# TECHNICAL UNIVERSITY OF CRETE

## SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

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**Optimal Coordination Control for Improved Power Flow of a Smart Grid Using Smart Metering Based on Genetic Algorithm**

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Graduation Thesis

by

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# Abstract

## An Abstract of Optimal Coordination Control for Improved Power Flow of a Smart Grid Using Smart Metering Based on Genetic Algorithm.

### by

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The conventional electric power grid has proven inadequate. Because the grid technology currently implemented is outdated, there is manifestation of reliability problems. In this thesis an Intelligent Energy Management System (EMS) for end consumers has been proposed. This system develops an optimal power flow control of a Smart grid using real time measurements in a grid offering energy at invariable price and Genetic Algorithm (GA) for a smart meter which is integrated between distribution grid and end consumers. GA methodology is an evolutionary process, which imitating evolution process of nature. The smart meter determines when to draw the energy from grid or the storage unit for consumption. Furthermore, the EMS provides the ability to end consumers for smart charging in Electric Vehicles (EVs). The first objective of using this algorithm is to reduce the cost for end consumers by charging energy storage unit (ESU) from the grid during the low cost periods. The second objective of this system is to prevent grid overload by shifting the power drawn from high demand period to low demand period. The algorithm use two parameters, the hourly price and the load demand of the grid. It demonstrated that the GA approach is much better in cost saving and grid load reduction compare to conventional grid and fuzzy logic approach. The implementation of GA strategy showed 26.1% cost saving rate in comparison with conventional grid for one year period. In addition, the above strategy is 2.4% better than fuzzy logic approach in cost saving rate.

**Keywords:** Energy Management System (EMS), Optimization, Genetic Algorithm (GA), Smart Grid, Smart Meter, Electric Vehicle (EV), Energy Storage Unit (ESU), Cost Saving, Grid Load Reduction.

**Περίληψη**

**Μία Περίληψη του Βέλτιστου Ελέγχου Συντονισμού για τη Βελτιωμένη Ροή Ενέργειας ενός Έξυπνου Δικτύου Χρησιμοποιώντας ένα Έξυπνο Μετρητή Βασισμένο σε Γενετικό Αλγόριθμο**

**από**

**Μάριο Παπανικολάου**

Το υπάρχον ηλεκτρικό δίκτυο έχει αποδειχθεί ανεπαρκές. Επειδή η τεχνολογία που εφαρμόζεται σήμερα στο δίκτυο είναι ξεπερασμένη, εμφανίζονται προβλήματα αξιοπιστίας. Σ' αυτή τη διπλωματική εργασία προτείνετε ένα Σύστημα Ευφυούς Ενεργειακής Διαχείρισης για τους καταναλωτές. Αυτό το σύστημα αναπτύσσει έναν βέλτιστο έλεγχο ροής ισχύος ενός έξυπνου δικτύου χρησιμοποιώντας μετρήσεις σε πραγματικό χρόνο σε δίκτυο που προσφέρει ενέργεια σε αμετάβλητη τιμή και το γενετικό αλγόριθμο για ένα έξυπνο μετρητή ο οποίος είναι ενσωματωμένος μεταξύ του δικτύου διανομής και των τελικών καταναλωτών. Η μεθοδολογία ενός γενετικού αλγορίθμου είναι μια εξελικτική διαδικασία, η οποία ουσιαστικά μιμείται την εξέλιξη της φύσης. Ο έξυπνος μετρητής καθορίζει πότε πρέπει να αντληθεί η ενέργεια από το δίκτυο ή την μονάδα αποθήκευσης για κατανάλωση. Επιπλέον, το σύστημα αυτό παρέχει τη δυνατότητα στους καταναλωτές να αποθηκεύουν σε ηλεκτρικά αυτοκίνητα. Ο πρωταρχικός στόχος της χρησιμοποίησης του αλγορίθμου αυτού είναι να μειωθεί το κόστος για τους τελικούς καταναλωτές φορτίζοντας τη μονάδα αποθήκευσης ενέργειας από το δίκτυο κατά τις περιόδους χαμηλού κόστους. Ο δεύτερος στόχος αυτού του συστήματος είναι η αποφυγή της υπερφόρτωσης του δικτύου με τη μετατόπιση ισχύος από περιόδους υψηλής ζήτησης σε περιόδους με χαμηλότερη ζήτηση. Ο αλγόριθμος χρησιμοποιεί δύο παραμέτρους, την ωριαία τιμή και τη ζήτηση φορτίου του δικτύου. Αποδείχθηκε ότι η προσέγγιση του γενετικού αλγορίθμου είναι πολύ καλύτερη όσον αφορά την εξοικονόμηση κόστους και τη μείωση στο φορτίου δικτύου σε σύγκριση με το συμβατικό δίκτυο και την προσέγγιση της ασαφούς λογικής. Η εφαρμογή της στρατηγικής γενετικού αλγορίθμου έδειξε ποσοστό εξοικονόμησης κόστους 26,1% σε σύγκριση με το συμβατικό δίκτυο για περίοδο ενός έτους. Επιπλέον, η πιο πάνω στρατηγική είναι 2,4% καλύτερη από την προσέγγιση της ασαφούς λογικής στο ποσοστό εξοικονόμησης κόστους.

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# Chapter 1

# 1. Introduction

## 1.1 General Introduction

The continuous global economy growth and the population increase over the years are contributing to the rapidly growing of global energy demand. According to 2017 report of the International Energy Agency, the global energy consumption expands by 30% until 2040. The biggest contribution to demand growth, almost 30, comes from India, whose share of global energy use rises to 11% by 2040. Also developing countries in Asia account for two-thirds of global energy growth, with the rest coming mainly from the Middle East, Africa and Latin America [1]. To avoid potential energy crisis, the global energy system must undergo a profound transformation, from one largely based on fossil fuels to one that enhances efficiency and is based on renewable energy.

Conventional energy resources, include petroleum, coal, fuel oil, natural gas and nuclear power, have been used as primary sources for the energy demand. Nevertheless this type of energy resources has seriously disadvantages. First is the limited resources that exist, over the years the quantity of this materials has been reduced and cost thousands of years for earth to regenerate these resources. Second and very serious is the pollution it causes to the earth. Fossil fuels emit greenhouse gases that highly affect the environment and the future generation. Among all energy sources, the emission factor of fossil fuels is very high and unfortunately is widely used as the main fuel in power generation [2]. Example of what damage which can cause is the big disaster of the Fukushima Daiichi nuclear accident. Following a major earthquake, a 15-metre tsunami disabled the power supply and cooling of three Fukushima Daiichi reactors, causing a nuclear accident on 11 March 2011. All three cores largely melted in the first three days and release huge amounts of radioactive in atmosphere [3]. Because of the environmental disasters, must replace the conventional resources with alternative energy solution which are more sustainable and renewable and more friendly to the earth.

To cover all the increasing demand must used renewable energy sources because they can contribute significantly to worldwide power production with less emission of greenhouse gases. These sources are natural like solar, wind, hydro, geothermal and biomass. Compare with conventional energy, the renewable energy has big advantage. The resources are naturally replenished and so will never run out. Also it has much lower environmental effects.

With the continuous global energy demand, management of energy has been more complex. This is where Smart grid will help. A Smart grid is a new concept that leads to the modernization of the transmission and distribution grid. Smart grids provide many benefits over conventional grid. Smart grids

improve both the physical and economic operations of the grid system, increasing reliability and sustainability. Energy security and optimization of the demand can be minimized by implementing the Smart grid system. The Smart grid system is designed to handle uncertain incidents. The three security objectives of Smart grid are to ensure the availability of the power supply based on customer requirement, the two-way communication system and the data security of the customer. The Smart grid mainly aims to enhance overall management, which refers to obtaining better control of the transmission system that will improve system reliability.

In conclusion, Smart grid offers significant benefits over a typical grid but need a prominent end economical method in optimization of the Energy Management System. A method, which reduce cost for end customers and avoid possible overloads.

## 1.2 Thesis Objectives

In this research is being proposed a design of intelligent Energy Management System (EMS) which has two main goals. First goal of this system is reduce the cost of end customers and the second is to help grid avoid possible overload or blackout.

The approach which decided to be implemented was based on Genetic Algorithm. This approach gives satisfactory results for achieve of the main goals. The proposed EMS was tested using real-time datasets. Results extracted from simulation indicated that the design exceeds expectations and performs admirably.

The proposed Energy Management System is made up of integrated "Smart Meter" and electric Energy Storage Unit, which are cooperating with other household appliance. Smart Meter is empowered by intelligent strategy and has under of control the Energy Storage Unit, which is responsible for storage the surplus electricity.

Moreover, the proposed EMS performance is compared with this one of fuzzy logic, implemented by the Thesis [17].

## 1.3 Overview of Chapters

This thesis is organized as follows.

Chapter One: The chapter briefly gives the description of the problem and the objective of this research.

Chapter Two: This chapter gives information about current practices in Smart grid technology. An overview about all technologies feature in Smart grid are presented and explained in this chapter.

Chapter Three: This chapter gives information about preparation of the proposed design. The physical framework will also be discussed in this chapter. Furthermore, datasets for testing the model will also be introduced and specified.

Chapter Four: This chapter presents a Genetic Algorithm based approach in design of Energy Management System.

Chapter Five: This chapter discusses the methodology in developing the proposed Genetic Algorithm system. Furthermore, it introduces the implementation of the proposed model, working platform and toolbox that help to complete the design.

Chapter Six: This chapter presents the results that were achieved during the simulation of the design using Matlab software.

Chapter Seven: This chapter gives a summary of this research. It also discusses the possible improvements that could be made in the future.

# Chapter 2

# 2. Smart Grid Overview

## 2.1 Introduction

Due to the rapid economic development, the electric grid suffers by huge problems in existing generation, transmission and distribution systems as they are not able to keep pace with the increasing demand. To cover this energy demand must install and incorporate large numbers of electrical power generation units with increased capacities, this can cause adverse impact on the environment. The conventional grid has proven inadequate for the purpose of managing the extensive and complex power systems. Because the grid technology currently implemented is outdated, there is a manifestation of reliability problems. The answer to these problems is called Smart grid. Smart grid is a modern energy system which implements a two way communications and also facilitates the two way flow of energy. Is an intelligent electricity network that integrates the actions of all users connected to it and makes use of advanced information, control, and communications technologies to save energy, reduce cost and increase reliability and transparency.

## 2.2 Current state of Energy Systems

### 2.2.1 Management of Conventional Energy Sources

The management of conventional energy resources is through electrical grids, which are interconnected and one-way network responsible for delivering electricity from generating power plants to end consumers. Power stations are usually large to take advantage of the "economies of scale". Also they are often located far away from heavily populated areas, near to fuels sources, like dams. The electrical power which is generated is converted to a much higher voltage, at which connects to the transmission network. The transmission network will transfer the power long-distance, sometimes across international boundaries, until it reaches to the substation where it is converted to lower voltage, to fit into the distribution grid. After it exits the substation, it enters the distribution wiring until it arrives the service location where it will be converted to the required service voltage. It is 230 V in Greece [4].

### 2.2.2 Management of Renewable Energy

Management of renewable energy is significantly different and more difficult than conventional energy. Also cause problems to the infrastructure of electrical grid, in particular to operation of generation, transmission and distribution.

As regards to generation, the sources of renewable energy are usually spread across wide distances. For example two types wind turbines, onshore and offshore, which require to be built in locations with constant high-speed winds. Another drawback is that the renewable energy use lower voltage line for transmission than conventional energy. Also the distribution of renewable energy, due to geographical reasons, is more complicated than the conventional.

Due to these problems, it is difficult the efficient integration of renewable energy without the Smart grid. With Smart grid will be benefited more consumers and in general the whole society from the disadvantages caused by conventional energy sources, especially in the environment. Increasing the use of renewable energy will significantly reduce the environment pollution, which cause from conventional resources. All this make the use of Smart grid more necessary.

# 2.3 Smart Grid

Smart grid is the technology that brings electric grid in a new level, a level that the grid can digitalize and computerize equipment and technology dependent on it, also which can automate and manage the increasing complexity and needs of electricity in the 21$^{st}$ Century. Smart grid makes everything better by establishing necessary two-way data communication among consumers and the others components of the electrical grid. This technology, gives an unprecedented opportunity to move the energy industry into a new era of reliability, availability, and efficiency that will contribute to our economic and environmental health.

Smart grid can face major problems such as blackout which can cause a series of failures that can affect banking, communications, traffic, security and homeowners without a heat in the winter. Smart grid add resiliency to conventional power system and make it better prepared to address emergencies like storms, earthquake and terrorist attacks. Also will allow automatic rerouting when equipment fails or outages occur. This has the effect to detect and isolate the outages and minimize the effect when they do happen.

Another benefit of Smart grid is that gives the control to the consumers by giving them the information and tools they need to make choices about the energy they use. The Smart grid will enable an unprecedented level of consumer participation. Its gives a clear picture to they see how much electricity they use, when they use it, and its costs. Therefore, this will allow them to save money by using less power when electricity is most expensive, combined with real-time pricing [5].

### 2.3.1 Self-healing

One of key features of a Smart grid is its ability of self-healing. Smart grid has the capability for fault self-prevention and self-repairing. With the increasing utilization of Wide Area Measurement System (WAMS) in power industries, by using Phasor Measurement Unit (PMU), can not only estimate the system state rapidly and precisely making it possible to monitoring voltage instability, to ascertain dynamic stability transmission power limits, but also to constitute fast protection system of wide-area stability control. Therefore the key technologies of self-healing in Smart grid contain real-time-monitoring and self-adjustment. Smart grid use an artificial intelligent, multi-agents system (MAs), which allows more effective monitoring and decision making without human intervention. The overall result is a more reliable grid that maximizes uptime and increases the efficiency and security of systems. Self-healing capabilities minimize many problems such as blackouts because they allow for continuous self-assessments that inspect, analyze, react to, and automatically respond to problems [6].

### 2.3.2 Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is one of the key components in Smart grid. An AMI comprises of systems and networks, which collects and analyzes data received from smart meters using two-way communications between user domain and utility domain, and gives intelligent management of various power-related applications and services based on that data. The implementation of AMI is widely seen as the first step in the digitalization of the electric grid control systems. In AMI systems, smart meters are regarded as the key interfaces for physical, information, and social domains of the Smart grid. AMI architecture that is integrated in a broader context of power generation, transmission, distribution, and customer using HAN, neighborhood area network (NAN), and wide area network (WAN) [7].

