 4.1. The energy consumption is about 1.44 kWh for one complete cycle of dishwasher. Dishwasher is classified in category of *schedulable load.*

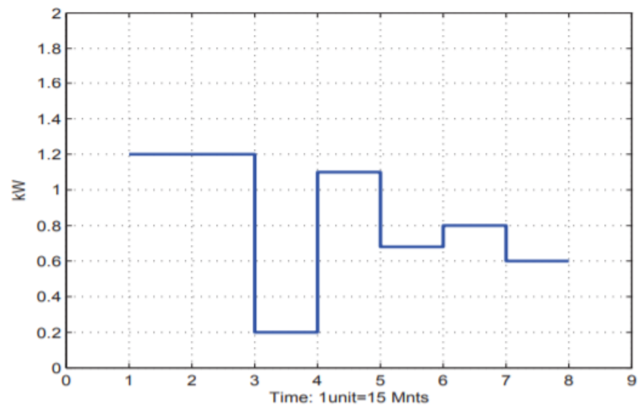


Figure 1 Load profile for Dishwasher

Laundry

This is a case of two appliances, washing machine and drying machine working in sequence. Cloth washing machine precedes the dryer. Cloth washing machine like dishwasher has three cycles of operation: wash, rinse and spin which takes 45 minutes to complete all the cycles. The power load varies between 0.52 kW to 0.65 kW. Then after lapse of 15 minutes, dryer starts which takes 60 minutes to dry the clothes. The load of dryer varies from 2.97 kW to 0.19 kW. Laundry is classified in category of *schedulable load*.

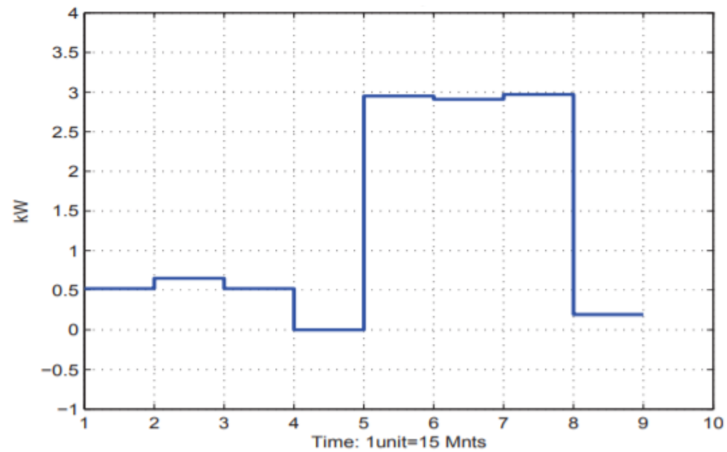


Figure 2 Load Profile for Laundry

Air-conditioner (AC)

The load profile of the central air-conditioner (AC) is shown in Figure 4.4 which resembles like a series of square wave train showing peak load of 2.75 kW when compressor of AC is working and, 0.25 kW when the compressor is off. This occurs when inside room temperature is equal or below the set room temperature. However, air fan continues to work for circulation of air. The energy consumption of 2.5-ton AC is around 31.15 kWh per day. AC is classified as continuous non-shiftable load with sub-classification as weather-based load.

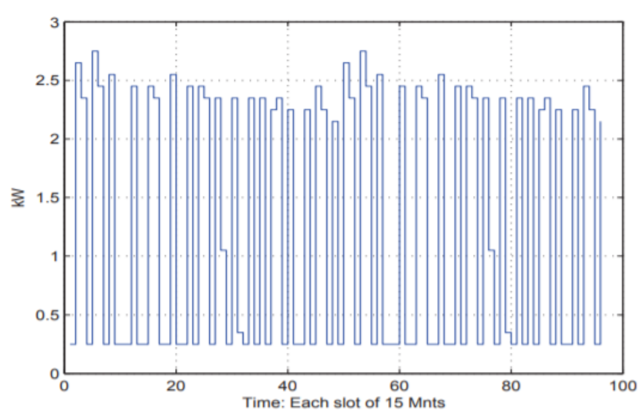


Figure 3 Load profile of air conditioner

Oven

The use of cooking ovens falls into the category of appliances which are used more than once in a day. For instance, an oven used in the morning and in the evening can be treated as two separate appliances. The use of oven in the morning is of short duration and usually finishes in 30 minutes. The load varies from 1.28 kW to 0.83 kW as shown in Figure 4.5. The electricity consumption is estimated to be 0.53 kWh. Oven is considered as shiftable load to user specified time preference.

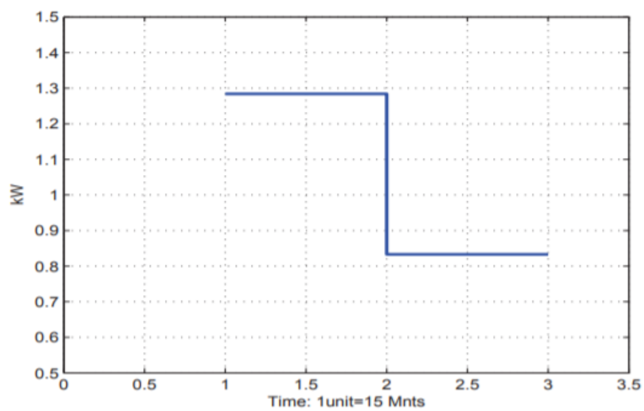


Figure 4 Load Profile for Oven

3.3 Solar Power Supply as Micro-Grid

In my model home, there is a solar installation which I have considered a micro-grid of 3kW photo-voltaic (PV)/solar panel system with on grid connection in which direct current produced by PV panels is directly converted to alternating current (as per national AC standards) by smart inverters.

