KOCAELI UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF ENERGY SYSTEMS ENGINEERING

MASTER’S THESIS

DEMAND SIDE MANAGEMENT – LOAD SCHEDULING OPTIMISATION IN SMART HOME BY USING MIXED INTEGER LINEAR PROGRAMMING

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LIST OF SYMBOLS AND ABBREVIATIONS

c^m	:	Electricity tariff in time interval m
$\underline{D}_{in}$	:	Lower delay limit between stages(in a number of time intervals)
$\overline{D}_{in}$	:	Upper delay limit between stages(in a number of time intervals)
E_{in}	:	Energy needed for stage n of device i, (Wh)
i	:	Index of devices
K_{in}^m	:	Power profile, describes assigned power to stage n of device i, (W)
$\underline{k}_{in}^m$	:	The lower power limit of stage n of device i, (W)
$\overline{k}_{in}^m$	:	The upper power limit of stage n of device i, (W)
m	:	Index of the time interval
N	:	Number of devices that subject to process
n	:	Index of Energy stage
$PEAK^m$	:	The peak power value during interval m, (W)
PP_i^m	:	The preference period to operate the device i
$\mathbb{R}$	:	The set of real numbers
t_{in}^m	:	Auxiliary integer variable
$\underline{T}_{in}^m$	:	Lower time limit for stage n in device i, (in intervals number)
$\overline{T}_{in}^m$	:	Upper time limit for stage n in device i, (in intervals number)
y_{in}^m	:	Auxiliary integer variable
z_{in}^m	:	Auxiliary integer variable

Abbreviations

ADC	:	Analog Digital Converter
ADSL	:	Asynchronous Digital Subscriber Line
CFL	:	Compact Fluorescent Lamp
CO_2	:	Carbon dioxide
CPP	:	Critical Peak Pricing
DC	:	Direct Current
DRP	:	Demand Response Programs
DSM	:	Demand-Side Management
ECT	:	Electricity Consumption Tax
EDGAR	:	Emission Database for Global Atmospheric Research
ENTSO	:	European Grid of Transmission System Operators
EPDK	:	Energy Market Regulatory Authority

EV	:	Electric Vehicle
EVSB	:	Enerji Verimliliği Strateji Belgesi (Energy Efficiency Strategy Document)
GBP	:	Grand British Pound Sterling
GNP	:	Gross National Product
GPRS	:	General Packet Radio Services, a technology for radio transmission of small packets of data
HEM	:	Home Energy Management
HES	:	Hall-Effect Sensor
kWh	:	kilo Watt per hour
LAN	:	Local Area Network
LED	:	Light-Emitting Diodes lamps
LM	:	Load Management
MILP	:	Mixed-Integer Linear Programming
NYC	:	New York City
OSOS	:	Otomatik Sayaç Okuma Sistemi (Automatic Meter Reading System)
PLC	:	Power Line Communication
PMI	:	Power Measurement İntegral
PQ	:	Power Quality
PSH	:	Perakende Satış Hizmetleri (Retail Services)
R&D	:	Research and Development
RTP	:	Real-Time Pricing
SEK	:	Sweden Krona
SR	:	Shunt Resistance
STDIV	:	Standard Deviation
TEİAŞ	:	Türkiye Elektrik İletim Anonim Şirketi (Turkey Electricity Transmission Corporation)
TL	:	Turkish Lira
TOU	:	Time-Of-Use Pricing
TRT	:	Turkey Radio and Television
TSE	:	Türkiye Standartlar Enstitüsü (Turkey Standards Institute)
TSSB	:	Türkiye Sanayi Strateji Belgesi (Turkey Industry Strategy Document)
UK	:	United Kingdom
USA	:	United States of America
USD	:	United States Dollar
USTDA	:	United States Trade Development Agency
VAT	:	Value-Added Tax
WAMPAC	:	Wide Area Monitoring Protection and Control
WMFS	:	Wind Monitoring and Forecasting System
WPP	:	Wind Power Plants
ZigBee	:	Standard for wireless technology designed to use low-power digital radio signals for personal area networks

KARMAŞIK TAMSAYI DOĞRUSAL PROGRAMLAMA İLE AKILLI EV UYGULAMALARINDA TALEP TARAFI YÖNETİMİ VE YÜK ZAMANLAMA OPTİMİZASYONU

ÖZET

En son teknolojiye sahip evin yanı sıra hızla büyüyen Talep Tarafı Yönetimi (TTY), hem tüketicilere hem de tedarikçilere daha fazla bilgi ve daha fazla esneklik ve kontrol sağlar. Ayrıca, iki yönlü iletişim teknolojileriyle kolaylaştırılan, tüketiciler ve servis sağlayıcılar arasında bilgi akışı, birçok akıllı uygulamaların ortaya çıkarmaya katkıda bulunmuştur. Akıllı ev teknik olarak, verimli enerji kullanımını sağlamak için, evdeki cihazların tümünü veya bir kısmını bir zaman çizelgesine göre çalıştırması anlamına gelmektedir.

Bu nedenle, ideal enerji tüketimi, yenilenebilir enerji üretimi, enerji maliyetini en aza indirgeme açısından, akıllı evlere doğru dikkat çekici bir eğilim görülmektedir. Bundan dolayı, farklı elektrik tarifeleri için, bu tezde ev cihazlarının belirli bir zaman aralığında yük zamanlama problemi ele alınmıştır.

Bu tez çalışmasında, elektrik maliyetini en aza indirgemek amacıyla, enerji ihtiyaçlarının kısıtlamaları, çalıştırma süresi ve koşulları ile kullanıcı tercihi şartlarına tabi olan bir Karmaşık Tamsayı Doğrusal Programlama (KDTP) tekniği kullanılmaktadır. Akıllı prizlerle donatılmış dört evsel cihazın matematiksel modelleri uyarlanmıştır. Buna göre, toplam enerji tüketiminin ideal yönetimini sağlamak üzere; Matlab yazılımı KTDP tekniği ile akıllı ev talep tarafı enerji yönetiminde ve yük zamanlama optimizasyonunda kullanılmıştır.

Geliştirilen teknik ile zaman çizelgeleme yöntemiyle hem elektrik faturasında hem de akıllı evin en yüksek talebinde bir düşüş görülmüştür. Önerilen programın, hem tüketicilere hem de enerji tedarikçilerine teknik ve ekonomik faydalar sağlayacağı beklenmektedir.

Anahtar Kelimeler: Akıllı Ev, Çok Zamanlı Elektrik Tarifesi, Gerçek Zamanlı Fiyatlandırma, Karmaşık Tamsayı Doğrusal Programlama (KTDP), Talep Tarafi Yönetimi (TTY).

DEMAND SIDE MANAGEMENT – LOAD SCHEDULING OPTIMISATION IN SMART HOME BY USING MIXED INTEGER LINEAR PROGRAMMING

ABSTRACT

The rapidly growing Demand Side Management (DSM) besides the state-of-art home technology supplies a greater amount of information, and far greater flexibility and control for both consumers and suppliers. Furthermore, exchanging information between consumers and service providers, facilitated by two-way communication technologies, has contributed to emerging many smart applications. A smart home under control means running its appliances according to a time schedule to coordinate the power usage required for the house efficiently.

Therefore, we see a remarkable trend towards smart homes from the standpoint of optimum energy consumption, renewable power generation, minimizing energy cost, and smart devices. Thus, the scheduling problem of home area appliance in a specific interval with a set of electricity tariffs like Time-Of-Use (ToU) pricing and dynamic pricing tariffs is discussed in this thesis.

In this paper, a Mixed Integer Linear Programming (MILP) technique - subjecting to energy requirement, duration, and user preference constraints- under several scenarios of TOU and Real-Time Pricing (RTP) tariffs has adopted with a goal of minimizing electricity cost. Models of four appliances in a smart home equipped with smart plugs and a smart meter are developed. And accordingly, optimal management of total energy consumption processed as a MILP problem using Matlab with Optimisation Toolbox which provides a solver able to address such kind of problem.

The appliance scheduling produces a decrease in the electricity bill and the peak demand of the smart home. It is observed that the proposed schedule brings technical and economic benefits to both customers and providers in the context of the DSM.

Keywords: Smart Home, TOU Tariff, Real-Time Pricing (RTP), Mixed Integer Linear Programming (MILP), Demand Side Management (DSM).

INTRODUCTION

Energy is on its way to becoming the most important factor driving economic, political and social balances in the world. In addition to the use of electricity in daily life, the use of electrical machinery and robots in the developed industries is increasing. Any person, community, institution, or state in our world that is nearly without exceptions related to an energy source; The whole cycle from natural production opportunities to the final consumer has become an important explorable issue. The four main processes that make up the electrical energy cycle are production, transmission, distribution, and consumption [2].

The electricity amount that circulating through these four processes and the correct use of systems are very important criteria. However, the tendency to increase profits and efficiency in production obstructs high investments in the electrical system devices. Less expensive, more efficient solutions are preferred. The trigger of many transitions from past traditional to current energy production and consumption was the Oil Crisis in1973 which indirectly caused the idea of Demand Side Management (DSM).

The concept of DSM first appeared in the 1970s, and the first examples were implemented in homes. The studies focused on the production, transmission and distribution parts of power systems before DSM concepts had been shifted to the consumption section, and it had been understood that the demand side can play an important role in power systems optimization [2].

In the old approach, when the power system is optimized, demand is considered as an uncontrollable factor and the whole system is directed to meet demand; capacities were kept high against unpredictable demand amounts. Then it was realized that demand could also be included in Research and Development (R&D) studies; hence when the demand side participated as an actor in this play, the efficiency of managing power systems has been increased. The control applied to the demand side in the DSM approach is not as strict as control applied to production.

Within the consumer demand restrictions, it is attempted to equalize the consumption along specific periods (smooth demand curve) or to reduce daily power consumption.

Liberalization in electricity markets has led to appearing complex and advanced systems. The time of consumption affects the electricity costs as well as prices, and that necessitates scheduling study that takes the price variable into account. In the last 20-30 years, short-term production planning and scheduling have gained more importance. In particular, electricity consumption was part of the operational scheduling problems, especially when energy consumption in industrial production was a strategy to focus on.