### 2.3.3 Demand Response in Power Consumption

Demand response is a change in the power consumption of an electric utility customer to better match the demand for power with the supply. Electric energy is difficult to be store on a large scale. Therefore utilities have traditionally matched demand and supply by throttling the production rate of their power plants, taking generating units on or off line, or importing power from other utilities. Nevertheless on the supply side there are limits to what can be achieved, because some generating units can take a long time to come up to full power, some units may be very expensive to operate, and demand can at times be greater than the capacity of all the available power plants put together. The primary purpose of demand response is to adjust the demand for power instead of adjusting the supply.

Utilities can give many options to their customers for demand requests, such including simple off-peak metering, in which power is cheaper at certain times of the day, and smart metering, in which explicit requests or changes in price can be communicated to customers. Customers must adjust power demand by postponing some tasks that require large amounts of electric power, or to pay a higher price for their electricity [8].

Demand response offers a cheaper and more reliable solution on handling peak load hours than adding a new power plant. Both customers and utilities benefit from this solution. Customers will shift their load to off-peak hours where electricity is cheaper and utilities will save money by not having putting more generators to produce energy for handling peak load.

### 2.3.4 Home Area Network (HAN)

A home area network is a dedicated network connecting devices in the home such as displays, load control devices and ultimately "smart appliances" seamlessly into the overall smart metering system. It also contains software applications to monitor and control these networks. It connects to the utility's electric meter and monitors energy usage so the home owner can see what energy is being used and where. The HAN also provides a way to conveniently turn appliances off and on. The utility companies are beginning to be able to better manage the energy demand and perform load balancing more efficiently. Also both utilities and consumers will be saving money by this way [9].

### 2.3.5 Energy Storage Units (ESU)

Research and development in energy conversion and storage are becoming increasingly important due to the increasing energy demand for economic and social development and it is fast becoming one of the principal challenges facing the energy sector. Energy storage can be defined as simply storing energy generated during periods of low demand to use during periods of high demand. The storage forms involve chemical, biological, electrochemical, electrical, mechanical, thermal and fuel conservation storage etc [10].

Current energy system works with large power stations that constantly generate power. Depending on the demand, the supplier can supply less or more power. It doesn't work like that with sustainable energy, where the supply is dependent on climatological conditions and not on demand. The good thing about sustainable energy is that its sources are free and inexhaustible. But at night time, when the demand for power peaks, the sun is gone. And wind turbines don't move without wind. At the moment, large power stations can step in when the solar or wind supply is not sufficient. But as we begin to use more sustainable energy, this will become increasingly difficult. This means that we need forms of energy storage that can absorb sustainable energy during periods of low demand and make it available again during peak moments.

Energy Storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent renewable energy. Locally, it can improve the management of distribution networks, reducing costs and improving efficiency. In this way, it can ease the market introduction of renewable, accelerate the decarbonisation of the electricity grid, improve the security and efficiency of electricity transmission and distribution, stabilize market prices for electricity, while also ensuring a higher security of energy supply.

### 2.3.6 Smart Charging in Electric Vehicles (EVs)

Smart charging is where the time and rate at which the car is charged is varied in response to signals from the grid operator or electricity market. Smart grid technology provides the means to match up supply and demand at a local level. A critical part of a Smart grid is to have forms of flexibility in the energy system. The millions of Electric Vehicles (EVs) predicted over the next few years offer flexible demand that could be optimised in order to deliver the smarter outcomes for electricity network operators and consumers.

Using 'smart' chargepoints able to transmit and receive data and respond to external signals to control levels of charging will be crucial to managing the impact on the electricity network. EV charging will mainly be at home or in the workplace, spreading this further to other locations and different times of day will help manage the impact on the network. Far from being a risk to electricity network security, with the right smart chargers and optimisation, EVs can provide new energy services and opportunities for consumers to benefit from. Third party aggregators and electricity suppliers are already looking to EVs as an important source of flexibility within a Smart grid [11].

### 2.3.7 Distributed Generation (DG)

Distributed Generation (DG) source is an interesting technology studied over several decades. DG is defined as an electric power generation source connected directly to the distribution network or on the customer side. DG system consists of several small scale generation units located near customer loads and is of smaller than large centralized power plants and has fewer customers but there is not defined limit on the minimum power generated, it varies depending upon the technology being used to generate electricity. DG integrated with Smart grid will allow utilities to move electricity around the system as efficiently and economically as possible. It will also allow the homeowners and business people to use electricity as economically as possible. They will have the choice and flexibility to manage their electrical use while minimizing costs. The basic purpose of this integrated system is to add monitoring, analysis, control, and communication capabilities to the national electrical delivery system to maximize the throughput of the system while reducing the energy consumption.

Sitting between microgeneration and utility-scale "central station" generation are microgrids. Microgrids are modern, localized, small-scale grids, contrary to the traditional, centralized electricity grid (macrogrid). Microgrids can disconnect from the centralized grid and operate autonomously, strengthen grid resilience, and help mitigate grid disturbances. Microgrids increasingly employ a mixture of different distributed energy resources, such as solar hybrid power systems, which reduce the amount of emitted carbon significantly.

# Chapter 3

# 3. Proposed Energy Management System and Explanation of Datasets Used

In this Chapter, in a grid offering energy at invariable price will be proposed a solution for Energy Management Systems consisting of EV as Energy Storage Units. In section 3.1, will be explained the datasets that were used to test the proposed model. The basic conception of the proposed design will be introduced in section 3.2. In this section the framework of proposed design will be demonstrated. In the end, in section 3.3 will be presented the working states of the Energy Storage Unit with many examples.

## 3.1 Datasets Used

Datasets are collected from ISO New England Inc, freely available online [12]. It is an independent, non-profit Regional Transmission Organization (RTO), serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont. ISO-NE oversees the operation of New England's bulk electric power system and transmission lines, generated and transmitted by its member utilities, as well as Hydro-Québec, NB Power, the New York Power Authority and utilities in New York state, when the need arises. ISO-NE is responsible for reliably operating New England's 32,000 megawatts [MW] bulk electric power generation and transmission system. One of its major duties is to provide tariffs for the prices, terms, and conditions of the energy supply in New England [13].

The datasets for proposed designed are real-time hourly grid load and electricity price for the year 2011. The datasets were collected and archived from power stations. Therefore, the simulation based on these datasets is promising and convincing.

The proposed design is focused on real time hourly price and grid load, which are critical parameters for the research on Energy Management System. Real time data are very important for effective and efficient strategies regarding the electricity market and when referring to a Smart grid.

# 3.2 Proposed Design Structure

## 3.2.1 Power Smart Pricing

The proposed Energy Management System for end customers will have two main goals. First is to reduce monthly bill for end users and second is to help the grid to avoid overload or blackout. To archive these important goals must takes advantage of the Smart Meter being integrated between the distribution grid and end consumers. The Smart Meter has the ability of two-way communication between the power suppliers and the end consumers. Furthermore, it informs end consumer with real time price and grid load from power supplier. The framework of the proposed design is illustrated in Figure 3-1.
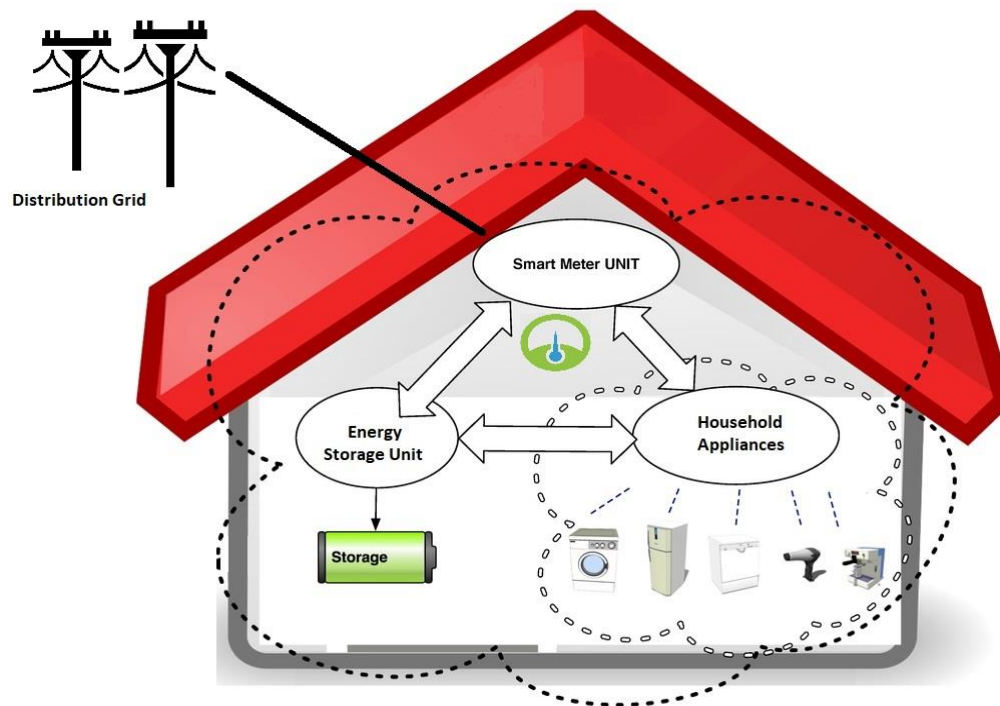


**Figure 3-1: Proposed Smart Home with Energy Storage Unit (ESU)**

Figure 3-1 shows a modernized household equipped with Smart Meter and Energy Storage Unit (ESU), along with all other household appliances such as washing machine, air-conditioning, television, etc. The house in Figure 3-1 is physically connected to the distribution grid. The owner of the house pays for the power consumption on a monthly basis in the conventional way. Nevertheless, the different here is Power Smart Pricing, which applied in proposed design. Power Smart Pricing indicates that the price customers pay for electricity varies from hour to hour, depending on the actual market price. The prices are set a day ahead by the hourly wholesale electricity market run by the power supplier. Power Smart Pricing has been applied by a few power suppliers such as ISO New England and Independent System Operator.

### 3.2.2 Smart Meter in the Proposed Design

The Smart Meter is the core of the proposed design which plays the most important role. Firstly, it is responsible to maintain an interactive connection between households of end consumers and distribution grid. Consumers are able to get real time data about power price and grid load from their power suppliers through a two way communication. Every single consumer sends their hourly power consumption to the Power suppliers, which is being called household load. So that power supplier gets informed about household Load of every single family on a real time basis. After all these information being collected and organized, power supplier will get an accurate grid load for some certain area of its coverage. This information will be helpful in every aspect of grid management and price determination.

Secondly, Smart Meter is responsible for management of power input incoming from the distribution grid and redirecting power to household appliances and EVs as Energy Storage Unit (ESU).

Furthermore, Smart Meter is in charge of controlling two switches. The first switch controls when to draw power from the grid and is called "Grid Switch". The other switch controls when the ESU charge or release power and is called "ESU Switch".

In figure 3-1, household appliances and ESU are interconnected via Smart Meter to receive power input from the distribution grid. The ESU has two basic states. First, the stage "ESU Charge", which implies that the ESU is charging itself by drawing power from distribution grid. Second, the stage "ESU Release" means that the ESU is releasing the storage power of itself to supply the household appliances.

Therefore, the "ESU Switch" is under control of Smart Meter, which is necessary to determine which state the ESU is working on. Smart Meter is also responsible for the continuous and steady power flow to household appliances and to ensure that the ESU is not charge beyond of its maximum capacity.


### 3.2.3 Energy Storage Unit in the Proposed Design

The Energy Storage Unit is the second important power component of the Proposed Design. The purpose of ESU is to store cheap energy during periods of low demand and to using it at high demand period where energy price is more expensive in order to reduce cost, save energy and reduce the overall grid load. Different forms of energy storage include: chemical, biological, electrochemical, electrical, mechanical, thermal and fuel conservation storage etc.

Most companies offer solutions consisting of Lithium-Ion batteries. In real word, there is some kind of problems. First, there is extra cost associated with the maintenance of storage unit. Another problem is that the storage device loses power storage capacity over the time. In proposed design, to simplify the problem, it is assume that the maintenance cost is zero and ESU is an EV that will maintain its maximum storage capacity regardless of time.

As already mentioned in Section 3.2.2, ESU has states of "Charge" and "Release" which are under control of the proposed design. In the real world, only two states are not enough in considering the

complexity of the situation. Because of this we allowed our system to work on a wide range of states such as "Charge 35%", which means ESU is supposed to charge 35% of its designed capacity or "Release 67%", which means ESU is supposed to release 67% of its designed capacity.

By allowing ESU to works in a more accurate way, the proposed design can fit in some more complex situation. This fact offers great potential to develop an intelligent strategy based Energy Management System. In next chapter, an intelligent strategy will be presented using a Genetic Algorithm to control the different states of ESU as to save energy and lower the total Grid Load.

# 3.3 Working States of the Proposed Design ESU

The parameters of power consumption are presented in the following way:

**PG[n]:** Power demand of entire household (including ESU and Household Appliances) in hour n from the grid.

**E[n]:** Power drawn from the grid by ESU in hour n.

**H[n]:** Power demand of household appliances in hour n.

**R[n]:** Power release to appliances by ESU in hour n.

The household power consumption meets the following Equation 3-1.

$$PG[n] = E[n] + H[n] - R[n] \tag{3-1}$$

The working states of ESU is represented as x[n], while n is the hour of a day ranges from 1 to 24. The specification of x[n] is introduced in following examples.

➢ **While x[n] > 0, ESU is in charging, so that R[n] = 0.**

**Example 1:** x[n] = 1
E[n] = 1 * H[n] = H[n]
PG[n] = E[n] + H[n] − R[n] = H[n] + H[n] − 0 = 2 * H[n]
This means that ESU is charging at 100% of the household appliances demand and power demand of household appliances is being drawn 100% from the grid.