1. It has an on-grid connection, which means that PV panels are connected to the national grid.

2. The expensive backup battery packs are omitted. The grid becomes a backup system when the sun is not shining or when the home uses more electricity than PV panels can produce.
3. Electricity generated by the PV system will be consumed in home.
    a. If during any instance of time, PV produced electricity is more than the demand of home, the surplus electricity will be exported to the national grid.
    b. Also, when electricity produced by PV is less than the demand of the home, the balance electricity will be imported from the national grid.
4. Power profile of a typical 3kW solar panel is shown in Figure 8, according to which power varies from 2.9 kW to 0 and energy production on sunny day is 23.11 kWh.

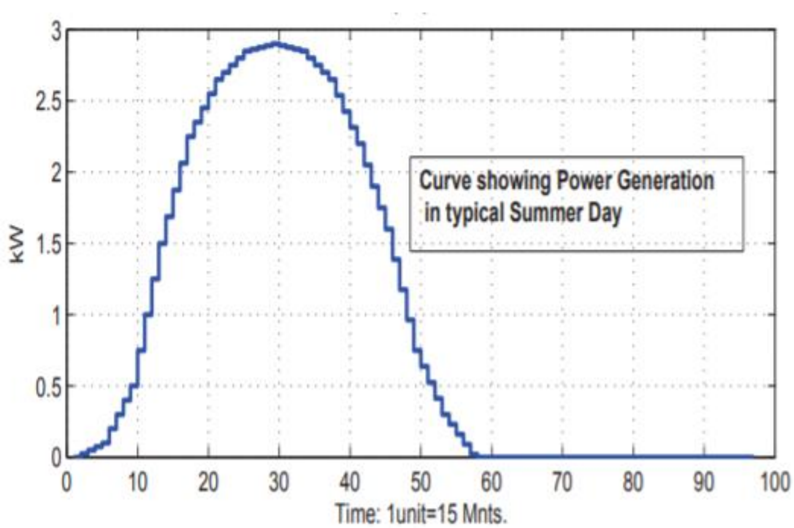


Figure 5 Photovoltaic (PV) Generation Profile

3.4 The Load Scheduling Algorithm

For this scheduling, all appliances cannot start at the same time. This is because, the energy demand would be higher than the energy supplied, which our PV energy might not be able to support. Therefore, the appliance use should be spread properly over the time to keep the peak demand to minimum and usage cost of electricity to minimum and yet not compromise on comfort of the user.

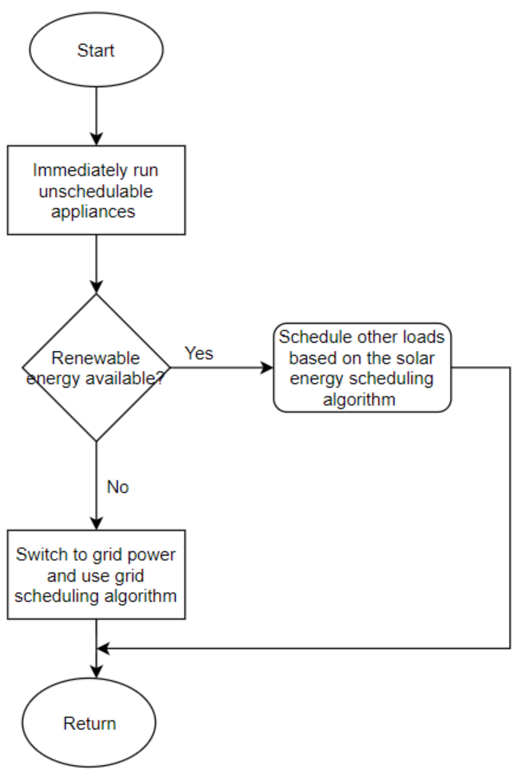
1. First, to enable me to determine the kind of load to be scheduled at a particular time of the day, data of energy consumption rate of home appliances across a time period on 24 hours would be obtained.
2. To know the exact time of the day for a load to be scheduled based on the solar energy produced, the solar irradiance data, estimating the solar energy produced at different times of the day would also be obtained. With that, the solar energy produced at times of the day would be calculated.
3. For my model home, the grid serves as a backup power supply should the solar energy run down. Therefore, the electricity tariff at different times of the day would also be obtained to enable efficient scheduling when the home needs to rely on the grid power.
4. Taking into consideration the amount of solar energy produced at different times of the day and the energy rating of appliances, specific times during the day would be determined for loads to be scheduled.
5. The everyday energy consumption profile of all the loads in the home would be obtained and termed as the ‘unscheduled load’.
6. It is to be noted that, appliances like the fridge and heaters in the home would operate 24 hours nonstop. Also, ‘user behavior based’ appliances like the light bulb, microwave, and electric stove would be accounted for since they could be turned on any time of the day.

Therefore, to get the actual solar energy left for scheduling, the energy consumption of these loads would be deducted from the solar energy produced. The remnant would be used to schedule the other loads.

7. At any time instance, before a load is scheduled, the program must check if the load is less than or equal to (<=) the solar energy produced. If TRUE, the load is scheduled. If FALSE, the load is shifted to the grid supply, where a different scheduling algorithm is used.
8. For the grid load scheduling, the electricity tariff would be used.

3.4.1 Flowchart of Scheduling Algorithm

The scheduling algorithm is illustrated in the flowchart below.