Nowadays, with the developments in mathematical programming and information technologies, well-formulated mathematical models provide the industry with an opportunity to combine energy management and production planning together. Thus, efficient and sustainable systems can be created [3].

When the current electrical system technologies which introduced and required by DSM programs, are listed in chronological order, firstly the Multi-Time Tariffs and Smart Meters come out. In the beginning, only smart meters with consumption time data have been developed and have gained features such as remote control and communication. These developments have brought smart grids wholly. Smart grids, which became increasingly widespread in recent years, have a large share in DSM development and increase; this means that the smart systems enable bidirectional communication between producer and consumers, thus enabling more efficient participation from the demand side.

In Turkey since the 2000s, the use of multi-time tariff was offered to consumers as an option; accordingly, smart meters are being used [4]. As a first step toward DSM programs implementation, the end-users should be included by increasing their transitions to multi-time tariffs. In addition, the prepared DSM programs should be national, and compatible with the production-consumption structure of this country. Therefore, in a DSM study carried out in our country, it would be appropriate to demonstrate an approach towards eliminating the smart grid deficiency.

Electricity supply is effective if demand is balanced. The main purpose of DSM for load management is to reduce grid instability. Make improvements in accordance with this purpose, brings cost reduction along with. In this thesis, such DSM approach will be used. Questions about how to organize demand and which demand scheduler are compatible with every consumer - without changing total electricity consumption and without affecting their welfare lever or business plans - will have good answers in our study. Giving priority to the utility and residential section to work on is reasonable, because of the limited DSM applications and the insufficient consciousness towards this approach. The fact that the use of multi-time tariffs in our country is more widespread in industrial consumers also confirms this.

The aim of such studies is to eliminate the challenges to achieve the DSM program when two-way digital communication in the electrical grid is not possible. With smart concepts and state-of-art applications, it is intended to overcome the lack of communication in the grid [5].

In order to meet the electricity demand and scheduling of industrial production process, production technological sequences and plans are seen as constraints; this feature increases our work reality. Another point that should be considered when carrying out load management is the comprehensive holistic approach. Load balancing can be done for a single consumer; but since the main purpose of this approach is to eliminate grid instability, the better to implement load management for a large group of consumers at once. The problem of managing the burden of groups of multiple consumers can be seen as a game. In the literature, the use of game theory in the implementation of DSM programs is new as well as the growing situation.

On the other hand, Load Management (LM) programs, which are modeled by the game approach, mostly have smart electrical systems, so it is possible to have bidirectional communication between power producers and consumers. In recent years, smart grid technologies have been guiding the power optimization studies that the demand side has participated in. However, there is no bidirectional communication infrastructure in our country, it is only possible to solve this deficiency by time-dependent tariffs and appropriate mathematical models. By filling up the smart system deficiency gap in our country, we hope to keep up with the world and not lag behind in the DSM field.

In the next section of this study, literature researches and optimization studies involvement of electrical systems have been explained. In the third chapter, the DSM approach with all its aspects in electrical energy and particularly our country situation has been explained. Then the smart electrical systems are explained in more detail. Finally, all DSM types and methods used in the past were classified and sorted.

1. RELATED WORKS

Energy Demand Management or DSM is a change in consumer demand through financial incentives and/or training. DSM is a planned and implemented process intended to affect electricity demand directly or indirectly by electricity companies. According to the energy sector, to address the growing demand problem, it is more cost effective to reduce power consumption than increasing power generation, that will be possible with DSM application. Although reducing energy sales after taking demand reduction procedures by supply companies seems unreasonable, it provides operational and financial benefits in peak periods [6].

DSM deals with actions implemented by electricity companies -such as incentives, discounts, specific programs and discounts to change the end-user electricity demand. These actions can be demand reduction in peak time (when electricity consumption is the highest) or shifting to off-peak times. The supply-demand balance should be ensured to minimize consumer bills and service costs. DSM is a set of applications that enable customers to use electricity more efficiently. The overall aim of the DSM applications is to reduce demand, cut or shift loads at peak times, and increase energy efficiency. Thus, the load factor (average load/peak load) will improve. The fact that load factor increases and remains high means that electricity is used efficiently. In addition, existing DSM applications include options such as integrating renewable energy sources into the system. An effective DSM program can be implemented by co-opting both energy efficiency and incentive-based demand. Wind and solar energy need to be added to the applications to meet future clean energy needs.

Variable tariffs encourage consumers to reduce their load during peak hours. Turkey applied 1-time tariffs and 3-times tariffs. 3-time tariff.is made by 3 different pricing. The unit price of electricity between 06:00-17:00 is 0.330447 TL/kWh, the unit price of electricity between17:00 and 22:00 is 0.499784 TL/kWh and between 22:00 and 06:00 the unit price of electricity is 0.208112 TL/kWh [7].

In this way, consumers who are priced according to the 3-time tariff are encouraged to use electricity more often in off-peak times. Electric energy is mainly consumed in residential and commercial real estates, industrial section and agriculture irrigation. Electricity companies, by making initial investments and providing additional incentives, tried to convince customers to adopt and adapt new ideas for DSM implementations.

The need for energy efficiency was greatly felt during the oil crisis of 1973 and 1979. The increase in oil prices caused an increase in production costs. Therefore, alternative ways have been studied to be tested. Until then, Demand Side Management did not consider that reducing consumption would be more cost-effective than increasing production capacity.

Energy efficiency programs were then tried in the United States of America (USA) and starting from California in 1974, comprehensive standards, such as the kWh consumed by each residential appliance, were determined by the state. The results for some programs implemented by the state have been very encouraging and have justified DSM investments [8] Along with state's political decision, building design regulations under name of energy efficiency has been also established in the USA [9]. Energy efficiency programs are designed to minimize the energy consumed in vain. It is aimed to increase efficiency by using energy-friendly devices.

With well-maintained building walls, the home illumination can be reduced by taking a maximum degree of windows and daylight. The use of efficient electrical equipment (Class A) will also increase energy efficiency. Similarly, the energy consumption of heating and cooling systems will vary depending on the walls, ceilings, and roof insulation quality. Energy efficiency will also be increased by replacing halogen or incandescent lamps with Compact Fluorescent Lamp (CFL) and Light-Emitting Diodes (LED) lamps [10].

In 1994, the United Kingdom (UK)'s Electricity Regulation Board launched an initiative called Energy Efficiency Standards. Under the name of this initiative, the Electricity Regulatory Board requested the electricity suppliers to pay each customer one Grand British Pound Sterling (GBP) for energy saving procedures at their homes.

Then energy saving targets were determined by suppliers. This program was extended to Scotland in 1995 and to Northern Ireland in 1997. The program was expanded in 2000 by the Regulatory Board to reach at least 50000 consumers of electricity and gas suppliers in the UK [11]. The results show that DSM can success if it is designed with economic benefits in mind. These programs also include loads shifting [12].

The purposed load change is to decrease on-peak time loads or increase load during off-peak times. Load management is particularly important at peak times because additional capacity or an extra energy purchase may be required to meet demand. In order to provide a more cost-effective and more reliable power supply to consumers, it is also important to reduce peak loads to relieve the grid.

2. DEMAND SIDE MANAGEMENT OF ELECTRICAL ENERGY

Electrical energy, an integral part of our lives, plays an important role in improving the living standards of all countries in social, economic and environmental development. The electrical energy demand in our country is increasing due to the industrialization, technological developments, and the rapid population growth.

Increasing demand for electricity; needs to be met in an economical, high quality and continuous manner. In order to meet this demand, fossil fuels are substantially used in huge amounts as affordable resources. The use of fossil sources such as oil, coal and natural gas causes a release of harmful gases to human health and increases greenhouse gas emissions to the atmosphere.

With Smart Grid applications, electricity from renewable energy sources can be integrated into the grid, thus reducing CO_2 emissions. In addition to the renewable energy being produced and integrated into the grid, it is important to be used efficiently, measured correctly, managed effectively and produced in line with needs.

Smart Grid can be basically defined as a system monitors and controls the electricity grid by integrating smart meter and monitoring systems to ensure the communication between producer and consumer in a fast and continuous manner, and concurrently ensuring the distribution efficiency as well as the consumer safety.

The smart grid is an advanced and versatile technology that improves the performance of energy systems using modern communication and control technologies. Smart grid technology side-by-side with the modern automation and communication technologies provides flexibility, reliability, efficiency, accessibility, and durability to the grid.

Smart grid systems should be integrated into all the electrical energy processes such as production, transmission, distribution, considering the subsidiary sides too like the consumer behavior and smart infrastructure availabilities.

Smart meters, which are key elements of smart home technologies, provide two-way data flow between service providers and consumers through its communication infrastructure. With smart meters, the consumed energy can be monitored, recorded and controlled in real time. Smart meters should be perfectly capable of transmitting data and information reliably.

By means of smart meters, the consumer's loads can be cut or reduced remotely in intervals where electricity unit price is high. Thus, both consumers and electricity companies will benefit. While consumers can reduce bill costs, providers or electricity companies can also benefit operationally, Comparison of smart meters with traditional meters is shown in Table 2.1.

Table 2.1. Comparison between smart meters with traditional meters [13]

Traditional Meters	Smart Meters
Analog	Digital
The consumer has no choice but one provider	Multi-provider system is available
Loss-leakage rate is low	Loss-leakage rate is high
The consumer can use one type of tariff	The consumer can benefit from different tariffs
The consumer cannot transfer energy obtained from renewable sources to	The consumer can integrate electricity obtained from solar or wind sources into
The consumers see just total electricity usage	The consumers can see their hourly and daily electricity consumption
Not suitable for DSM programs	Suitable for DSM programs.
The specialist is needed to read data	Data readout is automatic There is no need for help
Low accuracy	Great accuracy
The consumers can not control meter	The consumers can remotely command meters
Cheap	Expensive
Useless with smart grid	Compatible with transition from the existing grid to the smart grid

Comparison of the smart grid and the traditional grid is shown in Table 2.2. Switching from the traditional grid to the smart grid will provide both electricity companies and consumers with great advantages.