**Example 2:**     $x[n] = 0.6$
                   $E[n] = 0.6 * H[n]$
                   $PG[n] = E[n] + H[n] - R[n] = 0.6 * H[n] + H[n] - 0 = 1.6 * H[n]$

This means that ESU is charging at 60% of the household appliances demand and power demand of household appliances is being drawn 100% from the grid.

➤ **While x[n] < 0, ESU is in charging, so that E[n] = 0.**

**Example 3:**     $x[n] = -1$
                   $R[n] = 1 * H[n] = H[n]$
                   $PG[n] = E[n] + H[n] - R[n] = 0 + H[n] - H[n] = 0$

This means that ESU is releasing to feeding 100% of the power demand of household appliances.

**Example 4:**     $x[n] = -0.6$
                   $R[n] = 0.6 * H[n]$
                   $PG[n] = E[n] + H[n] - R[n] = 0 + H[n] - 0.6 * H[n] = 0.4 * H[n]$

This means 60% of power demand of household appliances is being met by ESU and remaining 40% of the demand is being drawn from the grid.

➤ **While x[n] = 0, ESU is neither charging nor releasing, so that E[n] = 0, R[n] = 0.**

**Example 5:**     $PG[n] = E[n] + H[n] - R[n] = 0 + H[n] - 0 = H[n]$

This means that ESU is not working at all and 100% power demand of household appliances is being drawn from the grid.

For example, value "0.5" implies Energy Storage Unit is charging itself until half of amount of current power load has being stored. In this case, total power demand to distribution grid would be Equation 3-2.

Power Load = (1 + 0.5) * Original Power Load = 1.5 * Original Power Load                     (3-2)

Another example would be when value equals to "-0.3", which means Energy Storage Unit is releasing itself to supply 30% of current power load. In this case, total power demand to distribution grid would be Equation 3-3.

Power Load = (1-0.3) * Original Power Load = 0.7 * Original Power Load                     (3-3)

For example, in a specific household the total power requirement of the household appliances is 1000 Wh. Not all the appliances are being used at any given time. Let us suppose from 9:00 PM to 10:00 PM the total power demand of appliances is 800 Wh and x[n] is 0.6 at the same time. Then from Equation it is known that PG[n] = 1.6 * H[n], which implies that 100% of the power demand of household is been drawn from the grid and in addition to that ESU is charging at the rate of 60% of H[n] which is 480 Wh. The total demand to the grid is 1280 Wh.

Moreover, the same parameters and equations are used by the comparable EMS with fuzzy logic, implemented by thesis [17].

In Chapter 4 the proposed Genetic Algorithm System is discussed and shown in full detail.

# Chapter 4

# 4. Genetic Algorithm Based Strategy in Energy Management System Design

       In this Chapter, an intelligent Energy Management System based on genetic algorithm is proposed. Section 4.1 gives background information of genetic algorithm. In section 4.2 will be presented the framework of proposed design. In the end, in section 4.3 will be discussed the details of proposed genetic algorithm strategy.

## 4.1 Background Information of Genetic Algorithm

### 4.1.1 Origins of Genetic Algorithm

       Genetic Algorithm (GA) is adaptive heuristic search algorithm that belong to the larger part of evolutionary algorithms. Genetic algorithm is based on the ideas of natural selection and genetics. Also is a subset of a much larger branch of computation known as Evolutionary Computation. This is an intelligent exploitation of random search provided with historical data to direct the search into the region of better performance in solution space**.** It is commonly used to generate high-quality solutions for optimization problems and search problems. The basic techniques of the GA are designed to simulate processes in natural systems necessary for evolution, especially those follow the principles first laid down by Charles Darwin of "survival of the fittest". GA was developed by John Holland and his students and colleagues at the University of Michigan, most notably David E. Goldberg and has since been tried on various optimization problems with a high degree of success [14].

## 4.1.2 Basic Concepts

- **Chromosome**

    In genetic algorithm, a chromosome is a set of parameters which define a proposed solution to the problem that the genetic algorithm is trying to solve. The set of all solutions is known as the population. The chromosome is often represented as a string of either real numbers or binary numbers such as 0 and 1.

- **Encoding**

    Encoding is a way of representing the problem as a chromosome, and it is a major challenge in GA. The most common approach is binary encoding. It is a string sequence of 0 and 1, where the digit at each position represents the value of some aspect of the solution. Also, the digits represent the genes that make up a chromosome.

| Chromosome A | 10110010110010101110101 |
|---|---|
| Chromosome B | 11111110000011000011111 |

**Figure 4-1: Example of chromosomes with binary encoding**

    There are many other ways of encoding such as permutation encoding, value encoding and tree encoding. Encoding method is dependent on the type of the problem.

- **Search Space**

    Search space is a set of chromosomes. Chromosomes are representing all possible solutions for given problem. Each solution has a fitness score depending on the problem. The purpose of genetic algorithm is to find the solution with the optimal fitness score in the search space.

- **Fitness Function**

    Fitness Function is a particular type of objective function which evaluate how close a given design solution is to the optimum solution of the desired problem. It determines how fit a solution is. Fitness function is quite different from one type of problem to another. Furthermore, it

is a function that it quantifies the optimality of a solution so that a particular solution may be ranked against all the other solutions [15].

- **Selection**

Selection is the process that a portion of the existing chromosomes (solutions) population is selected to breed a new generation. Each chromosome is chosen by fitness and there is higher probability for the chromosome of higher fitness to be picked for reproducing. The most selection methods are based in the higher fitness score of solution such as roulette wheel selection, tournament selection, rank selection, steady state selection and some others.

- **Crossover**

Crossover is a genetic operator analogous to reproduction and biological crossover that used to combine the genetic information of two parents (chromosomes) to generate new offspring. It is one way to stochastically generate new solutions from existing population, by combine genes from each pair of parents to create a new offspring. There are many methods of crossover operators. One simple method is One-Point crossover. One crossover point is put randomly on both chromosomes. The genes right of that point, swapped between parents and the result of this, is two new offspring. Other methods of crossover are two point, uniform, arithmetic and heuristic [16].

- **Mutation**

Mutation is a genetic operator used to maintain and introduce diversity in the genetic population from one generation to the next, to avoid the premature convergence. Mutation takes a chromosome and randomly changes one or more gene values from initial state. This can change entirely the chromosome. The purpose of mutation is to bring a better solution to the next generation. Mutation is usually applied with a low probability because if the probability is very high, the GA will turn into a random search. A common method of implementing the mutation is Flip Bit. The mutation operator chooses randomly one or more genes and inverting the value. Other methods of mutation are Boundary, Uniform, Non-Uniform, Gaussian and Shrink.

## 4.1.3 Flowchart of Genetic Algorithm

According to flowchart of genetic algorithm shown in Figure 4-2, genetic algorithm is executed with the following steps.

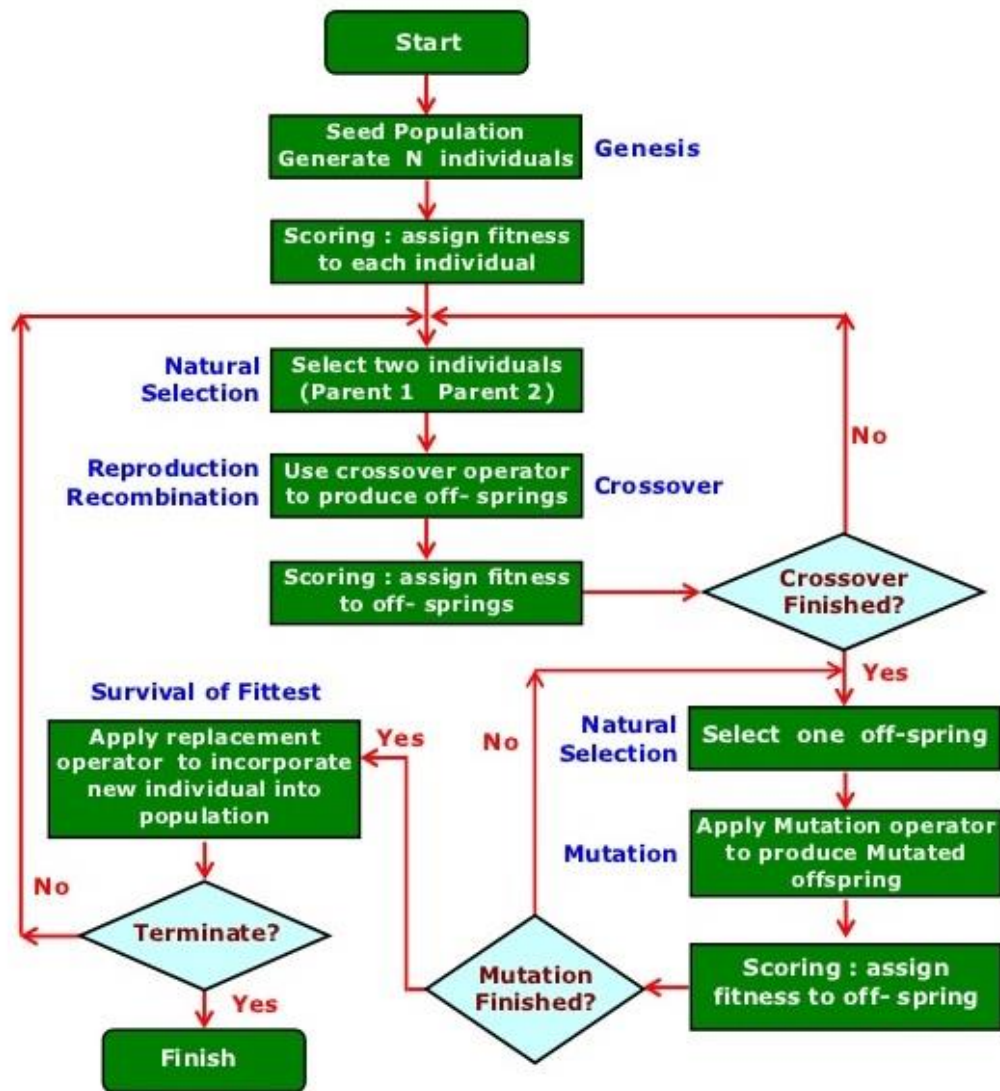**Figure 4-2: Flowchart of genetic algorithm**

❖ **Step 1:** [Start] - Random population of n chromosomes is generated.

❖ **Step 2:** [Fitness] - Fitness f(x) of each chromosome x in the population is evaluated.

❖ **Step 3:** [New population] - A new population is created by repeating following steps until the new population is equal to the original population.

- **Step 3.1:** [Selection] - Two parent chromosomes are selected from a population according to their fitness. Usually chromosome with the better fitness has a greater chance to be selected.

- **Step 3.2:** [Crossover] - Selected parent crossover their genes to produce offspring according to the crossover probability. If no crossover was performed, offspring is an exact copy of parents. In this case it is called self cloning.

- **Step 3.3:** [Mutation] - With a mutation probability, algorithm mutates new offspring at each position in chromosome.

- **Step 3.4:** [Accepting] - In this step a new offspring is placed in a new population.

❖ **Step 4:** [Test] - If the termination condition is satisfied, the algorithm will stop, and return the best solution in current population. If not, the algorithm will go back to step 2.

### 4.1.4 Advantages and Disadvantages of Genetic Algorithm

Genetic algorithm is a heuristic search and optimization technique that mimic the process of natural evolution to solve problems. It has many advantages. The concept is easy to understand. It can solve optimization problems over large space state. GA can support multi-objective optimization. Also it uses payoff information instead of derivatives. Unlike traditional artificial intelligence (AI), GA does not break on slight change in input or presence of noise.

However, there are some drawbacks of genetic algorithm. GA does not guarantee that it will find the most optimal solution (global optimum) to the defined problem in all cases. Like other AI techniques, GA is not always the best about the time of execution.

## 4.2 Proposed Strategy Based on Genetic Algorithm

### 4.2.1 Framework of Proposed Genetic Algorithm Model

Input of grid load and input of power price are to be sent to genetic algorithm to generate output signal which controls the Grid Switch and Storage Switch. The fitness function is determined to be daily cost in power consumption.
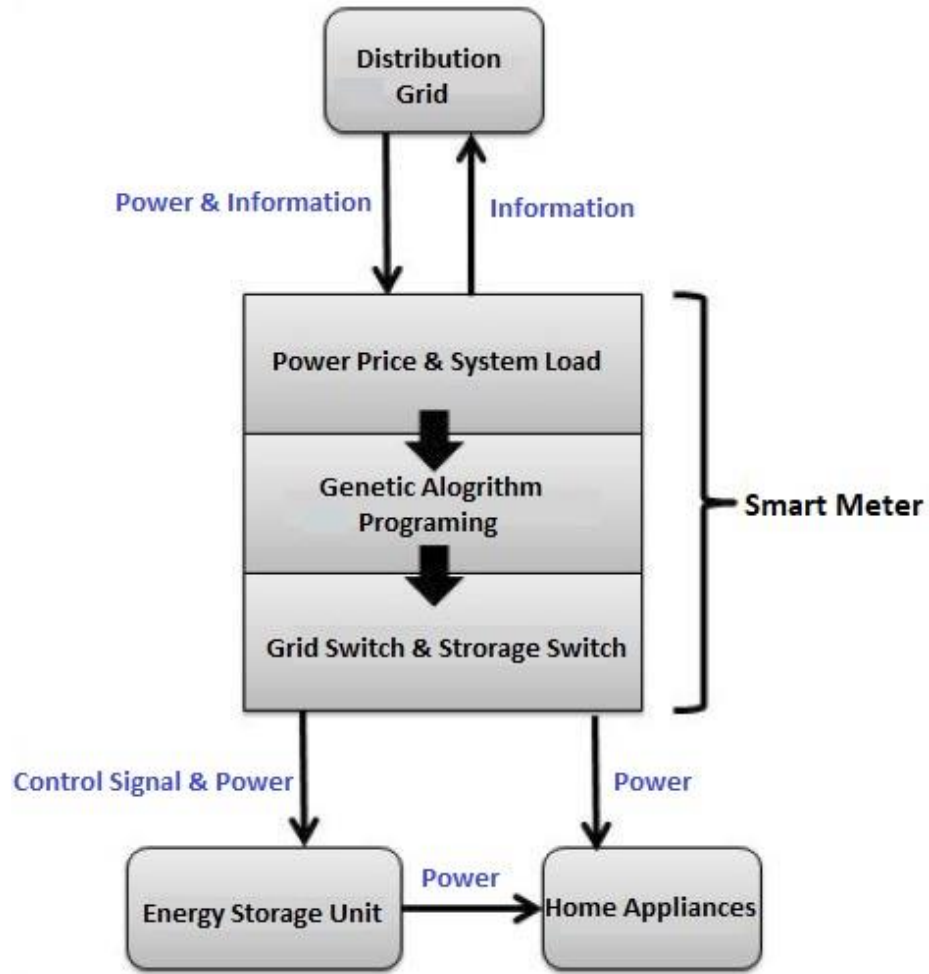
**Figure 4-3: Framework of proposed design based on genetic algorithm**

## 4.2.2 Gene Specification

In the proposed design genes are the states that Energy Storage Unit is working on in each hour. The gene is defined as x(n) while the "n" implies the hour. Figure 4-4 shows the Chromosome in proposed design.