3.5.1 Duration of Operation

A day of 24 hours is divided into 24 time slots. Thus, each time slot represents an interval of 1 hour. The appliances can be set to start at any time within this time frame and end its cycle of operation before or on 96th time slot; surely not later this time. All the time slots are represented by their starting times.

3.5.2 Execution Window of each Operation

Appliances must start in a user-specified window. Therefore, users specify a desired execution window for each appliance i.e., the interval when the appliance can run. More precisely, for each appliance, there is a minimal starting time (before that it cannot start), and a maximal ending time (by then it has to be finished).

1. If an appliance should run twice or more, it is enough to introduce two or more identical appliances with non-overlapping execution windows.

2. If an appliance should not run during a day, it is enough to set its length to zero. The scheduler is free to switch on the appliances on any time as long as it respects the starting and ending time constraints within the range.

3.6 Assumptions

1. I will consider a single home in the residential sector under utility and rooftop PV units.
2. I assume that the utility company power is always available to support prosumers' load.
3. The PV units generate electricity, depending on solar irradiance, ambient temperature, efficiency of PV units, and effective area of PV units. Ninety percent of the estimated PV generation in any timeslot of the scheduling time horizon is used to serve the load. The remaining 10% is left for uncertainty between the estimated and actual generation.
4. The home doesn't use batteries to store excess solar energy for use later

3.7 Steeple Analysis

The STEEPLE analysis is a strategic decision-making tool in which the societal, technological, environmental, ethical, political, legal and economic factors are taken into account. This strategic planning tool allow to consider the effect that has a project on the micro-environment and access its strengths and weaknesses.

Societal	• The demographic growth of the world population leads to a higher demand on the energy resources and a higher electricity consumption • The optimization algorithm is an efficient method to redefine the behavior of the user toward energy consumption by adequately scheduling the use of the home appliances.
Technology	• The continuous enhancement of technology makes the algorithms easier to be implemented in more and more innovative software. • The access to technology has become easier and has given rise to more innovation and competition.
Environment	• Reduce the environmental impact of energy generation and the ecological footprint on our planet. • Promote the use of renewable energies and sustainability to preserve and protect our environment.
Ethics	• Avoid the waste of energy and promote responsibility toward the environment.
Political	• Reduce the energy dependency of Morocco. • Orient the energy policy toward the use of renewables.
Legal	• The Moroccan government is setting new energy policy guidelines to promote renewable energies. The 58-15 law project gives the possibility of selling the surplus of energy from renewable sources to the ONEE.
Economic	• The implementation of the optimization algorithm along with the sizing of PV modules reduce the electricity bill and generate revenues when the surplus of energy is sold.

Figure 1.4: STEEPLE Analysis

Chapter 4 Optimal Load Scheduling Without Solar Energy

To be able to make a better conclusion on the load scheduling with solar energy, a control, load scheduling with grid energy only would be modelled in this section. The electricity price fluctuation for every hour is considered. The optimization scheduling requires the use of the MILP in the Matlab simulation and the addition of scheduling constraints.

4.1 Method 1: Mixed Integer Linear Programming

Linear optimization techniques are widely used to solve engineering problems by minimizing or maximizing an objective function. Indeed, many concrete problems can be expressed as a linear program and be efficiently solved by an algorithm. For instance, optimizing the time it takes to go from Ashesi to Accra can be found using linear programing methods. In linear programing, all functions and constraints are related to a variable x with the form

$$a^t x + b$$

These linear optimization techniques can be divided into three main types: continuous, integer and mixed-integer. The continuous linear method optimizes variables that are generally real numbers. It is solved using algorithms, which generate iterated values of the variables until a solution is found [8]. The integer programming method is similar to the continuous one, but includes an additional constraint that states that some or all the optimization variables need to be integers. The programming technique used in this paper is the mixed integer one. It is characterized by the fact that it combines continuous and discrete variables. Mathematically speaking, the mixed integer technique search for a vector x that maximize or minimize an objective function under a set of constraints [9]. The formal mathematical expression is given in equation (1).

$$max, \min c^T x$$

Let an appliance set G be defined as $G = \{1,2,3, \dots , n\}$ where n represents the total number of time-shiftable appliances, and let a vector pi,j, which represents the power consumption of the ith appliance in a time slot j ∈ $H = \{1, \dots ,24\}$ be defined by equation (2).

$$pi.j = (pi, 1, pi, 2 \dots \dots \dots ., pi, 24) \in R24, for\ i \in G \ \&\ J \in H$$

The power consumption pi,j have to be included within a certain range defined by the standby power α and the maximum working power β. The standby power, also called vampire power, refers to the small amount of electric power consumed by the appliances while they are switched off. The maximum working power defines the maximum energy that an appliance can consume over a period of time. The consumption constraint is formulated in equation (3).

$$\alpha i,j \leq pi,j \leq \beta i,j \quad \forall\ j \ \&\ i \in G$$

The electricity price: the tariff changes over a time of 24 hours according to the Electricity Company of Ghana's tariffs for residential usage. The defined electricity cost is given by a $1 * 24$ matrix such as:

[0.9,0.8,0.8,0.9,1,1,0.8,1,0.1,0.1,0.1,0.1,0.1,0.1,0.9,0.1,0.2,0.1,0.2,0.1,0.2,0.1,0.2,0.1]

Let the summation denoted as $\sum_{i \in G} p_{i,j}$ represents the non-negative required power of all five appliances for a time slot j, where $n = 5$ and $G = \{1,2,3,4,5\}$ since only five appliances are considered. The objective function, which represents the residential electricity bill for a day in our case, is given by multiplying the electricity cost that vary according to the fluctuation method used by the appliance power consumption as seen in equation (4).