Table 2.2. Comparison of smart grid and traditional grid [13]

Traditional grid	Smart Grid
Electromechanical, solid state	Digital/Microprocessor
One-way and local two-way communication	Global/integrated two-way communication
Centralized generation	Accommodates distributed generation
Limited protection, monitoring, and controlling	Wide Area Monitoring Protection and Control (WAMPAC), Adaptive
'Blind'	Self-monitoring
Manual restoration	Automated, 'self-healing'
Check equipment manually	Monitor equipment remotely
Limited control system contingencies	Pervasive control system
Estimated reliability	Predictive reliability

2.1. Theoretical Approach of DSM

Demand Side Management is a series of policies and procedures that range from long-term efficient optimization programs of consumption energy to real-time control of distributed energy resources [14]. DSM is an approach based on observing the consumer's demand by the electricity suppliers and aims to more efficient use of existing energy without establishing new systems and making new investments.

Reducing and shifting consumption are both the main common objectives of demand management programs. Reducing consumption can be achieved by raising awareness of consumers and by using appliances with high efficiency [15].

Starting from demand intensity fluctuates considerably along time zones and the pricing applied accordingly the shifted-consumption method (without changing total consumption) is the main purpose of today's DSM studies.

DSM began in the 1970s with the examples of working in the houses [16]. The huge increase in oil prices with the 1973 Oil Crisis triggered an increase in investment costs of the energy production facilities. Since license procedures are required for these facilities, so construction of a new plant lasts for 5 to 8 years, totally a period of 15 years.

On the other hand, legislative amendments have been made requiring more attention to air pollution; energy producers are faced with a need to reduce and control carbon emissions [17]. The traditional approach was to produce when energy is demanded, thus keeping the production and transmission line capacities high [18].

The current approach in the West is to provide control over the production system by making agreements with consumers [19]. With this new approach, supply-demand balance can be drawn to optimum points. DSM is a good way to match demand with production capacity. It controls all components that consume electricity and operates them efficiently to achieve the lowest cost [20]. DSM tries to correct the load curve by encouraging users to consume less power during the highest demand period or to shift their consumption to other periods.

In some cases, instead of correcting the curve, it is attempted to comply with a single sample of production schedule (day-ahead schedule). In both cases, there is control over consumption [19]. DSM focuses on supply-demand balance and prevents production costs from instability. In addition, The more renewable resource facilities are built, the fewer investments in fossil-based production [20]. The need for extra production capacities will be eliminated. It is very important for producers that customers demand remains constant; because it is more efficient for them to produce continuously at the nominal capacity [21]. This request has been expressed for many years by energy suppliers and has played an important role in the first DSM studies in the world. One of the main uses of DSM can be said to increase the stability of power grids [22].

In spite of intensive research, the audit that can be applied to the demand side consumers is relatively weak compared to the controllability in production. That is because there is no consumer's will to share decisions related to how using his/her home appliances. The widespread use of distributed energy production also makes control increasingly difficult. As a solution, if agreements between producer and consumer become increasingly stronger, the studies in this direction will increase [19].

Although DSM applications provide important information about real-world impacts, it shows the combined effects of some new technologies and control strategies. Therefore, there are still many issues to be investigated in this area [20]. A power grid consists of four parts: production, transmission, distribution, and consumption. Prior to the development of the DSM concept, the first three were studied; but now demand-side technologies are also important for efficient consumption [2].

The installed power capacity should always be able to meet the highest demand. Moreover, there is a need for reserve capacity to deal with unpredictable demand increases and production output variations [23]. The increase in electrical appliance automation in industry has increased the costs of electricity lack situations. On the other hand, procedures in this direction will cause capacity redundancy in lower demand periods. So there is a need for a solution that will balance the two situations.

One of the most important factors that reduce grid efficiency is the line losses in transmission and distribution stages [2]. Electrical energy grids that depend on different supply-demand balance points; this reduces the cost of the entire system and provides security of supply. It is known that any electrical system loses certain energy to supply demand points with power. These losses cannot be measured directly but can be calculated by the difference between the amount of power entering and leaving the grid [24].

The losses rate of the world’s countries is 8.1% and in the European Union is 6.2%. In May 2018, Chairman of Electrical Distribution Services Board (ELDER), evaluated leakage rate in electricity before and after privatization; from 20% to 13% [7]. The electrical lost-leak term, which corresponds to losses term in international research, includes the illegal use of electricity in our country. Losses are divided into physical technical losses and commercial Non-technical losses. Technical losses are those which cannot be eliminated; such as iron, copper and friction losses. Non-technical losses include illegal uses, and losses that relative to metering errors of tariff systems [24].

There are different ways of reducing losses for grid operators, one of which is the method of reshaping the power flow profile, which is also the main purpose of DSM [24]. The line losses are directly proportional to the square of the current flowing through the line. Therefore, decreasing the highest demand amounts will reduce losses and increase efficiency. A smooth, low fluctuate load curve is preferred for electricity supplier and utility infrastructures [2].

The consumption phase also requires DSM programs as much as the others. Electricity demand varies in different seasonal and different daily times. In addition to these basic variables, there are many factors that may cause changes depending on consumer preferences. Particularly in houses; different habits of devices usage cause high demand diversity. On the contrary, this situation is more predictable in the industry section. Seasonal, daily and hourly fluctuations are likely led to large fluctuations in production. For example, the lowest annual demand is at summers' nights and this is only 30% of the highest demand period in winter [23].

Suppliers' DSM configuration is created according to the power plant features and the external environment. No matter how much convincing and awareness-raising activities are carried out by the energy producers, the final success of the program is provided by the consumer decision. In order to achieve success, a partnership should be established in DSM that will provide the highest common benefit to both producers and consumers [25].

Demand Side Management programs have benefits for consumers, electricity companies, electricity grids and as well as for both environment and society [23,26]. Some of these benefits are listed below.

For consumers;

- Reduction of electricity bill costs.
- Increase production.
- Raise awareness of energy efficiency.
- Improving lifestyles.
- prevent electricity demand cross-subsidies .

For electricity companies and electricity grid:

- Lower service cost.
- Improve supply reliability, operational efficiency, and flexibility.
- Reduce peak demand, supply-demand unbalances and the load shedding problem.
- Flattening the load curve.
- Ensure the distribution grid relief.
- Stop the growth of electricity prices in the long term.
- Prevent high investments in grids.

For Society and environment :

- Prevent environmental degradation.
- Reduce greenhouse gas emissions.
- Protection of existing resources.
- Reduce dependence on expensive imported fuels.
- Reduce environmental pollution.

The benefits of DSM can be summarized as follows [25] :

- Reducing the highest demand point, and production peak.
- Improving the efficient investments in transmission and distribution grids.
- Ensures more efficient use of equipments.
- Contributes to supply-demand balance by integrating renewable resources production.
- facilitates the management of distributed production system.
- reduction in energy losses.

Not the total demand but the peak demand points reduction; reduces grid instability [2]. Concludingly, economic, social and the environment will benefit from all these results.

The challenges of implementing DSM programs can be summarized as follows [24]:

- Lack of information and communication technology infrastructures probably leads to social underestimating of DSM real benefits.
- Lack of motivation with such unsuitable energy market structures.
- Policy and regulatory barriers
- Lack of awareness of the potential of Energy efficiency
- Lack of industry initiatives to emphasize energy management as an integral part of total management systems
- Lack of technical capacity to identify, evaluate, justify and implement Energy efficiency projects
- Financial/Investment barriers
- Technology barriers

When the electricity grids are modernized and their technologies are improved, an increase of electricity production efficiency and reduction in the carbon emission footprint will become possible and that makes our grid more reliable and safe [19].

2.2. Demand Side Management in Turkey

Turkey does not have a strong long-term demand management plan. Although DSM is the most state-of-art and most cost-effective energy management program and new legislation has been recently made in energy market liberalization in our country, there is no serious step in this area [27].

Any program to be implemented must be designed for our country. This is the reason why DSM is a national characterization. Each country should have programs according to technical, economic and political conditions; demand should be managed by taking into consideration the energy resources, production capacities, and potentials.

There are both legal and technical deficiencies in this field in our country. Although motivation laws of demand management instead of supply, besides its encouragement of flexible energy market, they are insufficient yet. As DSM approach is not widespread in the country, deficiencies in laws implementation are not understood [28].

Moreover, expressions and application of laws are also prepared without background, how the system will operate in our country without sufficient understood by all parties [29]. Managers consider financial insufficiency as the most important reason [27].

In technical terms, the first deficiency is software used by electricity market doesn't form the monitor where DSM can be followed., demand management service companies need to provide

The systems that provide decision services to both consumers - who influence the market on a large scale - and DSM service companies are not yet used in our country. Without such systems, which are used extensively in Europe and the USA, it is very difficult to obtain efficiency from DSM programs [28]. These programs require detailed information and data on customers' electricity consumption charts. In our country, monitoring and making changes manually in the current conditions increases the cost considerably when compared to modern systems [2].

Social habits have a negative effect on overcoming these legal and technical deficiencies. Since 2006, consumers are not heavily affected by prices in our electricity market. Different tariffs applied since then have not changed demand curves. Consumers prefer to use fixed-price tariffs instead of using electricity market software [29]. Behind this situation, it can be said that DSM is known only in our country for its economic benefits and unfortunately there is no awareness about its contribution to the healthy operation of the electricity grid systems. The reason for considering DSM as a case of emergency is almost the same as other countries. Demand for electricity is growing faster than Gross National Product (GNP); the average of human electricity usage increases with new technological products; There are imbalances in the industry, workplaces, and housing in day-load curves and the peaks of these curves can rise to a level that cannot be met. Turkey has a wide range of energy sources. Most of them are seasonal sensitive or externally dependent sources and they are not sufficient in terms of supply security [28].