**Figure 4-4: Chromosome in proposed design**

The positive value means that Energy Storage Unit drawn power from the distribution grid to charging itself. In addition, the household appliances are also drawing power from the distribution grid. In this case, the power demand of the proposed household is higher than that of conventional household. The negative value means that ESU is releasing the stored power. In addition, the household appliances are drawing power partly or completely from power which released from ESU. In this case, the power demand of the proposed household is lower than that of conventional household. The specification of value for x(n) has been given in Section 3.3. The default setting of x(n) ranges from -1 to 1. It is defined as GA strategy.

### 4.2.3 Encoding to Chromosome

Each gene is a double vector in the interval [-1,1]. Chromosome is defined as [ x(1) x(2) x(3) x(4) x(5) x(6) x(7) x(8) x(9) x(10) x(11) x(12) x(13) x(14) x(15) x(16) x(17) x(18) x(19) x(20) x(21) x(22) x(23) x(24) ] according to Figure 4-4. For example, a typical chromosome is [0.5261 -0.6859 -0.4983 0.25901 0.2457 -0.1977 -0.9540 0.6575 -0.4475 0.8847 0.2282 0.3327 -0.4718 -0.1162 0.6654 -0.2214 0.9959 0.8576 -0.4417 -0.3357 0.7899 -0.4425 -0.5542 0.0221], which implies states of Energy Storage Unit in 24 hours of a day.

### 4.2.4 Fitness Function

The fitness function is the daily cost of the energy for household consumers and is given by the following function shown in Equation 4-1

$$f(x) = \sum_{n=1}^{24} [1 + x(n)] * L(n) * P(n) \qquad (4\text{-}1)$$

- f(x) is the fitness function.
- x(n) represents the states of Energy Storage Unit at hour n.
- L(n) is the household load at hour n.
- P(n) is the power price at hour n.

### 4.2.5 Constraints

Energy Storage Unit must store the required amount of power to meet the demand for other household appliances. This is to ensure that the ESU meets the demand and not run out of power. Consequently, in proposed design ESU charges same amount of power as it releases on a daily basis.

The constraint for GA can be presented as the following formulation shown in Equation 4-2

$$\sum_{n=1}^{24} [1 + x(n)] * L(n) = \sum_{n=1}^{24} L(n) \qquad (4\text{-}2)$$

The formulation indicates that household load after applied with GA strategy remains the same as that before applying GA strategy on a daily basis.

This formulation can be simplified to Equation 4-3.

$$\sum_{n=1}^{24} x(n) * L(n) = 0 \qquad\qquad\qquad (4\text{-}3)$$

## 4.3 Design Details of Genetic Algorithm

1. Initial population is generated randomly with the designated size. Initial population ranges from either [-1,1]. Population size is 1000.

2. Scores each member of the current population by computing the fitness value using fitness function listed in Formula 4.1. In this step, individuals that do not obey the constraint (Formula 4.3) will be given a very large value, which ensure it scores very low compared with those valid individuals who met the constraint.

3. Perform selection using stochastic uniform selection.

4. Some of the individuals in the current population that have more ability of cost saving are chosen as elite. These elite individuals are passed to the next population.

5. Perform crossover and mutation to produce offspring. Crossover function is set to be scattered and mutation function is set to be Gaussian.

6. Replaces the current population with the children to form the next generation.

7. If stop criteria is not met, go back to 2. Otherwise, result will be generated.

The best result or chromosome will be divided to 24 control signals to operate ESU daily. The fitness value associated with the best chromosome is the lowest daily cost came from genetic algorithm.

# Chapter 5

# 5. Methodology and Implementation of Genetic Algorithm in Matlab

In Chapter 5, details about the methodology and implementation of the design are presented. Section 5.1 gives background information of the simulation platform. In section 5.2, details in the development of genetic algorithm strategy based Energy Management System are presented.

## 5.1 Overview of the Matlab platform and Genetic Algorithm Toolbox

### 5.1.1 Introduction of Matlab

MATLAB (Matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

As of 2018, MATLAB has more than 3 million users worldwide, which come from various backgrounds of engineering, science, and economics.

Consequently, MATLAB is a great tool for programming and algorithm development, all phases of data analysis, from data acquisition to visualization, application and deployment. In our case extracting data from an excel document containing ISO grid's data for the year 2011.

Figure 5-1 shows the main desktop of MATLAB R2016a.
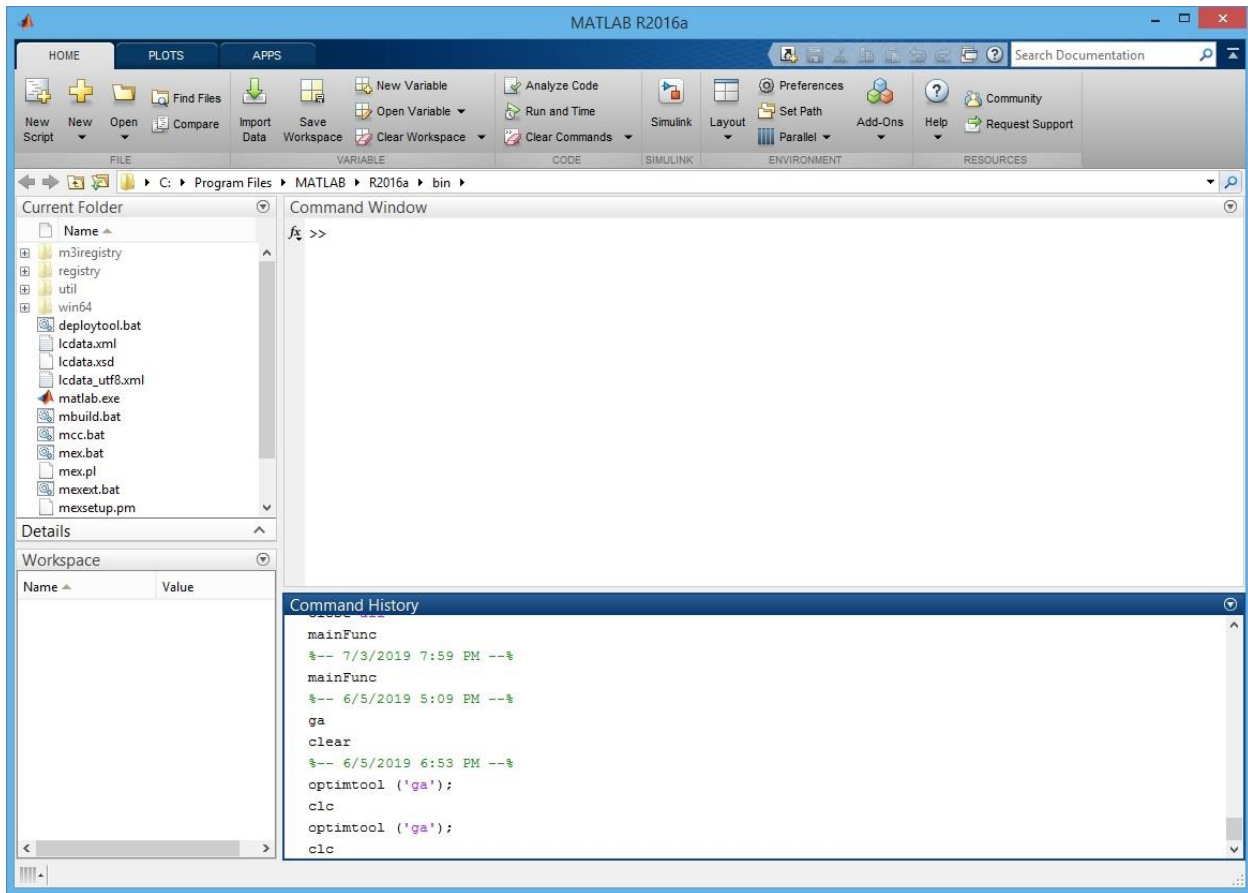
**Figure 5-1: Main desktop of MATLAB R2016a**

In the development environment of Matlab, many programming tools such as file management, variable management and application and so on are provided. On a Matlab desktop, following windows are integrated:

- The Command Window
- The Command History Window
- Workspace Browser and Array Editor
- Current Directory browser

The command window is the most important window in Matlab. Users can type commands in the command window and press enter button to run that command. In addition, m-files can be activated from the command window by typing the name of the m-file. M-files are files containing a series of Matlab commands to be executed

The command history window saves the history commands users typed in. All the history commands are listed in a descending order. By double clicking the command in this window, these commands can be activated too.

Work space and array editor display related information of current values of variables, including single value, array value and matrices value. In array editor, current values of variables can be inspected and edited directly.

The current directory browser contains information regarding other Matlab related files contained in the directory working on.

## 5.1.2 Genetic Algorithm Toolbox

Genetic Algorithm Toolbox is an integrated tool of Matlab which solves optimization problems by mimicking the principles of biological evolution, performing crossover and mutation. Figure 5-2 shows Graphical User Interface (GUI) of Genetic Algorithm Toolbox.
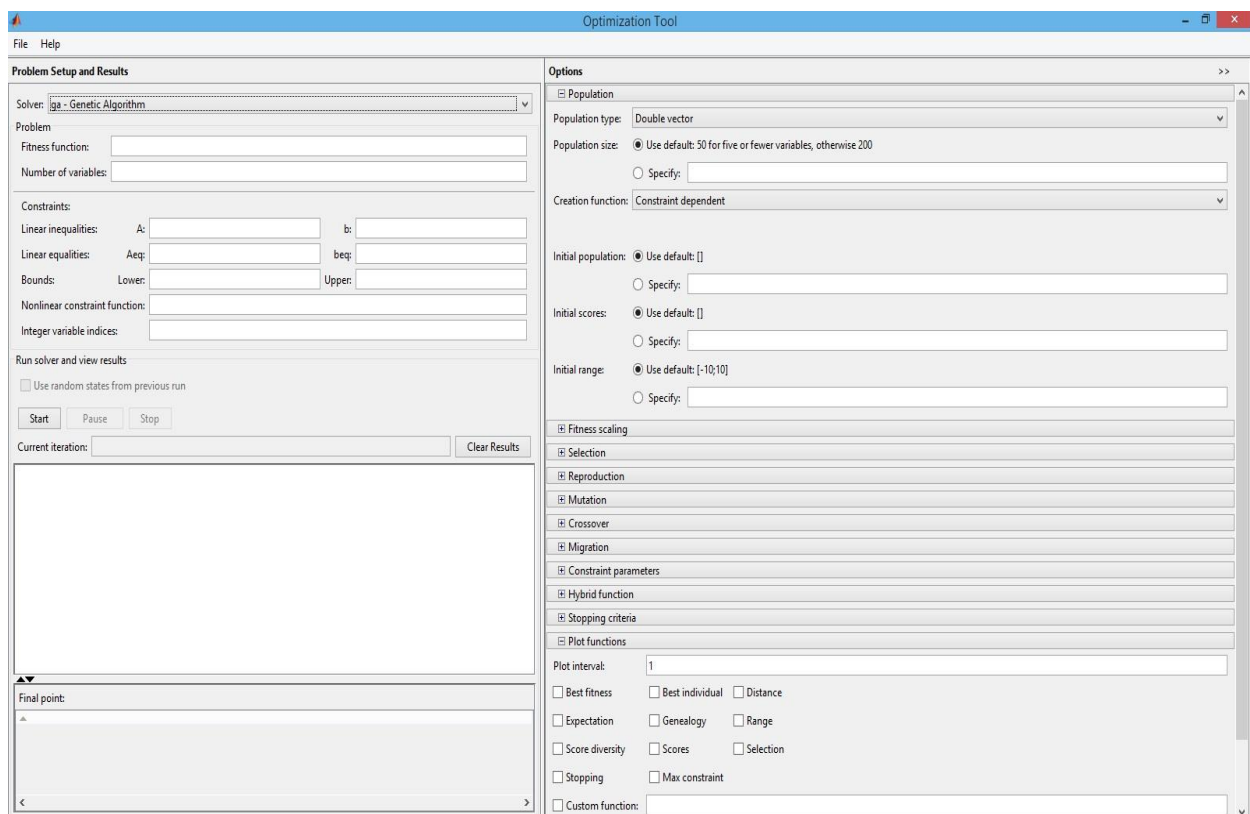


**Figure 5-2: GUI of Genetic Algorithm Toolbox**

Genetic Algorithm Toolbox provides the following configurable options.

1. **Fitness function:** Fitness function is the objective function to minimize.

2. **Number of variables:** Number of variables is the number of independent variables for the fitness function.

3. **Linear inequalities:** of the form $A*x \leq b$ are specified by the matrix $A$ and the vector $b$

4. **Linear equalities:** of the form $Aeq*x = beq$ are specified by the matrix $Aeq$ and the vector $beq$.

5. **Bounds:** are lower and upper bounds on the variables.

    - Lower: specifies lower bounds as a vector.
    - Upper: specifies upper bounds as a vector.

6. **Nonlinear constraint function:** defines the nonlinear constraints. Specify the function as an anonymous function. The nonlinear equalities are of the form $ceq = 0$ and the nonlinear inequalities are of the form $c \leq 0$.

7. **Integer variable indices:** is a vector whose entries give the components of $x$ that are integer-valued.