$$\sum_{j \in H} cost_{j,s} \sum_{i \in G} p_{i,j} = \sum_{i \in G} cost_{j,s}{}^T p_i$$

Where the value of $s = \{1,2,3\}$ represents which method of electric price fluctuation is used. The optimization objective based on the MILP method can be formulated as follow:

$$\sum\nolimits_{iEG} cost_{j.s^T}\ pi$$

The optimization function is given by a 5*24 matrix as seen in the equation below.

$$\sum\nolimits_{iEG} cost_{j.3^T} * pi = \begin{matrix} cost_{1.3} \\ cost_{2.3} \\ . \\ . \\ . \\ cost_{24.3} \end{matrix} * \begin{bmatrix} p_{1,1} & p_{1,2} & p_{1,3} & . & . & p_{1,24} \\ p_{2,1} & p_{2,2} & p_{2,3} & . & . & p_{2,24} \\ p_{3,1} & p_{2,3} & p_{3,3} & . & . & p_{3,24} \\ p_{4,1} & p_{2,4} & p_{4,3} & . & . & p_{4,24} \\ p_{5,1} & p_{2,5} & p_{5,3} & . & . & p_{5,24} \end{bmatrix}$$

$$= \begin{bmatrix} cost_{1,3} * p_{1,1} & cost_{2,3} * p_{1,2} & cost_{3,3} * p_{1,3} & . & . & cost_{24,3} * p_{1,24} \\ cost_{1,3} * p_{2,1} & cost_{2,3} * p_{2,2} & cost_{3,3} * p_{2,3} & . & . & cost_{24,3} * p_{2,24} \\ cost_{1,3} * p_{3,1} & cost_{2,3} * p_{3,2} & cost_{3,3} * p_{3,3} & . & . & cost_{24,3} * p_{3,24} \\ cost_{1,3} * p_{4,1} & cost_{2,3} * p_{4,2} & cost_{3,3} * p_{4,3} & . & . & cost_{24,3} * p_{4,24} \\ cost_{1,3} * p_{5,1} & cost_{2,3} * p_{5,2} & cost_{3,3} * p_{5,3} & . & . & cost_{24,3} * p_{5,24} \end{bmatrix}$$

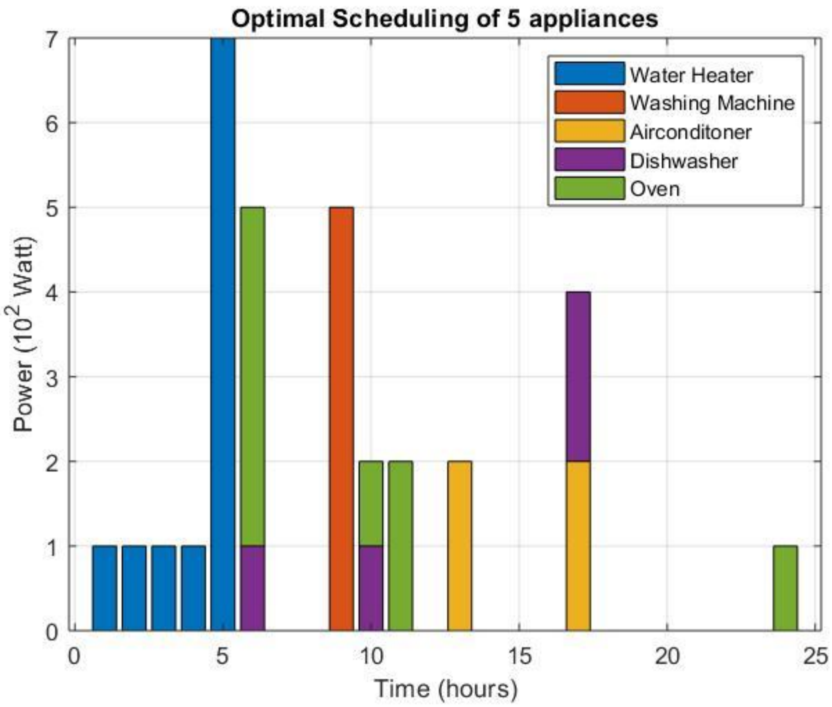
In order to implement the MILP model in Matlab, the solver "intlinprog" is used and take the following arguments (f, intcon,A, b, Aeq, beq, lb, ub) [14]. The vector f represents the coefficient vector, intcon refers to the vector of integer constraints, A is the linear inequality matrix, Aeq is the linear equality constraint matrix, beq is the linear equality constraint vector and lb and ub refers to the lower and upper bounds.

Below is the general form of the MILP method in Matlab.

$$min f^T x \ subject\ to \begin{cases} x(intcon) are\ integers \\ A.x \leq b \\ Aeq.x = beq \\ lb \leq x \leq ub \end{cases}$$

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

Based on the power consumption pattern given in the table, the following scheduling graph was obtained using Matlab.