Although these conditions make our country an attractive market to energy efficiency studies, the energy market, which is liberalized and undergoing a kind of reformation, is a very suitable environment for such innovative policies [27]. First of all, technical infrastructures should be prepared and appropriate market monitoring should be created for DSM. In order to enable DSM programs to penetrate into operation without disrupting the current functioning of the market, it should be started with pilot applications. By a system established by taking confident right steps; in such energy market like Turkey's one, It is possible to increase quality and safety energy while decreasing the costs, increase the share of renewable resources in supply and provide a total welfare increase [29].

2.3. Smart Meter and Grid Technologies

The smart grids that are increasingly structured and used whole the world; are the biggest supporter in the development field of DSM. According to the European Smart Grid Working Group, smart grid aims to ensure two-way communication between producer and consumer by integrating smart meters and monitoring systems to power grids. So that monitoring grids and intervening at required points will be possible. Thus, it is possible for power consumers to manage their consumption according to hourly prices, thus enabling effective participation of demand side in the process. In addition to restructuring the existing grid infrastructure, smart grid technologies are a good solution for energy supply security and quality [30].

A smaller step that can be taken in this direction before switching to intelligent grids is the use of a smart meter. Today, in some countries, the use of smart meters is more intense in households and industry alike. Unlike digital meters, which are more common these days, smart meters hold two-dimensional data rather than one-dimensional. Not only the amount of electricity consumed but also how much electricity is consumed per hour [4]. Such meters are very useful for better monitoring of electricity consumption and for actively load controlling [20].

Besides the above mentioned of the most basic features; Smart meters, which are the elements of today's smart grids, also have features of being read, accessed and communicated remotely.

Thus, through smart grid infrastructures providing two-way communication, modern DSM systems, and consumption scheduling on the appliance or consumer basis, the existing equipment, and smart meters can be used integrally [15].

Transition to smart grid usage in the world is faster than in our country. In some countries like UK, France, Spain, there are laws that require the smart meter usage and the pilot programs have been carried out there. In some other European countries, such as Germany and the Czech Republic, there are electricity distribution companies are switching to use smart meters, although they are not required by law. In the USA, since 2007, the smart meter has been started to be used, and it is planned to complete all transition and infrastructure works in a period of 20 years. In China, South Korea, Japan, Brazil and India, significant efforts have been made in this area with government supports. The first official step towards the transition to Smart Grid implementation in Turkey between the years 2012-2023; is the Energy Efficiency Strategy Document (EVSB). This document announced that start-up time for smart grid applications is 24 months from the document publication date. As for implementation, in the 2000s, there is a limited working process started in our country with Turkey Electricity Transmission Corporation (TEİAŞ) and continues now by distribution companies in smart meters field and remote reading systems [4] Management investments are being made for grid monitoring and distribution systems, but they do not serve an integrated design of national smart grid and remain independent. In fact, investments should be integrated with customer services and billing systems.

2.4. Types of Demand Side Management

It is possible to find different DSM classifications in the literature. DSM programs include conservation and energy efficiency programs, fuel substitution programs, demand response programs, and residential or commercial load management programs [15]. They have considered direct load control and smart pricing as subheadings of load management programs. Where users are encouraged to individually and voluntarily manage their loads, e.g., by reducing their consumption at peak hours. In this regard, Critical Peak Pricing (CPP), ToU Pricing, and RTP are among the popular options.

In a detailed classification study on DSM, the titles are different. DSM Can be found under three titles as energy efficiency programs, demand response programs, and strategic load growth programs. In DSM terminology, the transformations were seen from the 1970s, and the load management concept of the 1980s turned into demand response programs today. Now, the most common DSM approach is demand response programs [2]. Demand response programs are divided into six categories: Frequency-based, Direct control over utility equipment, Direct control over end-user equipment, Price-based, Market-based and Model-based predictive. However, this is not a strict distinction, because two or more of these categories can be combined together [14]. In the other DSM classifications in the literature, demand response programs are divided into two groups as price-based and incentive-based [2,19,26].

Frequency-based management programs are using frequency relays and dynamic demand types as indicators. Voltage reduction, protection practices, and remote control relay methods are used in the Direct control over utility equipment programs. When Direct control over end-user equipment programs is applied protection fuse, time switch and remote controlled relay methods are concerned. Price based programs are divided into three as static (like ToU), dynamic (like CCP) and real-time (like RTP) tariffs. Model-based programs, which are the last subclass of demand response programs, can be divided into two as centralized and decentralized [14].

The concept of LM cames together with DSM in the late 1970s. LM is a program to control and regulate the demands of more than one consumers who are using the same power source. These controls and modifications always aim to match supply and demand in the most economical way. This aim is expressed mathematically as bringing the load factor closer to 1, which is defined as the ratio of average load to the highest load [17]. [10] described industrial LM as a program aimed to reduce the cost of electricity without affecting product and production. LM programs offer users the option to reduce or stop their use during peak demand periods. The benefits of LM are generally to reduce the highest demand, reduce power loss, provide more efficient use of the equipment and provide financial savings [26]. The common feature of different LM techniques is to joint the power consumers participation [17].

Which DSM programs will be implemented depends on how the current demand curve appears and what type of demand curve will be targeted. The DSM programs described by Gelings and Chamberlin are shown in Figure 2.1 below.

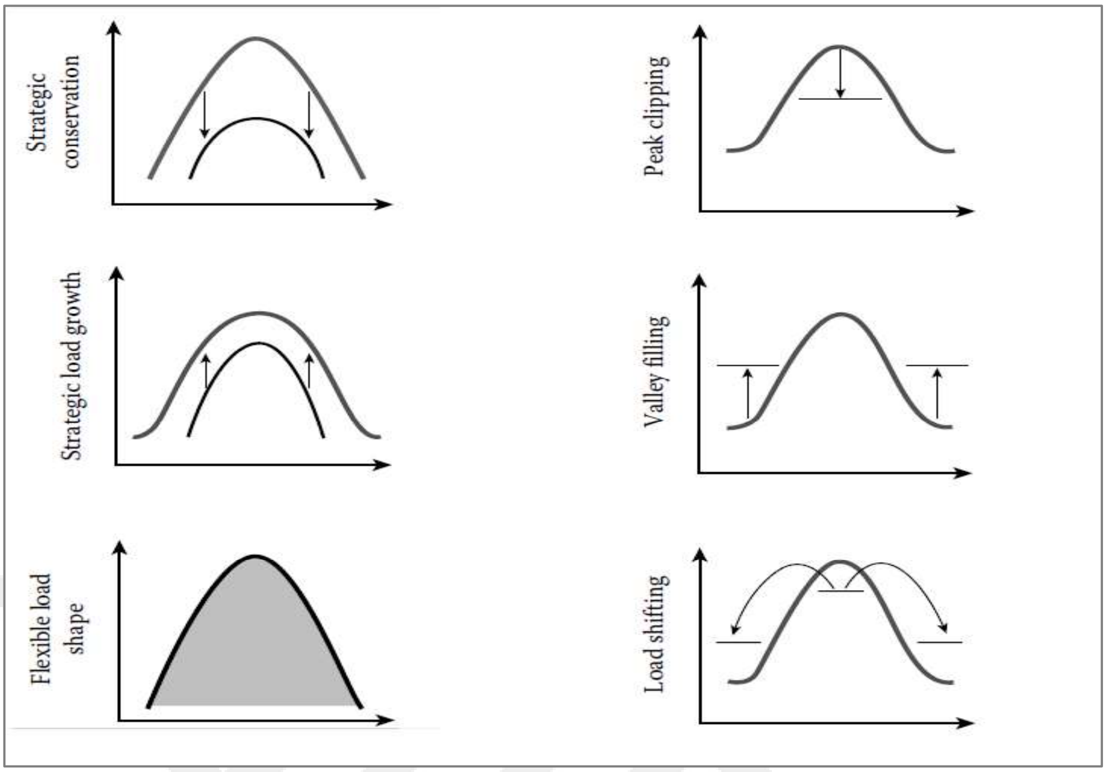


Figure 2.1. The DSM programs [31]

A. Peak Clipping / Reduction: It is the reduction of peak loads in the system and its management is provided by direct load control. Direct load control is mostly ensured by controlling electrical devices of consumers and companies directly. The net effect is the reduction in both peak demand and total electricity consumption.
B. Strategic Conservation: Downward shifting by Reducing loads in a whole day or most of the hours. It is a program to reduce consumer electricity consumption. It promotes the development of energy efficient building standards and device efficiency. In addition, government institutions and professional organizations need to have a wide range of understanding consumer behavior by cooperating together. The net effect is a decrease in both peak demand and total consumption of electricity.
C. Load Building/Strategic Load Growth: Upward shifting by increasing loads during the whole day or most of the hours. The net effect is an increase in both peak load and total electricity consumption.
D. Valley filling: It includes load generation in non-peak time periods and increases the load factor. Promotes production and distribution systems more efficiently by

encouraging additional energy consumption during low demand periods. The net effect is an increase in total energy consumption while there is no increase in peak demand. The use of thermal energy storage is a typical method of filling low demand times.

E. Flexible Load Shape: It includes a load shaping with high sensitivity to reliability conditions. Rather than affecting the load shape, electricity companies have the option to cut loads when necessary.

F. Load shifting: Used to shift loads from on-peak to off-peak periods. Consumers are advised to replace their load pattern with reliable methods such as ToU tariff. Appliance displacement also reduces peak loads. The net effect is that there is no decrease in total energy consumption while there is a decrease in peak demand. For load shifting strategies, customers may need more incentives as well as programs.

Applications for households and industries, and which DSM program is applied to these applications are shown in Table 2.3 and Table 2.4.