8. **Population Options:** Population options specify options for the population of the genetic algorithm; it includes population type, population size, creation function, initial population and initial range.
    - Population type specifies the type of the input to the fitness function. Population type can be set to be Double vector, or Bit string, or Custom.
    - Population size specifies the number of individuals in each generation.
    - Creation function specifies the function that creates the initial population. The default creation function is Uniform which creates a random initial population with a uniform distribution.
    - Initial population specifies an initial population for the genetic algorithm.
    - Initial scores specify scores for initial population.
    - Initial range specifies lower and upper bounds for the entries of the vectors in the initial population.

9. **Fitness Scaling Options:** The scaling function converts raw fitness scores returned by the fitness function to values in a range that is suitable for the selection function. Scaling function specifies the function that performs the scaling.

10. **Selection Options:** The selection function chooses parents for the next generation based on their scaled values from the fitness scaling function. Following functions are provided: Stochastic, Uniform, Roulette and Tournament.

11. **Reproduction Options:** Reproduction options determine how the genetic algorithm creates children at each new generation. Elite count specifies the number of individuals that are guaranteed to survive to the next generation. Crossover fraction specifies the fraction of individuals in the current generation which will be picked up for crossover to produce offspring for the next generation. The remaining individuals, other than elite individuals, in the next generation are produced by mutation.

12. **Mutation Options:** Mutation functions make small random changes in the individuals in the population, which provide genetic diversity and enable the GA to search a broader space. Two functions are provided: Uniform, Gaussian.

13. **Crossover Options:** Crossover combines two individuals, or parents, to form a new individual, or child, for the next generation. Following functions are provided: One point, Two point, Scattered, Intermediate and Heuristic.

14. **Migration Options:** The following three parameters control how migration occurs. Direction controls whether Migration to be unidirectional or bidirectional. Fraction controls how many individuals move between subpopulations. Interval controls how many generations pass between migrations.

15. **Constraint parameters:** refer to the nonlinear constraint solver.

16. **Hybrid Function Options:** Hybrid Function specifies another minimization function that runs after the genetic algorithm terminates.

17. **Stopping Criteria Options:** Generations specify the maximum number of iterations for which the genetic algorithm runs. Time limit specifies the maximum time in seconds the genetic algorithm runs before stopping. Fitness limit implies if the best fitness value is less than or equal to the value of Fitness limit, the algorithm stops. Stall generations determine if there is no improvement in the best fitness value for the number of generations specified by Stall generations, the algorithm stops. Stall time limit means if there is no improvement in the best fitness value for an interval of time in seconds specified by Stall time limit, the algorithm stops.

18. **Plot functions:** enable you to plot various aspects of the genetic algorithm as it is executing. Each one draws in a separate axis on the display window.
    - Plot interval: specifies the number of generations between successive updates of the plot.
    - Best fitness: plots the best function value in each generation versus iteration number.

- **Best individual:** plots the vector entries of the individual with the best fitness function value in each generation.
- **Distance:** plots the average distance between individuals at each generation.
- **Expectation:** plots the expected number of children versus the raw scores at each generation
- **Genealogy:** plots the genealogy of individuals.
- **Range:** plots the minimum, maximum, and mean fitness function values in each generation.
- **Score diversity:** plots a histogram of the scores at each generation.
- **Scores:** plots the scores of the individuals at each generation.
- **Selection:** plots a histogram of the parents. This shows you which parents are contributing to each generation.
- **Stopping:** plots stopping criteria levels.
- **Max constraint:** plots the maximum nonlinear constraint violation.

19. **Output Function Options:** History outputs the iterative history of the algorithm to a separate window. Interval specifies the number of generations between successive outputs.

20. **Level of display:** specifies the amount of information displayed in the MATLAB Command Window when you run the algorithm.

21. **Evaluate fitness and constraint functions:** specifies how functions you supply are evaluated.

## 5.2 Development of GA Model in Matlab

The proposed GA model was developed based on Genetic Algorithm Toolbox of Matlab. Figure 5-3 shows the settings for simulation of the proposed GA model. There are 24 variables represented as x[n]. n ranges from 1 to 24. The interval of x[n] is [-1, 1] in default setting which is called GA. Population size has been set to 1000. Simulation stops at generation 500.
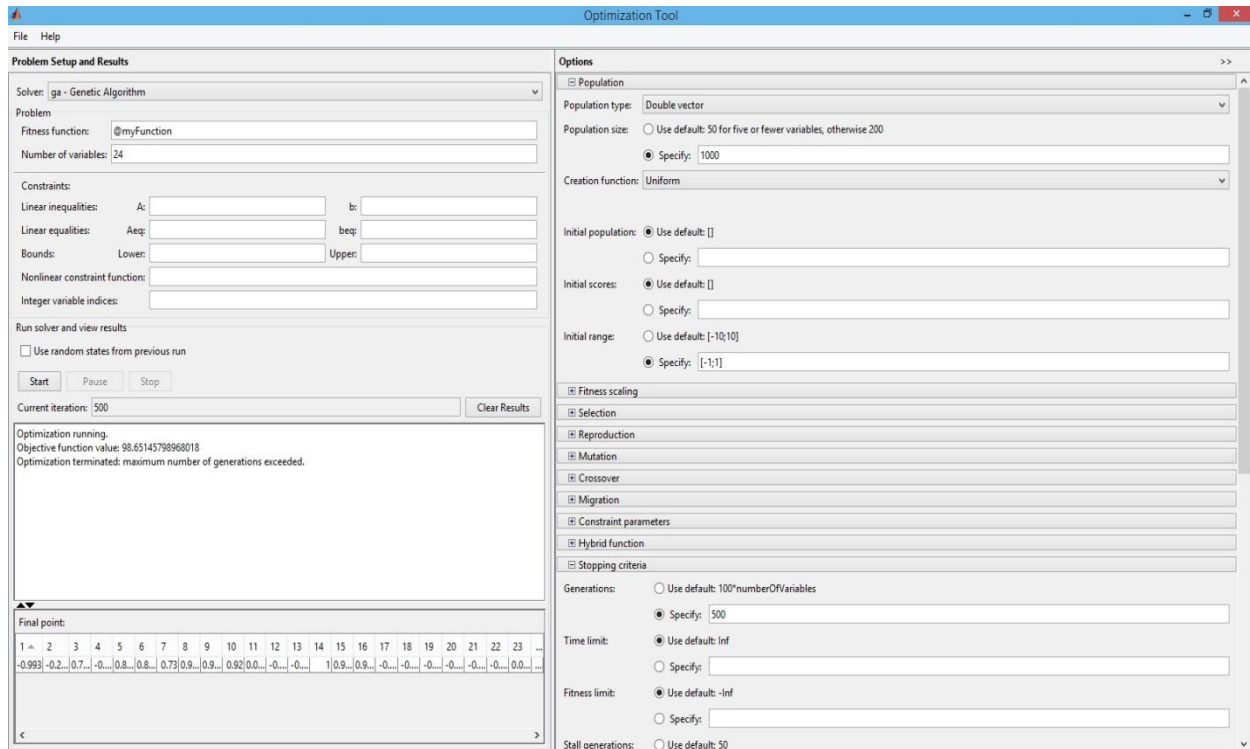
**Figure 5-3: Settings of the GA model in GA Toolbox**

Creation function is set to be Uniform. Fitness scaling function is set to be Rank. Selection function is set to be stochastic uniform. Reproduction elite count is set to be 2. Mutation function is set to be Gaussian with scale 1.0 and shrink rate 1.0. Crossover function is set to be scattered. Migration function is set to be forward.

The fitness function $Y=f(x)$ is the daily cost and has been discussed in Section 4.2.4. The pseudo code of the fitness function of GA is given below.

function $Y$ = fitnessfunc($x[n]$)                                             (Line 1)

if $x[n] < -1$  or  $x[n] > 1$                                                 (Line 2)

then return a maximum value                                                    (Line 3)

else if constraint for GA is not met                                          (Line 4)

then return a maximum value                                                    (Line 5)

else $Y$ = cost of consumption of appliances + cost for charging ESU          (Line 6)

return $Y$                                                                     (Line 7)

Line 1: defines the input of the fitness function.

Line 2 & 3: enable the fitness function to drop the invalid x[n] value away from the solution space.

Line 4 & 5: guarantees that the final minimum value is being met by the constraints of GA.

Line 6: gives the total power cost as predicted by GA for household appliances and ESU.

Line 7: returns the valid value and quit the simulation.

Figure 5-4 shows the results of simulation of GA for Jan 1, 2011. The upper part displays the best fitness after 500 generations of GA simulation which is 98.1. The lower part displays chart of the best individuals associated with best fitness. The actual values of x[n] are stored in an auto-generated array "ans" in Matlab. In command window the results are displayed. Figure 5-5 shows the results in command window.
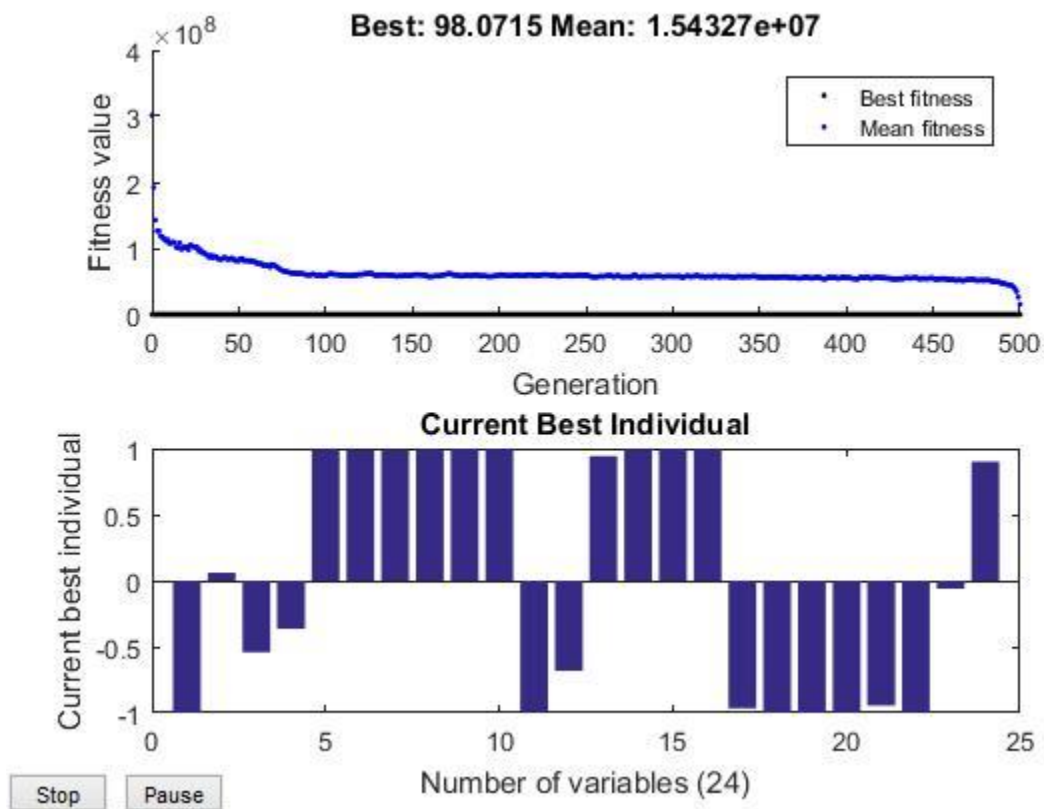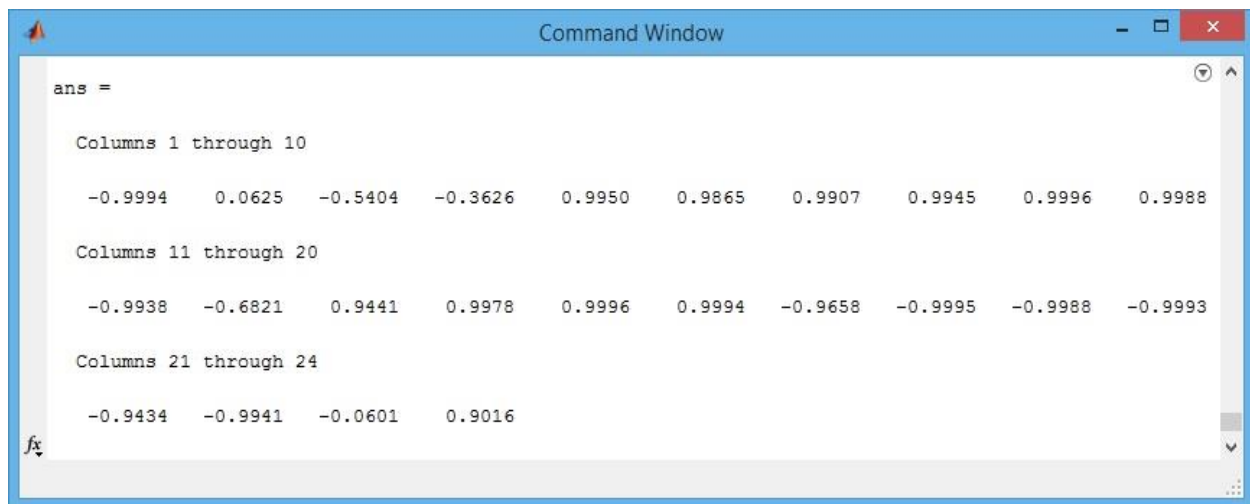


**Figure 5-4: Results of simulation of GA for Jan 1, 2011.**

**The bars in chart of the best individual, is the x[n] values, specifically the working states of ESU. The value 1 means that ESU is charging at 100% and -1 means that ESU is releasing 100% of its energy.**

**Figure 5-5: Actual value of x[n] from x[1] to x[24]**

# Chapter 6

# 6. Results and Performance Evaluation

In Chapter 6, comparison of results and performance evaluation of Genetic Algorithm strategy will be discussed. In Section 6.1, statistics of household without the use of an intelligent EMS are presented. Section 6.2 illustrates the performance of power consumption using the Genetic Algorithm approach. Also evaluates the performance of Genetic Algorithm in comparison to the performance of a typical grid. Section 6.3 compare and analyze the performance of Genetic Algorithm and Fuzzy Logic strategies. All the results in this chapter were based on measurements taken throughout the whole year and as a typical day January 1$^{st}$ was selected due to this date being in the winter, a season where high energy needs are observed due to the increased heating needs of a household.