4.2 Method 2: Artificial Neural Networks

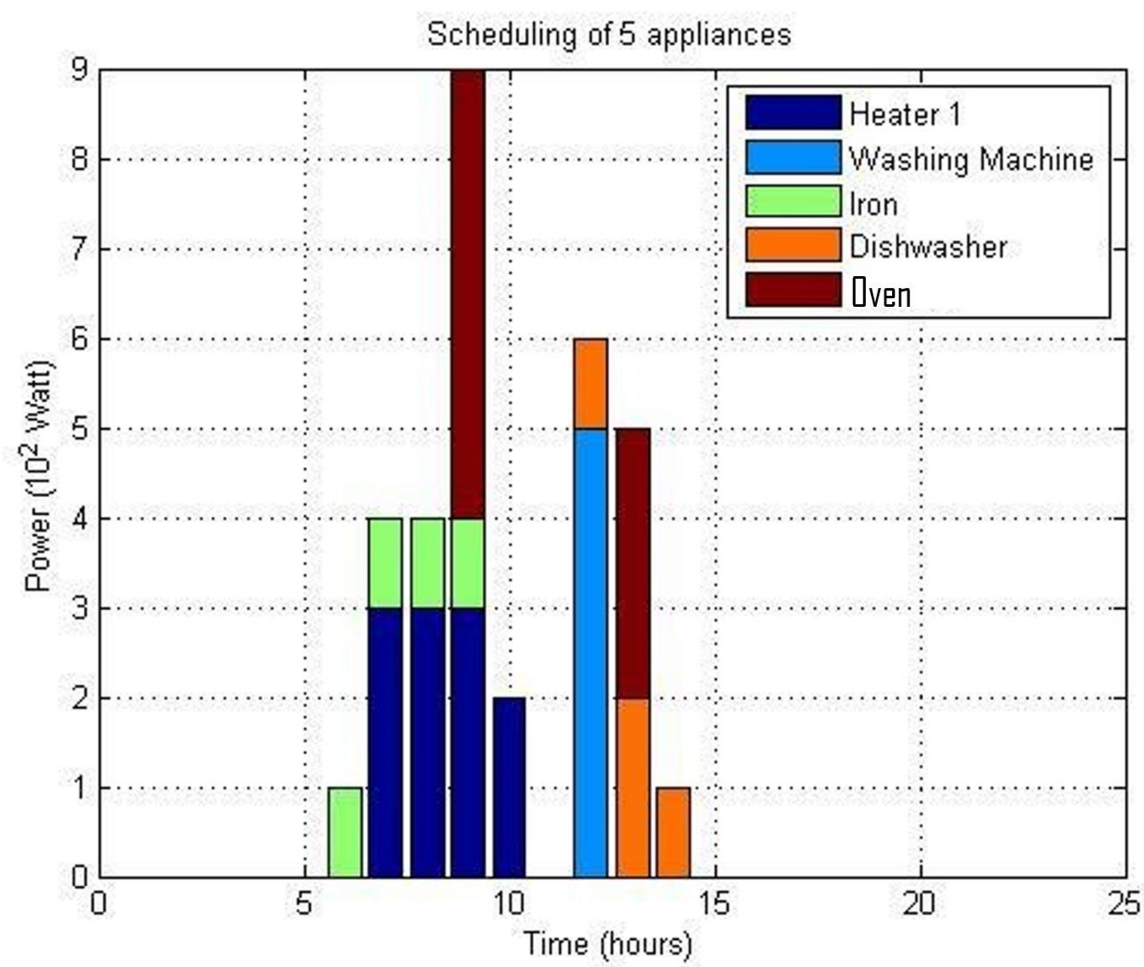
The actual training data for the ANN are generated from the simulation models. From the figure below, the inputs are the availability of grid supply, the rating of the device, and the user want. The user want is an arbitrary value between 0 and 5 with five being the highest. If the user want is 3 and above, the load would be scheduled for grid consumption. If the user want of the device at a time is less than 3, then the load is not scheduled at all.

On the other hand, the outputs of the ANN are the signals to consume from grid, to consume from solar or not consume at all. The ANN parameters are shown in the table below.

Table 2 ANN Parameters

Parameters	**Value**
Number of inputs	5
Number of outputs	5
Number of hidden layer	2

Number of neurons in hidden layer N1	18
Number of neurons in hidden layer N2	20
Number of iterations	1000
Learning rate	0.6175
Regression Coefficient	0.99518



Chapter 5 Optimal Load Scheduling Using Linear Programming Optimization with Solar Energy

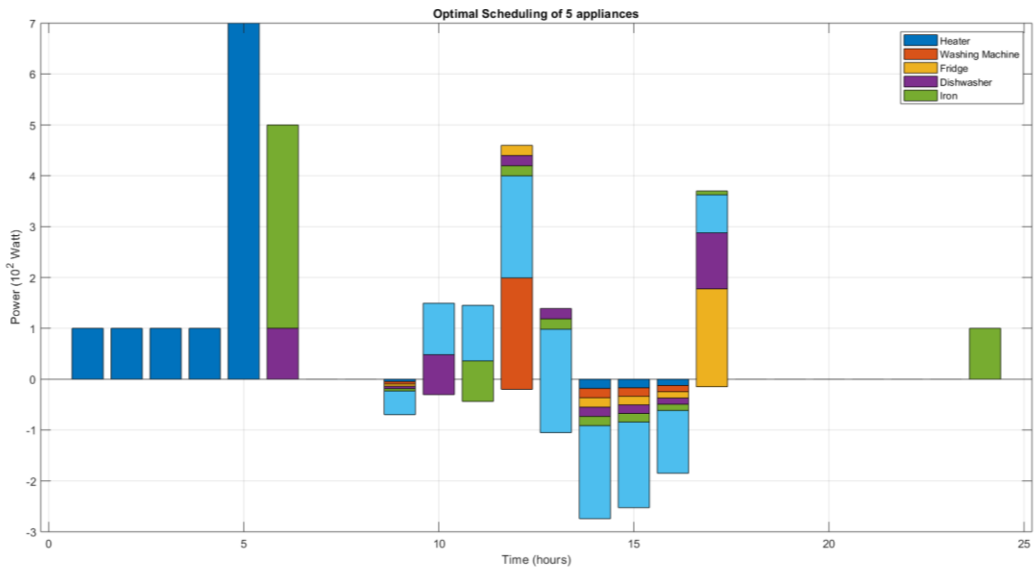
5.1 Method 1: Mixed Integer Linear Programming

This Chapter focuses on the ultimate load scheduling of household loads, which involves the consumption of solar energy and the grid. The same approach from chapter 4 was used however, here the solar energy produced was considered. Data of solar irradiance data for Ghana was downloaded from NASA's website for an average day in May. The factors my ANN networks depend on are

1. User Want
2. Power Rating of the device

The user want is an arbitrary number between 0 and 5 with 5 being the highest. If the user want of 3 and above, the load would be scheduled for grid energy consume. If the user want of the device at time is less than 3, then the load is not scheduled at all.