Table 2.3. DSM program applied in house applications [32]

Applications for Houses	Used DSM Program
Insulation	Strategic Conservation
Double Glass System	Strategic Conservation
Electric Water Heater	Load shifting
Energy Efficient Motors	Strategic Conservation
Gas Heaters	Peak Clipping
Efficient Electrical Appliances	Strategic Conservation
Photovoltaic Systems	Peak Clipping, Strategic Conservation
Heat Energy Storage	Load shifting, Valley filling

Table 2.4. DSM program applied in industry applications [32]

Applications for industry	Used DSM Program
Insulation	Strategic Conservation
Cold Storage	Load shifting, Valley filling
CFL	Strategic Conservation
Energy Efficient Motors	Strategic Conservation
Gas Heaters	Peak Clipping
Energy Efficient Devices	Strategic Conservation
Cogeneration	Peak Clipping
Heat Exchangers	Peak Clipping, Strategic Conservation

2.5. Demand Response Programs

Demand Response can be considered as the tariffs and tools used by end users/consumers to regulate and reprogram its energy usage profiles. In other words; they are programs in which electricity companies can reshape consumers load profiles to improve the grid reliability and efficiency [33]. Demand Response Programs (DRP) aims to change end-users load shape decreasing their peak consumption and provides demand change in which consumers react to price signal in short-term applications [29]. Although DRP has been evaluated under DSM as the literature, it has become an area that needs to be evaluated alone by increasing the importance of the smart grid. DRP's are divided into incentive-based and price-based programs.

2.5.1. Incentive-Based programs

It includes programs that give incentives to consumers to reduce their load at high electricity prices or when grid reliability is compromised. Incentive-based demand response programs are examined under four main headings.

A. Direct Load Control: These are programs that allow electrical companies or system operators to control the consumer's electrical devices (registered to the program, such as air conditioners and kettles). In order to ensure remote access and control, incentive payments are provided to consumers. The aim here is to reduce loads during peak hours. The load is reduced by turn off or switching devices to standby mode at peak time. This direct load control targets small commercial consumers and householders [34].

B. Interruptible / Curtailable Load: This is the program that allows consumers to cut and reduce some of their loads when grid reliability is compromised. Consumers can receive a certain incentive reduction in electricity bills in exchange for reducing and cutting their loads [35].

C. Demand Bidding / Demand Buyback: In peak demand periods or in case of system failures, consumers can save money if they are willing to cut electricity, in exchange for a specific offer. This program is mainly offered for large consumers (1 MW or higher). If small consumers want to benefit from this program, they should come together and offer to third parties or agencies [36].

D. Emergency Demand Reduction: In case of emergency reliability problems or in cases where grid reserve is insufficient, subsidy payments are made to consumers in exchange for a decrease in their loads. In this program, large consumers can provide ancillary service to electricity companies by reducing their loads [37].

2.5.2. Price-Based Programs

Price-based demand response programs offer consumers different electricity prices at different times. With such an application, consumers will consume less electricity in times of high electricity prices and reduce electricity demand during peak hours. In short, changes in energy consumption in response to changes in electricity prices. This program enables consumers to change their electricity consumption and electricity usage habits according to the change in electricity prices instead of directly controlling the consumer's load. Price-based demand response programs are basically divided into four headings:

A. TOU: Consumers are provided with different hourly prices per day; and different seasonal prices per year. 3-time tariff in our country is an example of this. The peak time period (17: 00-22: 00) is the time period where the electricity consumption cost is the most expensive, while the night rate (22: 00-06: 00) is the time period when electricity consumption is the cheapest. Consumers are encouraged to increase their electricity consumption during off-peak times, depending on the difference in electricity prices during the day [38].
B. CPP: When grid reliability is at risk or when it is compromised, peak pricing is replaced by higher-rate pricing to reduce electricity demand. This program aims to ensure grid reliability or supply-demand balance in specific hours or days of the year [39].
C. RTP: This program is also known as dynamic pricing where electricity prices change at different times of the day (every 15 minutes or every hour). The real-time pricing program is a program where consumers are informed about prices before an hour or a day [40]. RTP is considered to be one of the most effective and economic price-based programs [41].
D. Inclining Block Rate: There are two blocks (lower and higher blocks) in this program. If the consumer's hourly / daily / weekly / monthly energy consumption

exceeds a certain threshold, the electricity price per energy consumption will climb to a greater value. This program will allow consumers to avoid excessive use of electricity, thus increasing the load factor (average-peak ratio) [41]. This program has been implemented by many energy companies since 1980.

3. RESIDENCE APPLIANCES

The appliances used in residence are divided according to their characteristics and manageability into:

3.1. Appliance by Characteristics:

Electrical appliances in household are divided into two categories depending on householder behaviors and climate conditions [42].

3.1.1. Behavioral appliances

The electric appliances under this heading are closely related to the householder lifestyle habits. These appliances are independent or less associated with external factors such as outside temperature, wind speed, and daylight.

Behavioral loads are given in Table 3.1. The relationship between the electricity consumed in households and the end user/consumer has been widely discussed [43]. The working time of loads in this group is considered “flexible”.

3.1.2. Physical loads

Loads under this heading are closely related to climate changes, and electricity consumption varies from season to season. The relationship of such loads with heating, cooling and building designs is high, but their relation to human habits is low. Among all the loads in household, dishwashers and washing machines can be shifted to another time slot Without disturbing the consumers convenience.

However, the rest of the appliances in Table 3.1 may cause discomfort to consumers. The working time of loads in this group is considered “constant”.

Although the annual electricity consumption of the dishwasher, washing machine and clothes dryer is less than heating and cooling systems, the shifting of these loads plays an important role in reducing peak loads and penetrating renewable energies into the system [44].

Table 3.1. Behavioral and physical loads in the house [44]

Behavioral Loads	**Physical Loads**
Washing machine	Air conditioning
Computer / Laptop / TV	Lighting
Oven, microwave	Heater
Refrigerator	Heating Systems
The dishwasher	Cooling Systems
Clothes dryer	Freezer

3.2. Loads According to Manageability

Depending on whether time working can be changed or not; household appliances are divided into two parts.

3.2.1. Unmanageable/uncontrollable loads

Appliances directly controlled by user like television, microwave and laptop, consumers will be adversely affected when these appliances are interruptible from external signals. These appliances are not included in the DSM scope (As a hungry person will not wait to time period in which electricity unit price becomes low).

3.2.2. Manageable / controllable loads

It is the loads that the consumer / user will not be adversely affected from external intervention. Changing the time working ranges of these loads is more suitable for Demand Side Management.

3.2.2.1. Controlled loads with thermostat

They can be controlled by thermostat such as refrigerator, air conditioner.

3.2.2.2. Manually controlled loads

Manual controllable loads such as washing machines, dishwashers and dryers are included in this group. With the development of smart plug technology, the loads in this group can be controlled remotely with scheduler programs. Classification of household loads is shown in Figure 3.1.

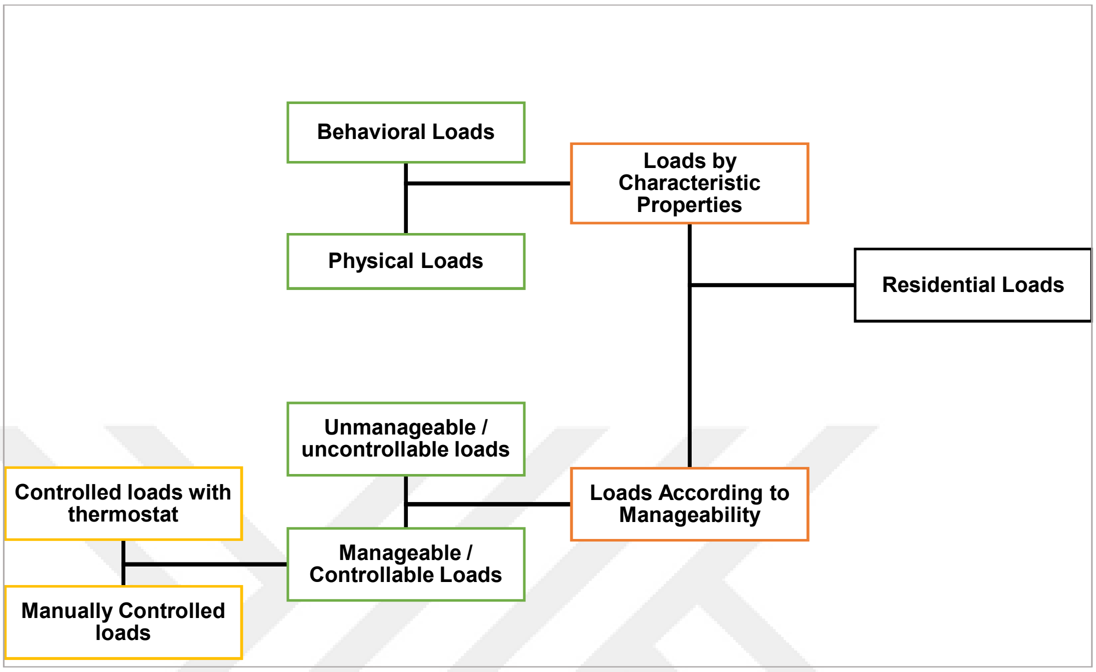


Figure 3.1. Classification of the household loads

4. IMPROVING DSM BY SMART CONCEPTS

4.1. Smart Grids

Electrical energy is the most widely used indispensable resource. Today the correct and efficient usage of energy has also become important. Serious investments and studies have been started to make more efficient of electricity usage, which is increasing every day [45]. The "Smart Grids" in which many countries have a wide range of investments are one of the state-of-art projects that facilitate efficiency enhancement.

4.1.1. Smart grid concept

The emergence source of smart grids is based on an interesting basis. In 1980, a jet under an Israeli pilot command encountered a failure, and that was the reason behind the birth of the smart grid concept as a solution to this problem [46].

In a brief introduction of this new concept, we can start with various definitions made about smart grids. According to the European conference of smart grid standardization achievements -organized by the European Commission with the support of the European Standardization Organizations (CEN, CENELEC, ETSI) including the Turkish Standards Institute (TSE)- the smart grid is a grid structure where manufacturers and consumers are able to connect, and this grid provides a more quality, security, economic efficiency, uninterrupted power systems integrated with the consumers behavioral actions [47].

The fact that the system has the ability to make decisions by itself and provides greater operating flexibility comes first for any smart structure. In smart grids, making decisions is performed after gathering information from specific points distributed along the grid. In this context, interoperability is the key concept of smart grids [47]. Smart grids aim to ensure that the existing grid, and the new energy systems, and of course the consumers are interactively monitored and controlled in real time. [46].