## 6.1 Household Power Consumption without Genetic Algorithm Strategy

Figure 6.1 shows hourly power price curve of the entire grid during January 1$^{st}$, 2011. In this day, the highest hourly price was at 17:00 PM. Figure 6.2 shows the hourly grid load curve during the same day. Consequently, the highest grid load also occurred at 17:00 PM in this Figure. Figure 6.3 shows the hourly cost of power consumption curve of the same day. The Equation 6-1 shows how cost was calculated by load and price.

$$Cost = Price * Load \tag{6-1}$$

In Figure 6.3, the lowest hourly cost was at 14:00 when the most people were usually at work and the highest was at 17.00 when people have already come home from work and started household activities.
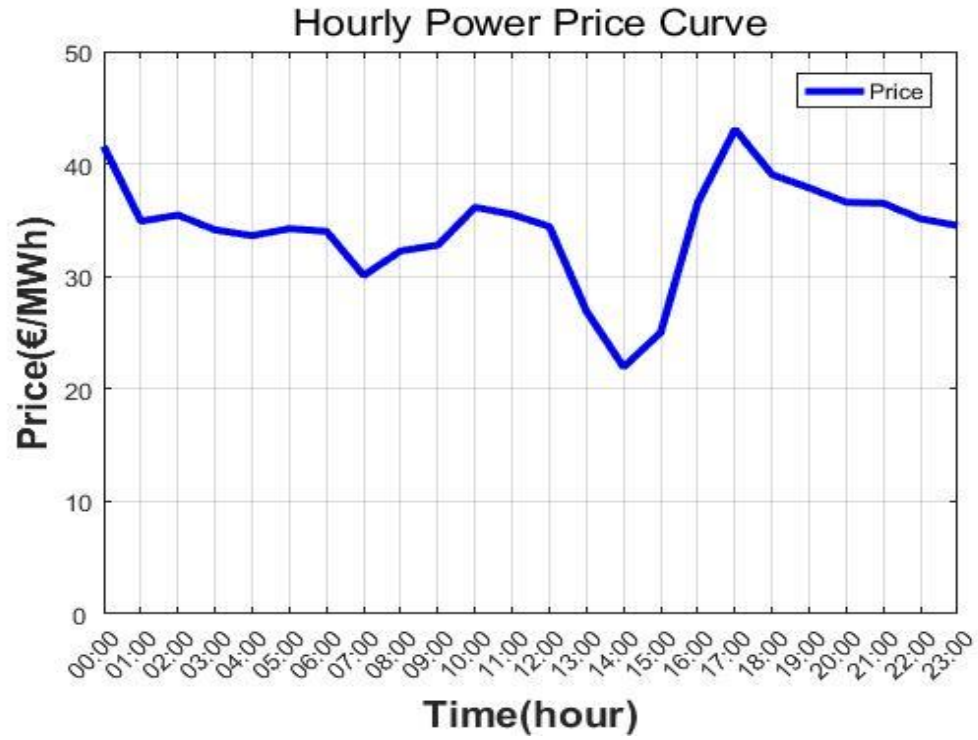
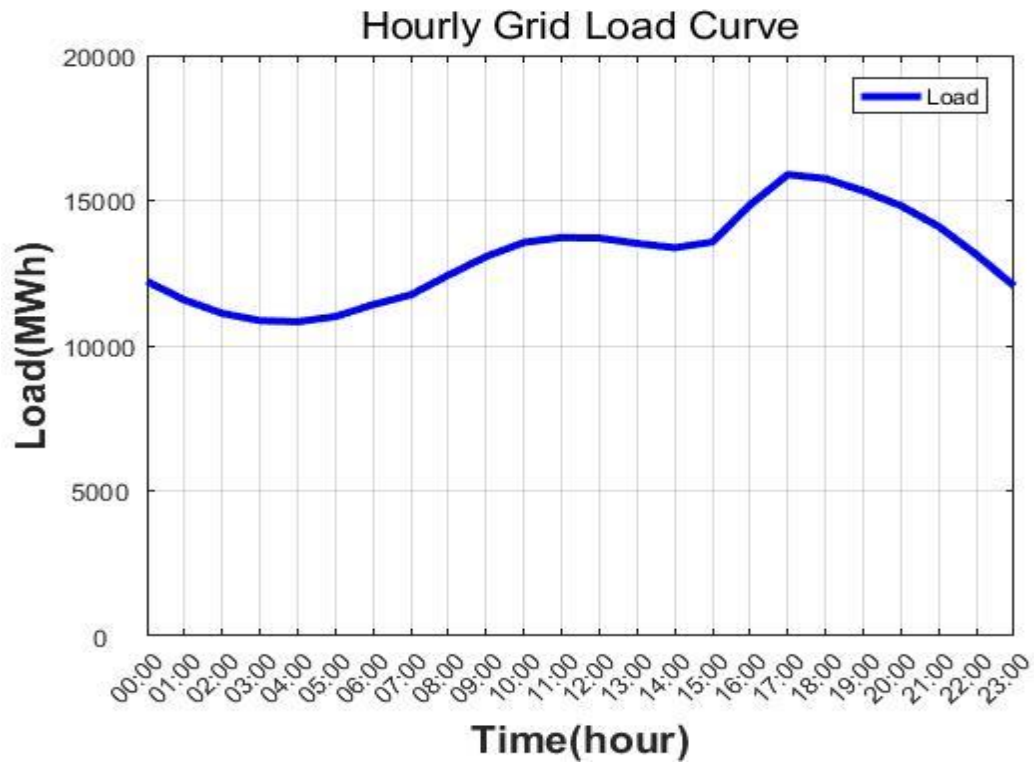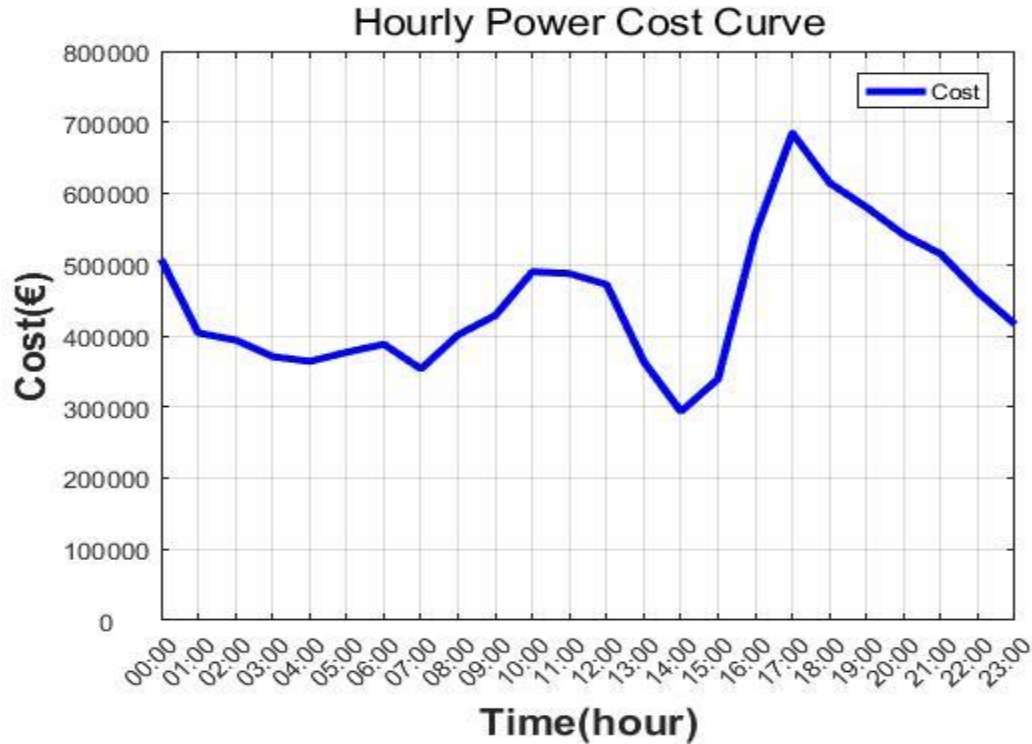**Figure 6-1: Power price curve of household on Jan/1/2011**



**Figure 6-2: Grid load curve of household on Jan/1/2011**

**Figure 6-3: Cost of power consumption curve of household on Jan/1/2011**

Figure 6.4 shows monthly grid load of year 2011. As shown the highest monthly load was in July when people have strong cooling needs due to the high temperatures and the second highest occurred in February when people have strong heating needs due to the low temperatures. The lowest monthly load appeared in April, when the climate is often moderate and people have not many cooling or heating needs.

Figure 6.5 shows monthly cost of power consumption of year 2011. It is very clear that the trend indicated by monthly cost curve is the same compared with monthly grid load curve. The months with the highest grid load are these with highest cost.
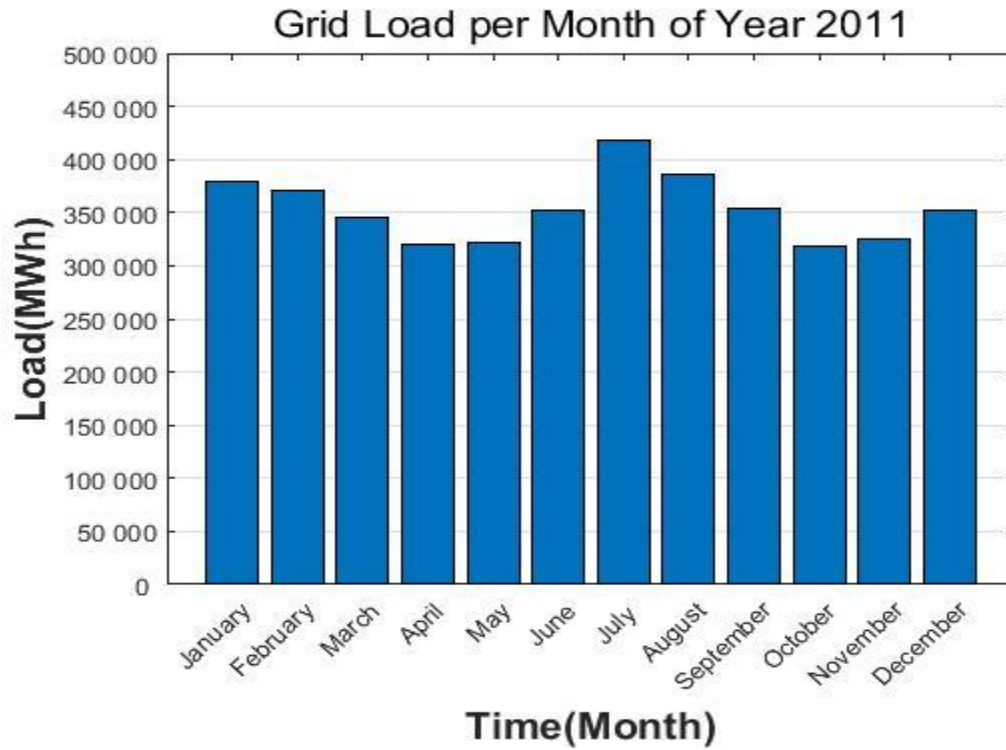
**Figure 6-4: Monthly grid load of Year 2011**
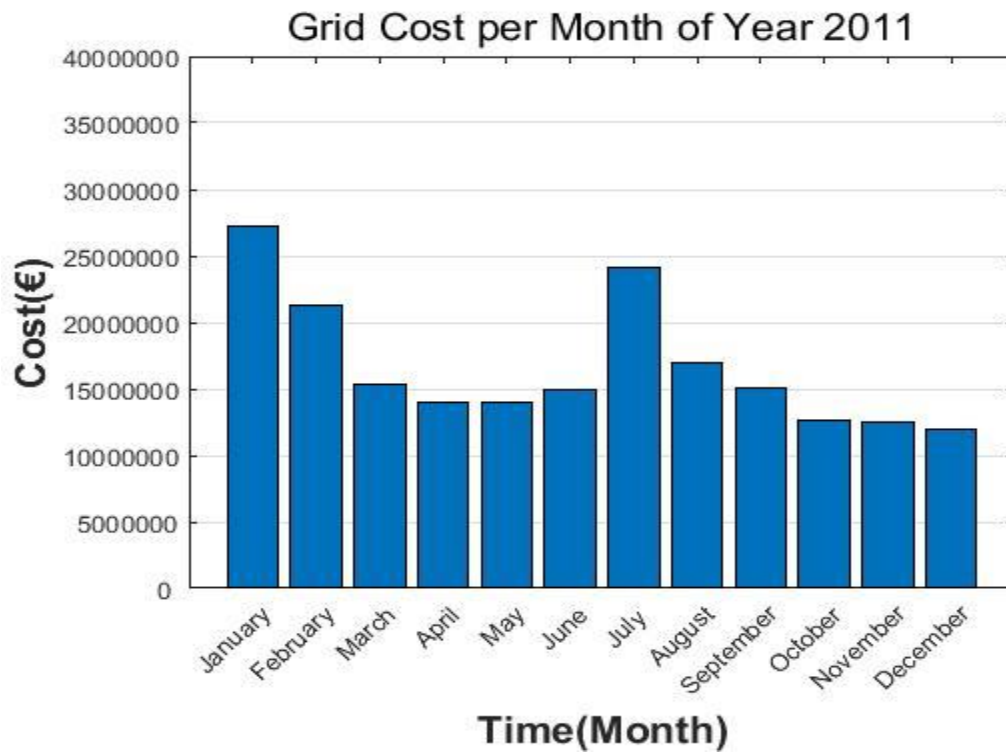