Household loads were scheduled according to Table 1 in Chapter 4.

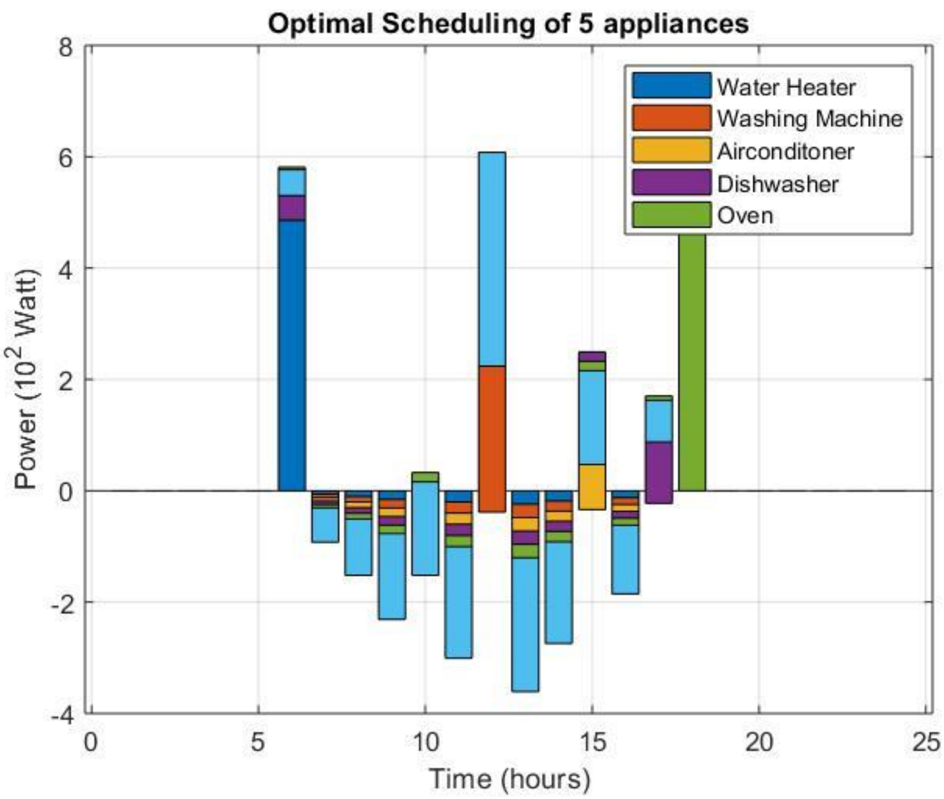


5.2 Method 2: Artificial Neural Networks

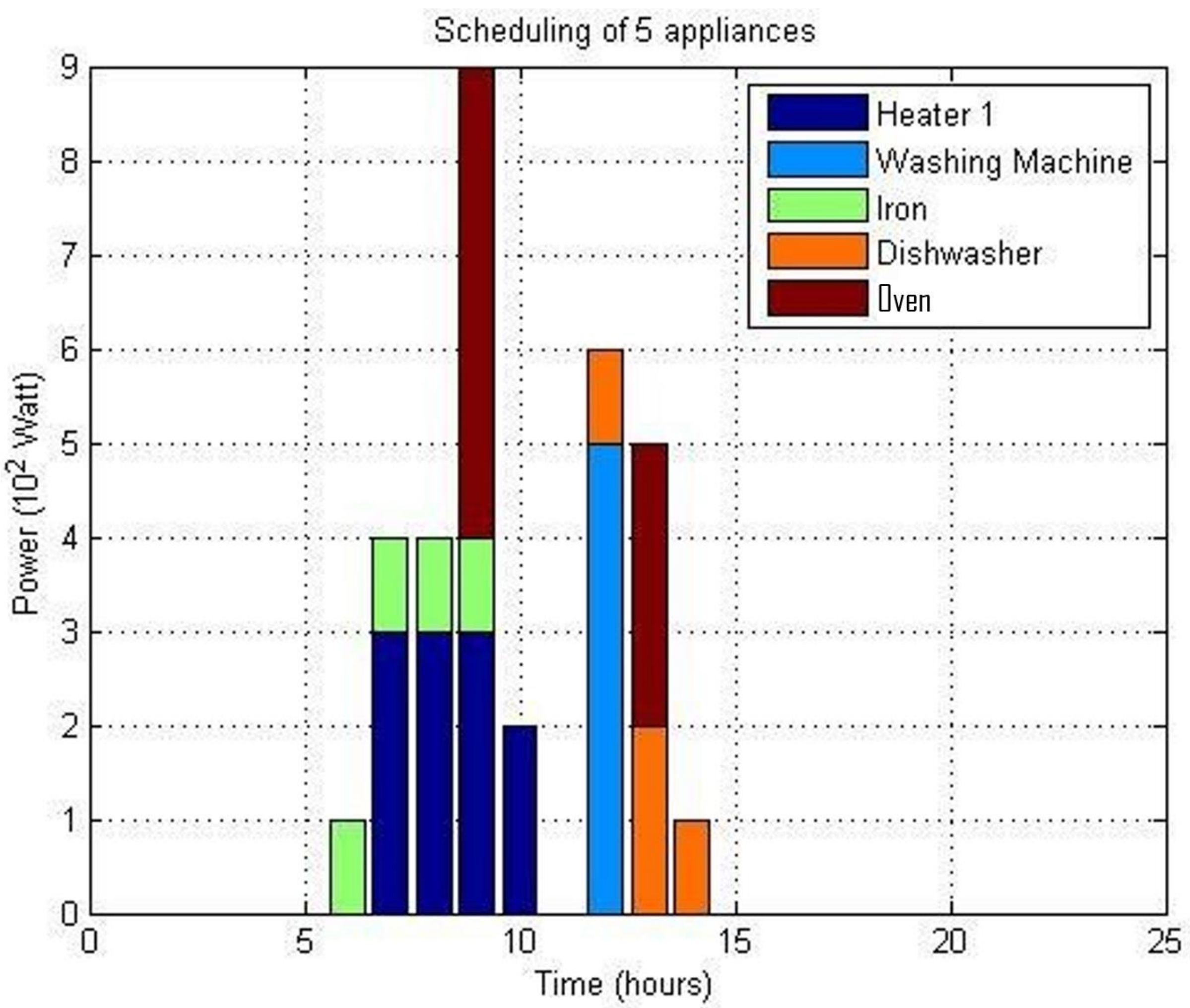
This Chapter focuses on the ultimate load scheduling of household loads, which involves the consumption of solar energy and the grid, using Artificial Neural Networks. The same approach from chapter 4 was used however, here the solar energy produced was considered. Data of solar irradiance data for Ghana was downloaded from NASA's website for an average day in May. This makes the factors my ANN network change from four to five, with the availability of solar energy included. Household loads were scheduled according to Table 1 in Chapter 4.