In short, the smart grids allow the consumer to have two-way communication with the energy providers and allow them all to control the electricity demand and the energy supply in a harmony utilizing all the new technologies such as the internet, computer, automation, and control elements [48].

4.1.2. Reasons for transition to smart grids

The reasons that helped us realize the true necessity of the smart grid are countless reasons. Many different reasons make the transition to smart grids essential and mandatory. One of the most famous catalysts that created the launch spark of the smart grid idea is the electricity blackout that happened in the United States due to air conditioning loads in 2003.

After the event, which affected the lives of 50 million people, the renovation of the existing electricity grid and its smartness were brought to the agenda. In addition, the reduction of fossil fuels has encouraged more efficient use of existing energy.

Considering that energy demand will increase by 30% in 2030, it is important to meet this need without increasing carbon emissions. In this context, alternative electricity energy production also has come to the agenda. The fact that the existing power grids cannot serve appropriately with the alternative electricity generation is one of the reasons for switching to smart grids.

On the other hand, the serious damage caused to the environment by carbon emissions and greenhouse effect according to the Kyoto protocol is one of the important reasons for this inevitable transition.

4.1.3. Smart grid components and technologies

Effective control and real-time monitoring systems, which are the main components of smart grids, require interdisciplinary work. In this context, energy system engineering has been working together with information and communication technologies departments. The existing grid systems and smart grids are compared in Table 4.1[49].

Table 4.1. Comparison of existing grid systems with smart grids [49]

AVAILABLE GRID	SMART GRID
Electro-mechanic	Digital
One-way communication	Two-way communication
Central generation	Distributed generation
Hierarchical structure	Net structure
Limited sensor applications	Fully sensor application
Closed system	Self-monitoring system
Manual maintenance	Self-healing system
Distortion and interruption	Adaptability and customizability
Limited options offered to the consumer	Many consumer options

There are various subtitles within the applications of smart grids. These titles are: transmission and distribution automation, renewable energy integration, smart applications, storage systems, system coordinator, stations evaluation and distributed generation. It is shown in Fig 4.1 the switching process to smart grids.

Smart grid technologies can be examined under 5 main topics: developed components, improved control methods, sensor and measurement, improved interface and communication [50]. The main headings are given in Figure 4.2.

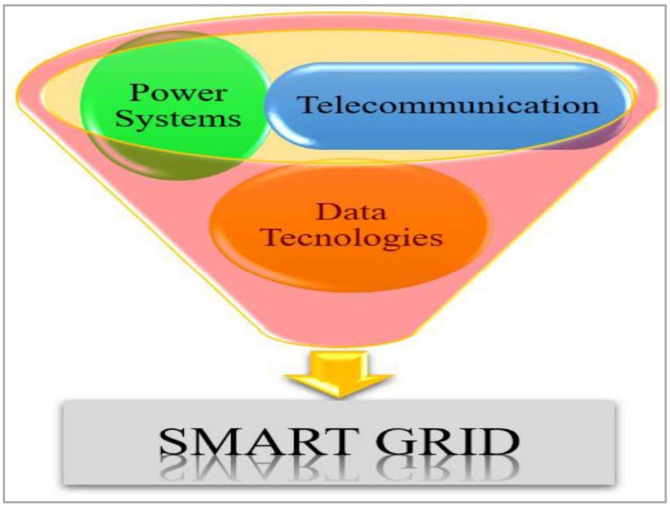


Figure 4.1. Scheme of switching to the smart grid

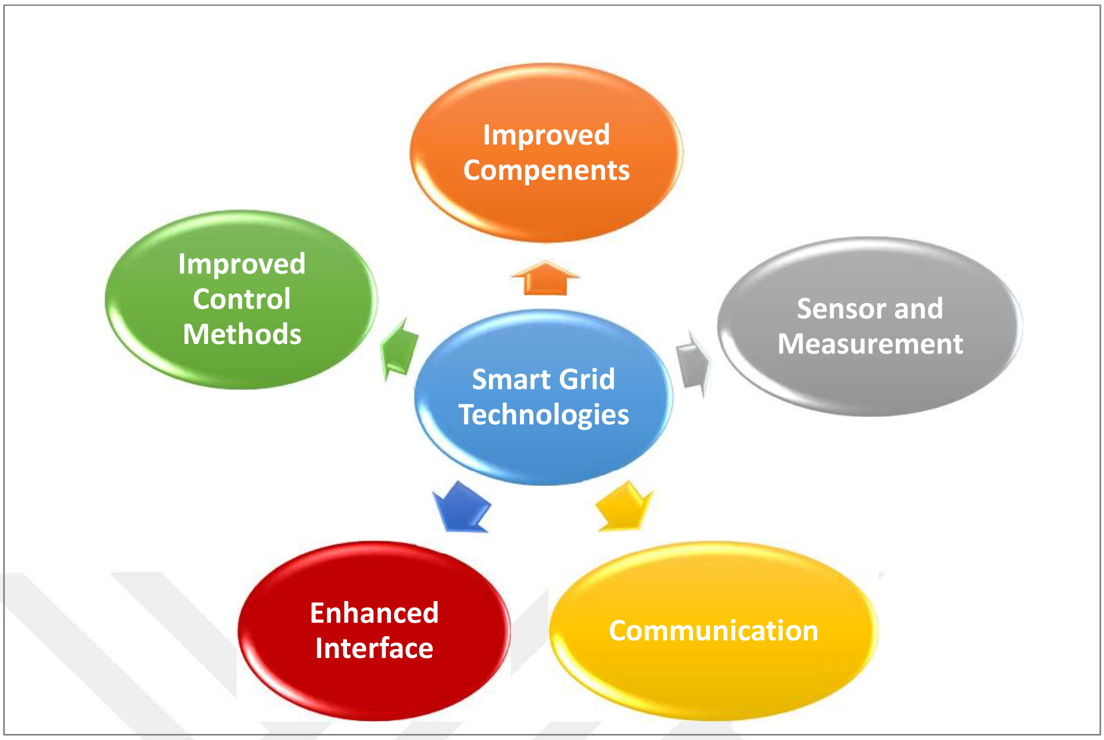


Figure 4.2. Smart grid technologies [50]

4.1.4. Benefits of smart grid

Smart grids are naturally evaluated under energy efficiency. We can summarize the benefits of smart grids as follows [48, 51].

- Enable monitoring and controlling of the energy consumption remotely, and more efficient use of the existing structure, and finally detecting the fault place and reducing losses.
- The instantaneous energy data, measurement, and analysis all of those provide cheaper energy investments as well as dynamic pricing for consumers in a real-time tariff form.
- Since the energy transition capacity of the existing grid will be strengthened by smart grids, a strong infrastructure is created for the electric vehicles and for the future smart devices.
- Consumers will be able to adopt renewable resources to their homes more easily with the smart grid. In this way, dependence on fossil fuels and thus carbon emission will be reduced.

- The less operating costs and maintenance costs, the more increase in equipment life and grid security.
- New business opportunities and more business areas will be created and will contribute to economic and social development.

4.1.5. Smart grid implemented projects in the world

A wide range of smart grids were introduced in Malta with the project called "Enemalta", 250.000 meters size projects have been installed and trainings have been organized to raise public awareness. One of the most significant works is the "Telegestro" project in Italy. Nearly 30,000,000 meters were installed in the scope of this project with an expenditure of £ 2,100,000. It aimed to provide demand management along with other features such as billing, customer tracking and fault detection. Today, studies on smart grids is continuing throughout the world.

"OG & E Positive Energy Smart Grid Project" (US) "Townsville Queensland Solar City" (Australia), "Smart Grid, Smart City" (Australia), "Yokohama Smart City Project" (Japan), "Búzios Smart City Project ú" (Brazil). The projects carried out within the scope of these titles have made smart grids more popular in the world in 2013 [52].

In addition, according to the Global Smart Grid Federation 2012 report, many countries have serious investments in smart grids (Table 4.2, Table 4.3, Table 4.4, Table 4.5). In addition to these countries, projects are carried out in South Korea under the following headings: "Jeju Smart Grid System Demonstration Complex", "Smart Transportation ($18M)", "Renewable Energy Source Operating System", "Consumer-participating smart place ($30M)". Finally, there are many studies in the USA, including works have smart names like "Pacific Northwest Smart Grid Demonstration Project ($ 180M)", "Houston's Smart Grid ($ 640M)" and "Smart Texas ($ 3.4M)" [53].

Table 4.2. Smart grid projects in Europe [53]

Europe	Organization	Suppliers	Scale	Type	Cost
ADDRESS (Active Distribution grid with full integration of Demand and distributed energy RESourceS)	•The utilities UK Power Grids •Enel Dustribuzione •VTT •Iberdrola Distribucion •Vattenfall •The energy suppliers Enel DistributieDobrogea and Electricité de France •the universities and research institutes of Università degli Studi di Cassino •Universidad Pontifical Comillas •VITO NV •Consentec •Enel Ingegneria ed Innovazione SpA – Research division •Fundación Tecnalia Research & Innovation •Kema Nederland •University of Manchester •Università degli Studi di Siena	•Landis & Gyr •ABB •ZIV PmasC •Current •Electrolux Italia •Electronics Nederland •RLtec •Philips •Alacatel Lucent Italia •Ericsson Espana	Demonstration project involving 400 customers.	Multiple Technologies	€16 million.
GREEN eMOTION	•Danish Energy Association •EDF •Endesa •Enel •ESB •Eurelectric •Iberdrola •RWE •Rome •Berlin •Bornholm •Copenhagen •Cork •Dublin •Malaga •Malmö •PPC and the municipalities of Barcelona	•Alstom •IBM •SAP •Cartif •Bosch •BMW •CTL •RSE •TCD •Siemens •DTI •Daimler •Micro-Vett •TÜV Nord •Nissan •Renault •FKA •Better Place •Cidaut •Imperial •IREC •DTU	9 electric mobility demonstration projects across Europe	Multiple Technologies	€24,2 million

Table 4.2.(Continuation) Smart grid projects in Europe [53]