**Figure 6-5: Monthly cost of power consumption of Year 2011**

## 6.2 Power Consumption of Genetic Algorithm Strategy

Figure 6.6 shows hourly grid load curve of Genetic Algorithm compared with the corresponding one without intelligent EMS in a typical day. Figure 6.7 shows hourly cost curve of Genetic Algorithm, also compared with the corresponding one without intelligent EMS in a typical day.
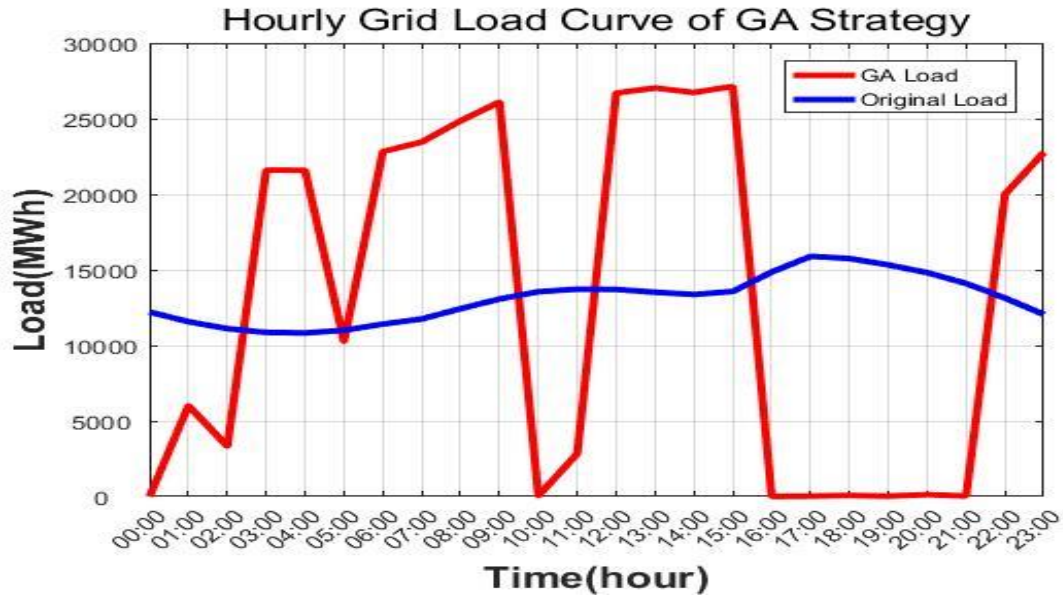


**Figure 6-6: Load curve of GA on Jan/1/2011**
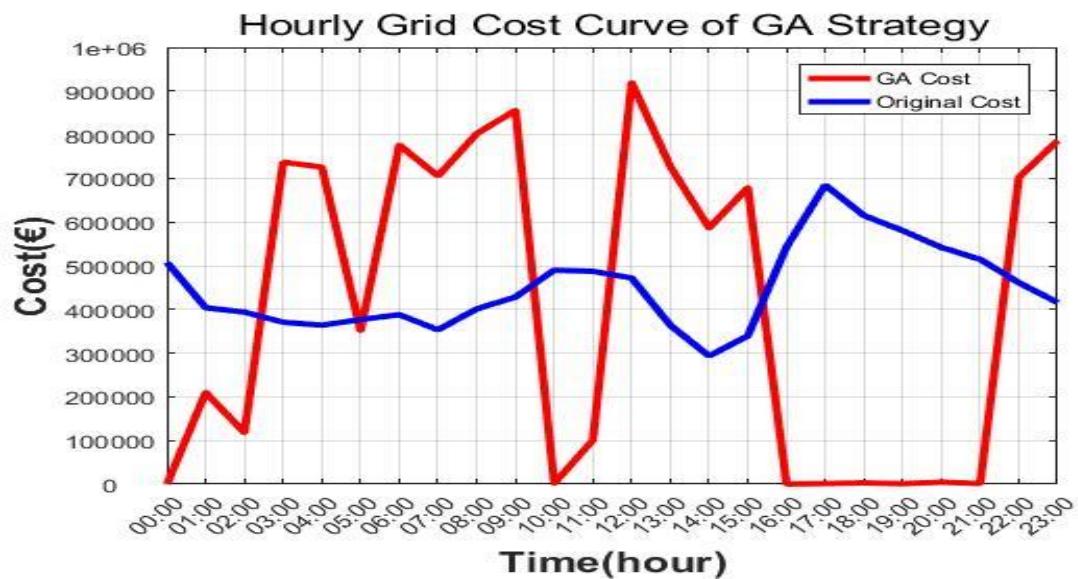


**Figure 6-7: Hourly cost of GA on Jan/1/2011**

Figure 6-8 shows the comparison of quarterly cost of GA strategy and a typical electricity grid without intelligent EMS in the year of 2011.

Table 6.1 shows quarterly saving rates of GA strategy in the year of 2011. It is shown that the saving rate of GA strategy is from 23.8% to 30.1%.
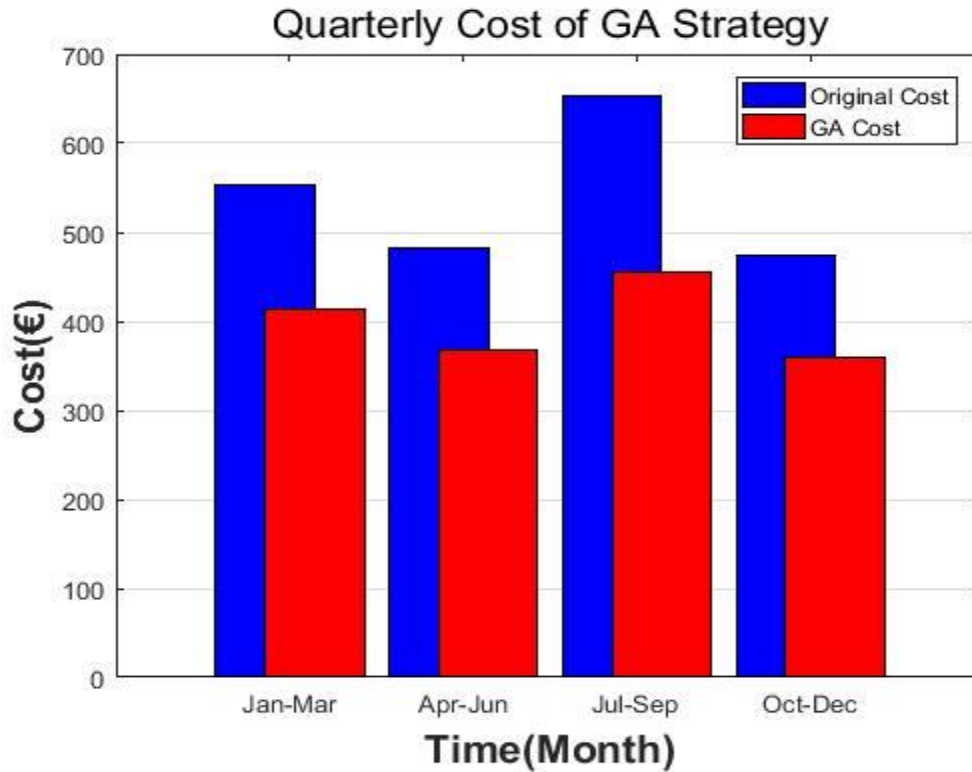


**Figure 6-8: Quarterly cost of GA strategy vs conventional grid**


**Table 6-1: Quarterly saving rates of GA strategy**

| Months | Original Cost (€) | GA Cost (€) | GA Saving |
|---|---|---|---|
| Jan - Mar | 553.2 | 414.3 | 25.1% |
| Apr - Jun | 482.1 | 367.4 | 23.8% |
| Jul - Sep | 652.3 | 455.9 | 30.1% |
| Oct - Dec | 474.7 | 358.9 | 24.4% |


From what is shown in the previous figures and Figure 6-8 and Table 6.1 it can be concluded the main goals of this research are succeed. With convert of the conventional electrical grid to a Smart grid with develop of a Genetic Algorithm strategy, succeed to reduce cost for end customers and help the grid to avoid possible overload.

# 6.3 Comparison of Saving Cost between the strategies of Genetic Algorithm and Fuzzy Logic

Figure 6-9 shows the comparison of saving rates between the strategies of GA and Fuzzy Logic, which is developed in a thesis based in the same datasets from ISO New England of year 2011 [17].

Table 6-2 shows the quarterly saving rates of two strategies with more details. It is shown that the GA strategy can achieve saving rate up to 4.6% higher than Fuzzy Logic during the April to June period.
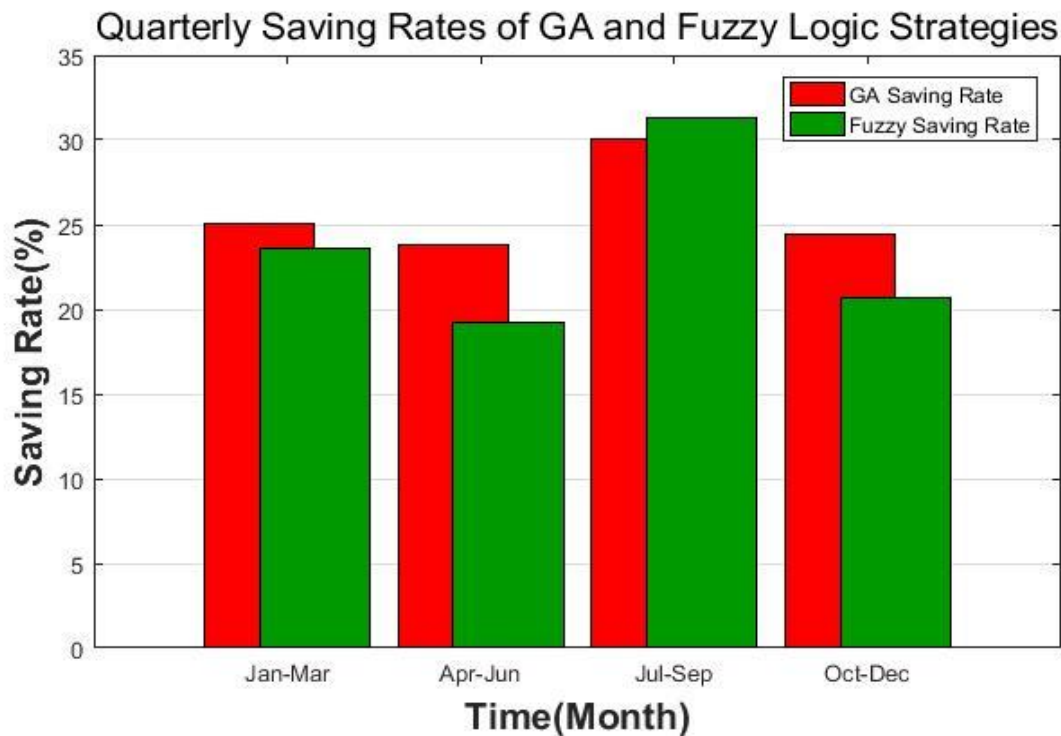


**Figure 6-9: Quarterly saving rates of GA and Fuzzy Logic Strategies**

**Table 6-2: Quarterly saving rates of GA and Fuzzy Logic Strategies**

| Months | Original Cost (€) | GA Cost (€) | Fuzzy Cost (€) | GA Saving | Fuzzy Saving |
|---|---|---|---|---|---|
| Jan - Mar | 553.2 | 414.3 | 422.1 | 25.1% | 23.6% |
| Apr - Jun | 482.1 | 367.4 | 389.3 | 23.8% | 19.2% |
| Jul - Sep | 652.3 | 455.9 | 448.1 | 30.1% | 31.3% |
| Oct - Dec | 474.7 | 358.9 | 376.4 | 24.4% | 20.7% |

From the Figure 6-9 and Table 6-2 it can be concluded that the Genetic Algorithm strategy is generally better approach for the saving cost if exclude the quarter of July September, where the saving rate of the two strategies is close with the fuzzy logic approach is little better than GA.

# Chapter 7

# 7. Conclusion and Future Work

## 7.1 Summary and Conclusion of work

In this thesis an infrastructure of household intelligent EMS was proposed. The infrastructure developed and analyzed was based on Genetic Algorithm strategy. A smart meter has been designed with the strategy of Genetic Algorithm and is responsible for charging an energy storage unit. This approach was compared to the current working system and with the strategy of Fuzzy Logic, using datasets obtained from ISO New England for the year 2011. The results that emerged, have shown that the GA strategy performs very well to achieve the main goals of cost saving for end consumers and to avoid grid overload during peak hours. The GA strategy shows better performance than the Fuzzy logic approach in most cases.

## 7.2 Future Work

There are many ways to improve this research. One way is to improve the performance of Genetic Algorithm. Many things can be change in almost all stage of methodology, like in gene specification. Can be change the range of the x(n) value, which represent the working states of Energy Storage Unit, in longer scale.

Also future work will focus on other heuristic algorithms on cost saving based on the proposed design, which may lead to best cost saving rates for end consumers and better performance in peak demand response for power suppliers.

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# Appendix A. Matlab Code

# Source Code of Genetic Algorithm Based Strategy

The program was developed on Matlab platform. The fitness function calculates the daily cost and the main function minimizes the fitness. The main function is based on the integrated Global Optimization Toolbox provided by Matlab platform.