1. Sunshine Intensity
2. User Want
3. Power Rating of the device

The user want is an arbitrary number between 0 and 5 with 5 being the highest. If Sunshine is available, with a user want of 3 and above, and the Power Rating of the device less the solar energy produced, the load would be scheduled for solar energy consume. If all conditions remain constant; however, the power rating of the device is higher than the solar energy produced, then the load is scheduled for grid. If the user want of the device at time is less than 3, then the load is not scheduled at all.



Chapter 6 Load Consumption Without Optimization



Chapter 7 Cost Benefit Analysis for the Best Optimization Algorithm

After having compared the different pricing methods and their relative cost, it is important to compare the costs associated with the different optimization methods. Three different approaches are compared namely: optimal scheduling, PV optimal scheduling and optimization considering that the surplus of solar energy can be sold back to the grid. The percentage reduction of the daily cost is formulated for each method with respect to the scheduling plan without optimization. We assume that the selling price of the solar energy back to the grid is equal to the electricity cost value for a constant pricing method. A summary of the different costs with respect to each pricing and optimization method is given in the tables below.

The percentage change of the cost from one optimization approach to another and with respect to each billing method can be calculated using equation (15).

$$percentage\ change = \frac{cost_{i+1} - cost_i}{cost_i}$$

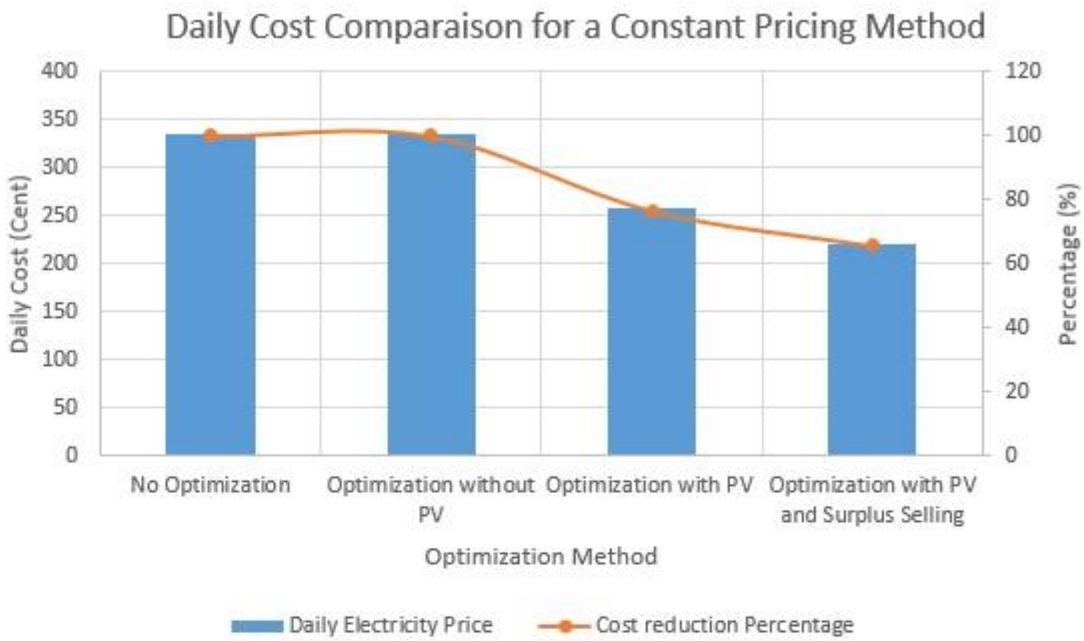
The percentage change can then be derived and gives an idea about the most cost effective pricing method.