Europe	Organization	Suppliers	Scale	Type	Cost
ECOGRID	DSOs Energinet.dk •ELIA •Østkraft •EANDIS (+ORES) •Center for Electric Technology •Austrian Institute of Technology •Tallinn University of Technology (TUT) •SINTEF ER •Tecnalia •DTU •ECN •TNO •EDP	Siemens IBM Landis+	28,000 residential customers, 300 large customers & 56MW renewable generation	Multiple Technologies	€21 Million
GRID4EU	•ERDF •Iberdrola •EDF •Vattenfall Eldistribution •Enel •Cez Distribuce •Rwe •Iberdrola Generacion •Cez	•Alstom Grid •ABB •Cisco Current •Emeter •Landis&Gyr •Itron •Ormazabal •Selta •Siemens •Telvent •the universities •Ziv •research institutes Armines •Comillas •Tud •Rse •Kth •Kul	R&D pilot with 6 demonstration sites	Multiple Technologies	€54 million

Table 4.3. Smart grid projects in the USA [53]

USA	Organization	Suppliers	Scale	Type	Cost
Pacific Northwest Smart Grid Demonstration Project	•Pacific Northwest National Labs •U.S. Department of Energy •Bonneville Power Administration •Avista Utilities •Idaho Falls Power •Inland Power and Light •Lower Valley Energy •Portland General Electric •Milto-Freewater City Light and Power •Flathead Electric Cooperative •NorthWestern Energy •Peninsula Light Company	•3TIER Inc •AREVA T&D •IBM •QualityLogic Inc •Netezza Corporation •Drummond Group Inc	20 types of assets across 12 utilities serving more than 60,000 customers	Distribution Automation, Distributed Generation, Energy Storage, Advanced Meter Infrastructure, Demand Response	~$180M
Smart Texas	OnCor	IBM •EcoLogic Analytics •Landis+Gyr	3.4M smart meters and grid automation	Multiple Technologies	Not Available
Houston's Smart Grid	Houston Electric •US Department of Energy	IBM •General Electric •ITRON •eMETER •Quanta Services	2.2M smart meters and grid automation	Multiple Technologies	~$640M (including $200,000 from the U.S. government)

Table 4.4. Smart grid projects in South Korea [53]

S. Korea	Organization	Suppliers	Scale	Type	Cost
Jeju Smart Grid System Demonstration Complex	•KEPCO •Samsung SDIHyosung •Omni-system •AID •Rootech	•Secui.com •Hyosung •ABB •PCS •Omni System •Millinet •Samsung Electronics •Samsung SDI	Demonstration Project	Multiple Technologies	Not Available
Smart Transportation	SK Innovation •SK Telecom •Hyundai Heavy Industries •Renault Samsung Motors	•SK Innovation •SK Telecom •SK Grids •Hyundai Heavy Industries •Renault Samsung Motors •CT&T •DH Holdings ILJIN Electric •EN Tech •KODI-S	12 consortiums approximately 600 households, 72 EVs, 89 charging stations,9 home (3 kWh) and building (150 kWh) storage units, and 1 wind power energy storage system.	Electric Vehicles	$18 million invested by the SK consortium
Renewable Energy Source Operating System	POSCO ICT	•LG Chem •Woojin Industrial System •Daekyung Engineeri"ng •Korea Institute of Energy Research •Research Institute of Industrial Science & Technology •Chungbuk University	wind generators (750kW), Energy Storage System 2MVA •500kWh, Lead-Acid Energy Storage System 275kW •137.5kWh	Distributed Renewable Generation and Grid Monitoring & Telemetry	Not Available

Table 4.4. (Continuation) Smart grid projects in South Korea [52]

S. Korea	Organization	Suppliers	Scale	Type	Cost
Consumer-participating smart place	KEPCO	•Samsung SDI •Hyosung •AID •Omni-system •Rootech •ABB •Secui.com •Millinet •Samsung Electronics	600 households	Consumer Engagement, Demand Response, Advanced Metering Infrastructure, Energy Storage, Electric Vehicles, and Distributed Generation	•₩ 33B • $30M

Table 4.5. Smart grid projects in Canada [53]

Canada	Organization	Suppliers	Scale	Type	Cost
Transmission Dynamic Line Rating	Manitoba Hydro	The Valley Group a Nexans company	45km section of 115kV transmission circuit	Grid Monitoring & Telemetry	~$200K per 26 km line section
Wide-Area Control System	•Hydro Quebec	•IREQ •ooper •AREVA •ABB	10 PMUs	Grid Monitoring & Telemetry	~$200K per 26 km line section
Ontario Smart Metering Initiative	•Hydro One •Toronto Hydro •Powerstream among others	•Trilliant •ITRON •eMETER among others	4.5M smart meters	Advanced Metering Infrastructure	Estimated capital costs of $1 billion - net increase in annual operating costs estimated at $50 million

4.1.6. Smart grid studies in Turkey

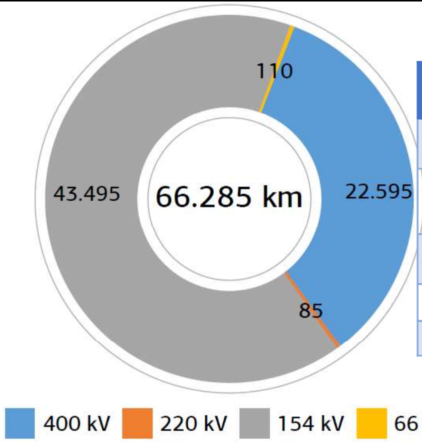
Among developing countries, Turkey's electricity demand is increasing significantly every year. Figure 4.3 shows the 2018-2030 year electricity demand forecasts (TWh) after analyzing the 1990-2017 electricity consumption values by using the proper forecasting function [54].

Figure 4.3. The 2018-2030 electricity demand forecasts (TWh) according to the 1990-2017 electricity consumption values [54]

Turkey's electricity grid with 66.285 km long transmission line and with an annual capacity of 242 billion kWh consumption has been working parallel with the European Grid of Transmission System Operators (ENTSO-E) and became the 5th largest grid in ENTSO-E [55].

Turkey's electricity grid system is divided into three sub-sectors: production, transmission and distribution. In 2005, the distribution sector was divided into 21 state-owned distribution companies and gradually privatized since 2006. Smart grid concept is accelerating rapidly with the start privatization of the distribution sector in Turkey and more step forward.In other words, the idea of the smart grid is speeding up as privatization of Turkey's distribution sector starting and further steps are taken [13]. The basis of the studies relating to smart grids in Turkey constitutes replacing existing meters with smart ones and remotely reading of these meters by automatic reading system.

Automatic Meter Reading project, conducted by TEİAŞ, is continuing on the supply and installation works of communication channels (ADSL, GPRS) [55]. In addition, related to the communication infrastructure of this system, works are carried out for healthy duties too. After the provisional acceptance of the Automatic Meter Reading System (OSOS) project which carried out for remote automatic reading of electricity



POWER TRANSMISSION LINE (31 December 2017)	400 KV	154 KV	220 KV	66 KV	TOTAL
TRANSMISSION LINE	22,506	43,152	84.82	109.67	65,853
UNDERGROUND CABLES	73.31	342.6	-	-	415.91
SEA CABLES	15.96	-	-	-	15.96
TOTAL (KM)	22,595	43,495	85	110	66,285

Figure 4.4. Power transmission line lengths (km) [55]

transmission system meters within TEİAŞ, an automatic collection of measurement data from approximately 2.761 digital electricity meters installed in 948 different locations was carried out through OSOS by the end of 2012. The user name and passwords required to log in to the system’s web interfaces were provided to allow 349 users to view their own information and read the energy data from the internet [55].

According to the energy and power amount -within the scope of Energy Efficiency Strategy Document prepared by the Ministry of Energy and Natural Resources- smart management applications for transportation systems have been introduced in order to implement the graded tariffs, the multi-terminal meters, and smart grid applications as well as to increase energy efficiency in transportation [37].

It also contributed to the feasibility works proposed by the United States Trade Development Agency (USTDA) on smart grid applications in the National Electricity Transmission System [56].

There is also a wide range works on real-time monitoring of energy in our country. "Turkey National Power Quality Project" has been carried out, in accordance with A-class measurement requirements which issued in Turkey Electricity Transmission System and IEC 61000-4-30 standard, in order to monitor Power Quality (PQ) components, reactive power and energy flow in a continuous and uninterrupted manner.

Within the scope of this project, a nationwide real-time monitoring system has been developed, and in this monitoring system, real-time monitoring of all electrical parameters and PQ components of the electricity transmission system, including the interfaces of distribution systems, has been carried out nationally [57]. Within the scope of the project, it was ensured that the electrical parameter magnitudes -one of the important topics of the smart grid- were traceable.

Besides, the Wind Monitoring and Forecasting System's Development Project (WMFS) which is targeting the electrical power produced from wind in Turkey, aims to provide integration of large-scale Wind Power Plants (WPP) into the Turkey Electrical Systems [58]. The relay coordination in the transmission lines is disrupted by "Distributed Generation" which is caused by wind and solar energy.

But under a project named "Protection of Low Voltage Distributed Generation Grids" enhanced by power electronics interface, many works are carried out to achieve the dynamical adapting and improvement for the protection relay coordination which is disrupted as a result of distributed generation [59].

The above-mentioned projects are given in Fig 4.5. In scope of energy efficiency, there are many accomplished and ongoing projects in Turkey.

"Increasing Energy Efficiency in Industry Project" for the realization of energy efficiency in the Turkish industry, "Market Transformation of Energy Efficient Household Appliances Project" to increase the use of energy efficient household appliances and to accelerate market transformation, "Improving the Energy Efficiency Monitoring and Evaluation in Turkey Project (Netherlands / Turkey Cooperation)" aims to support monitoring and evaluation, "Increasing Energy Efficiency in Buildings Project" increasing energy efficiency in the building sector are among the ongoing projects [56].