## Source Code of Fitness Function

```
1    function Y = myFunction(x)

2    global M;
3    global Original_Cost;
4    global Simu_Hour;
5    global ESU_Cap;

6    Y = 0;
7    %%Caculate ESU Cost
8    for i=1:Simu_Hour
9    Y = M(i,2)*M(i,3)*x(i)/100000+Y;
10   end

11   %%Total Cost = ESU Cost + Appliances Cost
12   Y = Y + Original_Cost;

13   %%Dispose Invalid Inputs
14   for j = 1:Simu_Hour
15   if (x(j)>ESU_Cap||x(j)<-1)
     a. Y=99999999;
16   return
17   end
18   end

19   %%Apply Constraints
20   T = 0;
21   for i=1:Simu_Hour
22   T = M(i,3)*x(i)/10000+T;
23   end
```

```
24   if (T<0)
25   Y = Y-99999999*T;
26   end


27   return
```

# Source Code of Main Function

```
1    function [x,fval,exitflag,output,population,score] = mainFunc
2    % This is an auto generated MATLAB file from Optimization Tool.

3    clc
4    close all
5    clear all

6    global M;
7    global M2;
8    global Original_Cost;
9    global Original_Cost2;
10   global Original_Cost_Jan_Mar;
11   global Original_Cost_Apr_Jun;
12   global Original_Cost_Jul_Sep;
13   global Original_Cost_Oct_Dec;
14   global Simu_Hour;
15   global Simu_Hour2;
16   global ESU_Cap;

17   % Setting Capacity of ESU, Default Value is 1
18   ESU_Cap = 1.0;
19   Simu_Hour = 24;
20   Simu_Hour2 = 8760;      %% Case 2 (M2)

21   % Read Data From Excel File, Setting the Arrange to The Day of
22   % Simulation
23   filename = 'WorkingData2011.xls';
24   M = xlsread(filename, 1, 'A2:D25');
25   M2 = xlsread(filename, 1, 'A2:D8761');

26   % Caculate Original Cost
27   Original_Cost = 0;
28   for i=1:Simu_Hour
29   Original_Cost = M(i,2)*M(i,3)/100000+Original_Cost;
30   end

31   Original_Cost2 = 0;
32   for i=1:Simu_Hour2
```

```matlab
33    Original_Cost2 = M2(i,2)*M2(i,3)/100000+Original_Cost2;     %% Case 2 (M2)
34    end



35    %%Fitness function
36    fitnessFunction = @myFunction;
37    fitnessFunction2 = @myFunction2;     %% Case 2 (M2)


38    %%Number of Variables
39    nvars = 24;
40    nvars2 = 8760;       %% Case 2 (M2)


41    %Start with default options
42    options = gaoptimset;


43    %%Modify some parameters
44    options = gaoptimset(options,'PopInitRange' ,[-1 ; ESU_Cap ]);
45    options = gaoptimset(options,'PopulationSize' ,2000);
46    options = gaoptimset(options,'StallGenLimit' ,5000);
47    options = gaoptimset(options,'StallTimeLimit' ,2000);
48    options = gaoptimset(options,'MigrationFraction' ,0.3);
49    options = gaoptimset(options,'Generations' ,500);
50    options = gaoptimset(options,'MutationFcn' ,{ @mutationgaussian 0.1 1 });
51    options = gaoptimset(options,'Display' ,'off');
52    options = gaoptimset(options,'PlotFcns' ,{ @gaplotbestf @gaplotbestindiv
      });


53    %%Run GA
54    %%%%%%%%
55    [x2] = ga(fitnessFunction2,nvars2,options); %% Case 2 (M2)   ===> For all
      days of year 2011 Gia oles tis meres tou xronou

56    [x,fval,exitflag,output,population,score] =
      ga(fitnessFunction,nvars,options);         %%  ===> For the day January 1st




57    %%%%%% FIGURES &&&&&&
58    %%%%%%%%%%%%%%%&&&&&&&&


59    %% Figure 2 - Price-Hour (Hourly Power Price Curve)
60    Pri = M(1:24,2);
61    Xtick_hours = ['00:00';'01:00';'02:00';'03:00';'04:00';'05:00';'06:00';
62    '07:00';'08:00';'09:00';'10:00';'11:00';'12:00';'13:00';'14:00';'15:00';'1
      6:00';'17:00';'18:00';
63    '19:00';'20:00';'21:00';'22:00';'23:00'];


64    Ytick_load1a = [0 ; 10 ; 20 ; 30 ; 40 ; 50];


65    t = 0:23;
66    figure();
67    plot(t, Pri, 'b','linewidth',3);
68    xlabel('Time(hour)','fontsize',16,'fontweight','bold');
69    ylabel('Price(€/MWh)','fontsize',16,'fontweight','bold');
```

```matlab
70    title('Hourly Power Price Curve','FontWeight','demi','FontSize',16);
71    set(gca,'ygrid','on');
72    set(gca,'xgrid','on');
73    set(gca,'XLim',[0 23]);
74    set(gca,'XTick',[0:1:23]);
75    set(gca, 'XTickLabel',Xtick_hours);
76    set(gca,'YLim',[0 50]);
77    set(gca,'YTick',[0:10:50]);
78    set(gca,'YTickLabel',Ytick_load1a);
79    legend('Price');
80    ax = gca;
81    ax.XAxis.TickLabelRotation = 45;


82    %% Figure 3 - Load-Hour (Hourly Grid Load Curve)
83    Lod = M(1:24,3);

84    Ytick_load1 = [0 ; 5000 ; 10000 ; 15000 ; 20000];

85    t = 0:23;
86    figure();
87    plot(t, Lod, 'b','linewidth',3);
88    xlabel('Time(hour)','fontsize',16,'fontweight','bold');
89    ylabel('Load(MWh)','fontsize',16,'fontweight','bold');
90    title('Hourly Grid Load Curve','FontWeight','demi','FontSize',16);
91    set(gca,'ygrid','on');
92    set(gca,'xgrid','on');
93    set(gca,'XLim',[0 23]);
94    set(gca,'XTick',[0:1:23]);
95    set(gca, 'XTickLabel',Xtick_hours);
96    set(gca,'YLim',[0 20000]);
97    set(gca,'YTick',[0:5000:20000]);
98    set(gca,'YTickLabel',Ytick_load1);
99    legend('Load');
100   ax = gca;
101   ax.XAxis.TickLabelRotation = 45;


102   %% Figure 4 - Cost-Hour (Hourly Power Cost Curve)
103   %  For Cost the following formula is used: COST = LOAD*PRICE

104   Ytick_load2 = [0 ; 100000 ; 200000 ; 300000 ; 400000 ; 500000 ; 600000 ;
      700000 ; 800000];

105   Cost = Pri.*Lod;

106   figure();
107   plot(t, Cost, 'b','linewidth',3);
108   xlabel('Time(hour)','fontsize',16,'fontweight','bold');
109   ylabel('Cost(€)','fontsize',16,'fontweight','bold')
110   title('Hourly Power Cost Curve','FontWeight','demi','FontSize',16);
111   set(gca,'ygrid','on');
112   set(gca,'xgrid','on');
113   set(gca,'XLim',[0 23])
114   set(gca,'XTick',[0:1:23])
```

```matlab
115    set(gca, 'XTickLabel',Xtick_hours);
116    set(gca,'YLim',[0 800000]);
117    set(gca,'YTick',[0:100000:800000]);
118    set(gca,'YTickLabel',Ytick_load2);
119    legend('Cost');
120    ax = gca;
121    ax.XAxis.TickLabelRotation = 45;


122    %% Figure 5 - Monthly Grid Load (Grid Load per Month of Year 2011)

123    [monthly_energeia,monthly_timi] = calculate_monthly_data(M2);

124    month_days = [31,28,31,30,31,30,31,31,30,31,30,31]';
125    daily_average_load_per_month = monthly_energeia./month_days;
126    daily_average_price_per_month = (monthly_timi./month_days)/24;
127    daily_average_cost_per_month =
       daily_average_load_per_month.*daily_average_price_per_month;

128    %bar(monthly_energeia);
129    create_monthlyfigure_load(daily_average_load_per_month);


130    %% Figure 6 - Monthly Price of 2011 Bar Graph (Grid Cost per Month of Year
       2011)
131    create_monthlyfigure_cost(daily_average_cost_per_month);


132    %% Figure 7 - Hourly Load Curve of GA Strategy

133    for k = 1:length(Lod)
134    ga_load(k) = Lod(k) * (1+x(k));
135    end;

136    Ytick_load3 = [0 ; 5000 ; 10000 ; 15000 ; 20000 ; 25000 ; 30000];

137    figure();
138    plot(t, ga_load, 'color', 'r', 'linewidth',3);  hold on;
139    plot(t, Lod, 'color', 'b','linewidth',3);
140    xlabel('Time(hour)','fontsize',16,'fontweight','bold');
141    ylabel('Load(MWh)','fontsize',16,'fontweight','bold');
142    title('Hourly Grid Load Curve of GA
       Strategy','FontWeight','demi','FontSize',16);
143    legend('GA Load','Original Load' );
144    set(gca,'ygrid','on');
145    set(gca,'xgrid','on');
146    set(gca,'XLim',[0 23]);
147    set(gca,'XTick',[0:1:23]);
148    set(gca, 'XTickLabel',Xtick_hours);
149    set(gca,'YLim',[0 30000]);
150    set(gca,'YTick',[0:5000:30000]);
151    set(gca,'YTickLabel',Ytick_load3);
152    ax = gca;
153    ax.XAxis.TickLabelRotation = 45;
```

```matlab
154   %% Figure 8 - Hourly Cost Curve of GA Strategy

155   for f = 1:length(Lod)
156   ga_cost(f) = ga_load(f) * Pri(f);
157   end;

158   Ytick_cost = [0 ; 100000 ; 200000 ; 300000 ; 400000; 500000; 600000;
      700000; 800000; 900000; 1000000];

159   figure();
160   plot(t, ga_cost, 'color', 'r', 'linewidth',3);  hold on;
161   plot(t, Cost, 'color', 'b','linewidth',3);
162   xlabel('Time(hour)','fontsize',16,'fontweight','bold');
163   ylabel('Cost(€)','fontsize',16,'fontweight','bold')
164   title('Hourly Grid Cost Curve of GA
      Strategy','FontWeight','demi','FontSize',16);
165   legend('GA Cost','Original Cost' );
166   set(gca,'ygrid','on');
167   set(gca,'xgrid','on');
168   set(gca,'XLim',[0 23]);
169   set(gca,'XTick',[0:1:23]);
170   set(gca, 'XTickLabel',Xtick_hours);
171   set(gca,'YLim',[0 1000000]);
172   set(gca,'YTick',[0:100000:1000000]);
173   set(gca,'YTickLabel',Ytick_cost);
174   ax = gca;
175   ax.XAxis.TickLabelRotation = 45;




176   %% Figure 9 - Quartely Cost of GA

177   % Cost for Jan - Mar
178   % ------------------

179   Original_Cost_Jan_Mar = 0;
180   for i = 1:2160
181   Original_Cost_Jan_Mar = (M2(i,2).*M2(i,3))/100000 + Original_Cost_Jan_Mar;
182   end

183   Original_Cost_Jan_Mar;

184   pri2 = M2(1:2160,2);
185   lod2 = M2(1:2160,3);

186   for j = 1:length(lod2)
187   lod_ga(j) = lod2(j) * (1+x2(j));
188   end;

189   for f = 1:length(lod2)
190   cost_ga1(f) = lod_ga(f) * pri2(f);
191   end;
```

```
192    sum(cost_ga1);


193    % Cost for Apr - Jun
194    % ------------------

195    Original_Cost_Apr_Jun = 0;
196    for i = 2161:4344
197    Original_Cost_Apr_Jun = (M2(i,2).*M2(i,3))/100000 + Original_Cost_Apr_Jun;
198    end

199    Original_Cost_Apr_Jun;

200    pri2 = M2(2161:4344,2);
201    lod2 = M2(2161:4344,3);

202    for j = 1:length(lod2)
203    lod_ga(j) = lod2(j) * (1+x2(j));
204    end;

205    for f = 1:length(lod2)
206    cost_ga2(f) = lod_ga(f) * pri2(f);
207    end;

208    sum(cost_ga2);


209    % Cost for Jul - Sep
210    % ------------------

211    Original_Cost_Jul_Sep = 0;
212    for i = 4345:6552
213    Original_Cost_Jul_Sep = (M2(i,2).*M2(i,3))/100000 + Original_Cost_Jul_Sep;
214    end

215    Original_Cost_Jul_Sep;

216    pri2 = M2(4345:6552,2);
217    lod2 = M2(4345:6552,3);

218    for j = 1:length(lod2)
219    lod_ga(j) = lod2(j) * (1+x2(j));
220    end;

221    for f = 1:length(lod2)
222    cost_ga3(f) = lod_ga(f) * pri2(f);
223    end;

224    sum(cost_ga3);


225    % Cost for Oct - Dec
```

```matlab
226  % ------------------

227  Original_Cost_Oct_Dec = 0;
228  for i = 6553:8760
229  Original_Cost_Oct_Dec = (M2(i,2).*M2(i,3))/100000 + Original_Cost_Oct_Dec;
230  end

231  Original_Cost_Oct_Dec;

232  pri2 = M2(6553:8760,2);
233  lod2 = M2(6553:8760,3);

234  for j = 1:length(lod2)
235  lod_ga(j) = lod2(j) * (1+x2(j));
236  end;

237  for f = 1:length(lod2)
238  cost_ga4(f) = lod_ga(f) * pri2(f);
239  end;

240  sum(cost_ga4);


241  %% Figure 10 - Quarterly Cost of GA Strategy

242  Xtick_months = ['Jan-Mar';'Apr-Jun';'Jul-Sep';'Oct-Dec'];
243  figure();
244  graph = [553.2 414.3 ; 482.1 367.4 ; 652.3 455.9 ; 474.7 358.9];
245  b=bar(graph,'BarWidth',2);
246  b(1).FaceColor = 'b';
247  b(2).FaceColor = 'r';
248  legend('Original Cost','GA Cost');
249  xlabel('Time(Month)','fontsize',16,'fontweight','bold');
250  ylabel('Cost(€)','fontsize',16,'fontweight','bold');
251  title('Quarterly Cost of GA Strategy','FontWeight','demi','FontSize',16);
252  set(gca,'ygrid','on');
253  set(gca,'XLim',[0 5]);
254  set(gca,'XTick',[1:1:4]);
255  set(gca, 'XTickLabel',Xtick_months);


256  %% Figure 11 - Quarterly Saving Rates of GA and Fuzzy Logic Strategies

257  Xtick_months = ['Jan-Mar';'Apr-Jun';'Jul-Sep';'Oct-Dec'];
258  figure();
259  graph = [25.1 23.6 ; 23.8 19.2 ; 30.1 31.3 ; 24.4 20.7];
260  b=bar(graph,'BarWidth',2);
261  b(1).FaceColor = 'r';
262  b(2).FaceColor = '[0 0.6 0]';
263  legend('GA Saving Rate', 'Fuzzy Saving Rate');
264  xlabel('Time(Month)','fontsize',16,'fontweight','bold');
265  ylabel('Saving Rate(%)','fontsize',16,'fontweight','bold');
266  title('Quarterly Saving Rates of GA and Fuzzy Logic
       Strategies','FontWeight','demi','FontSize',16);
```

```
267    set(gca,'ygrid','on');
268    set(gca,'XLim',[0 5]);
269    set(gca,'XTick',[1:1:4]);
270    set(gca, 'XTickLabel',Xtick_months);
```