Scheduling With Solar Energy		
Appliances	**Cost without Optimization ($)**	**Cost with PV Optimization ($)**
Heater	0.099	0.069

Washing Machine	0.055	0.049
Iron	0.032	0.03
Dishwasher	0.048	0.048
Oven	0.064	0.045
Total	0.298	0.24

7.4 Overall Best Scheduling Algorithm

Daily Electricity Cost of the Appliances ($)				
Pricing / Optimization Method	No Optimization	Optimization without PV	Optimization with PV	Optimization with PV and Energy selling
Daily Electricity Cost	0.336	0.336	0.257	0.221



The cost analysis shows that the optimal scheduling of electric appliances reduces the cost and proves to be effective. It can be concluded that the most cost-effective method is the bi-daily pricing method because the savings can reach 47.1%, even if its initial cost without optimization is higher.

Chapter 8 Conclusion and Future Works

Reducing the environmental impact of energy generation and responding effectively to the energy demand is crucial toward achieving sustainability. The purpose of this capstone project was to identify the best algorithm for household load scheduling to reduce the cost of electricity bills in the home. Two optimization methods, the Mixed Integer Linear Programming and Artificial Neural Networks were considered. The scheduling optimization was implemented respectively according to the availability of solar energy. Moreover, the optimization part was divided into two main sections namely optimizing without solar energy resources and optimizing in conjunction with solar energy. The simulation results showed that optimizing the scheduling of the electric appliances could reduce the bill by up to 38% when no renewable energy is considered and by up to 47% when it is considered with renewable energy.

Finally, the results obtained demonstrated the efficiency of the ANN to achieve the appliances optimal scheduling, as against the efficiency of the MILP. In this project, the utility function, which represent the satisfaction level of the consumer was not considered. The algorithm and optimization method could be enhanced to take into account the user’s time of preference to use a particular appliance.

References

[1] D. Hopwood, "Renewable Energy Focus changes", Renewable Energy Focus, vol. 14, no. 5, p. 1, 2013. Available: 10.1016/s1755-0084(13)70081-4.

[2] "Smart Grid Technology and Renewable Energy Integration in the Ghanaian Grid System", International Journal of Science and Research (IJSR), vol. 5, no. 5, pp. 829-835, 2015. Available: 10.21275/v5i5.nov163405

[3]Publications.lib.chalmers.se,a2019.a[Online].aAvailable:ahttp://publications.lib.chalmers.se/records/fulltext/218826/218826.pdf. [Accessed: 10- Nov- 2019

[4]Aps.org, 2019. [Online]. Available: https://www.aps.org/policy/reports/popa-reports/upload/integratingelec.pdf. [Accessed: 10- Nov- 2019].

[6]D. Adelman and C. Uçkun, "Crosscutting Areas—Dynamic Electricity Pricing to Smart Homes", Operations Research, 2019. Available: 10.1287/opre.2019.1882.

[7]GSM Based Industrial Appliances Control Using Arduino Processor", International Journal of Science and Research (IJSR), vol. 5, no. 3, pp. 1680-1682, 2016. Available: 10.21275/v5i3.nov162287.

[8]Q. Yu, M. Duan, T. Zhang, H. Wu and S. Lu, "An Wireless Collection and Monitoring System Design Based on Arduino", Advanced Materials Research, vol. 971-973, pp. 1076-1080, 2014. Available: 10.4028/www.scientific.net/amr.971-973.1076.

[9]M. Amine Rafkaoui, "OPTIMAL SCHEDULING OF SMART HOMES ENERGY CONSUMPTION IN CONJUNCTION WITH SOLAR ENERGY RESOURCES", 2019. [Accessed 14 November 2019]. *

[10]"Design Optimization of Solar Photovoltaics — Increasing Profit Generation - Renewable Energy World", Renewable Energy World, 2019. [Online]. Available: https://www.renewableenergyworld.com/2018/03/21/design-optimization-of-solar-photovoltaics-increasing-profit-generation/#gref. [Accessed: 14- Nov- 2019]

[11]B. Silva, M. Khan and K. Han, "Load Balancing Integrated Least Slack Time-Based Appliance Scheduling for Smart Home Energy Management", Sensors, vol. 18, no. 3, p. 685, 2018. Available: 10.3390/s18030685. *

[12]Y. Ren, H. Wu, H. Yang, S. Yang and Z. Li, "A Method for Load Classification and Energy Scheduling Optimization to Improve Load Reliability", Energies, vol. 11, no. 6, p. 1558, 2018. Available: 10.3390/en11061558.

[13]M. Bragard, N. Soltau, S. Thomas, and R. W. De Doncker, “The Balance of Renewable Sources and User Demands in Grids: Power Electronics for Modular Battery Energy Storage Systems,” IEEE Trans. Power Electron., vol. 25, no. 12, pp. 3049-3056, Dec. 2010.

[15] J. Zhao, Z. Dong, Z. Xu, and K. P. Wong, “A Statistical Approach for Interval Forecasting of the Electricity Price,” IEEE Trans. Power Syst., vol. 23, no. 2, pp. 267-276, May 2008.

[17]2019. [Online]. Available: https://www.researchgate.net/figure/The-Household-Load-Data_tbl2_266459811.

[18]Xin Liu, L. Ivanescu, Rui Kang and M. Maier, "Real-time household load priority scheduling algorithm based on prediction of renewable source availability", IEEE Transactions on Consumer Electronics, vol. 58, no. 2, pp. 318-326, 2012. Available: 10.1109/tce.2012.6227429.Accessed: 15- Nov- 2019].