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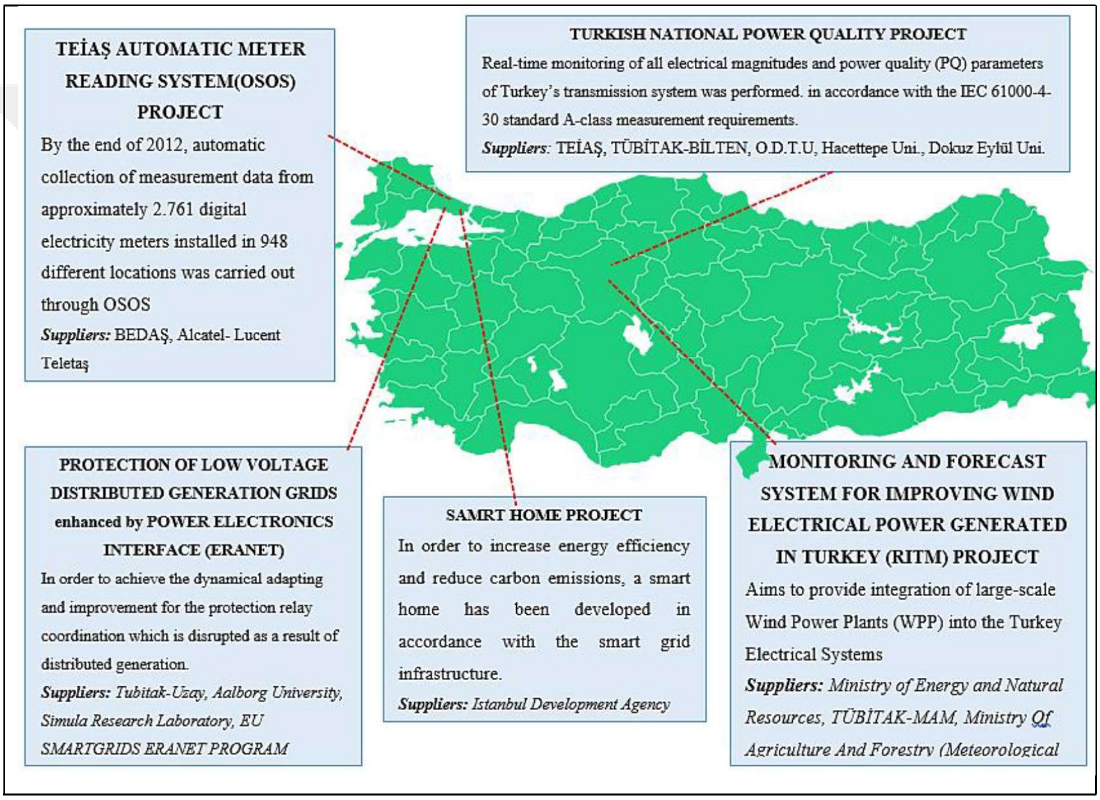

Figure 4.5. Smart grid applications made in Turkey [59]

"The most efficient and cost-effective use of energy at every stage from production to final consumption", and "the maximization of the local renewable sources' share in the generation system" such statements have been announced in the accepted "Ninth Development Plan" in Turkey, [60].

Again, under the heading of "Medium Term Program", the expressions "The policies, which aim to minimize the electricity losses/leaks in generation, transmission, and distribution, maximize the support opportunities within the framework of Energy

Efficiency Law, and expand the applications such as Demand-side Management, High-efficiency Cogeneration and Thermal Isolation, will be followed.” were given frequently.

In Turkey Industry Strategy Document (TSSB), the expressions like “It is envisaged that energy efficiency actions will be taken to achieve less energy use in the industry, buildings and transportation sector by 2020. In this context, in the short term, energy efficiency studies carried out in relation to lighting, insulation, transportation and electrical devices are continued; upgrading the efficiency of existing power plants using new technologies and completion of rehabilitation works to increase production capacity; high efficiency cogeneration practices are planned to be expanded.” were clarified [61].

In line with these goals, and under the requirements of Energy Efficiency Law, a 20% reduction in the consumption energy is targeted in Turkey by the end of 2023 [56].

The transmission to smart grid based on energy efficiency and traceability becomes mandatory for the anticipated targets and programs in Turkey. In order to disseminate renewable energy sources in Turkey, the issued incentive law gives the permit to unlicensed energy production up to 1 MW. Table 4.6 and Figure 4.6shows the rates of unlicensed installed electrical resources at the end of August 2017 [62].

Table 4.6. Capacity distribution of unlicensed electrical sources in 2017 [62]

Resource Type	**Installed Power (MW)**	**Rate (%)**
Solar (Photovoltaic)	1,772.59	92.19
Natural gas	63.84	3.32
Biomass	55.49	2.89
Wind	22.15	1.15
Hydraulics	7.42	0.39
Solar (Concentrated)	1.22	0.06
Grand Total	1,922.71	100.00

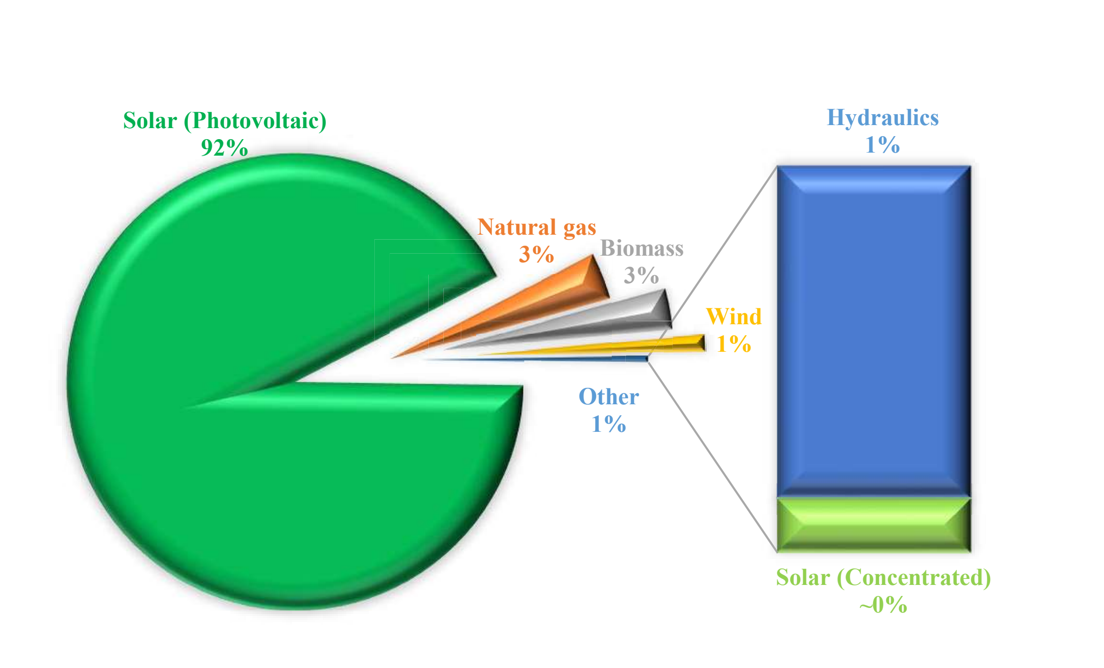

Figure 4.6. Distribution of unlicensed electrical sources installations at the end of August 2017 (%) [62]

Owing to renewable energy sources, consumers have become producers with the ability to produce their own energy and even supply energy to the grid. Therefore, the real-time pricing activation, and integration the renewable energy sources into the grid gives Turkey's work on smart grids distinct importance.

One of the benefits to be passed into the smart grid in Turkey is to reduce the loss in the existing electricity transmission and distribution grids. As shown in Figure 4.7, the losses in the distribution line are higher than the losses in the transmission lines [63].

It is likely that these losses in the distribution line can be reduced by switching to the smart grid system. When both Smart Grids and balanced distribution of load are made, minimization of losses in both transmission and distribution lines can be realized.

4.2. Smart Homes

Smart Houses can be defined as residential houses which can be monitored and controlled by equipping the classical house with information and communication technologies.

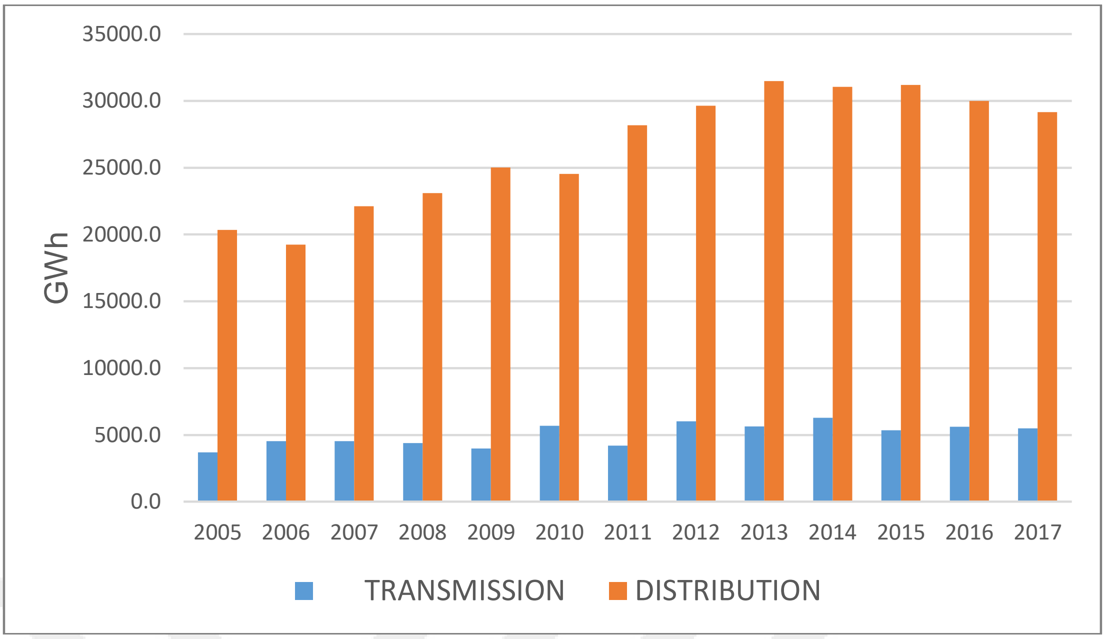

Figure 4.7. Loss rates in transmission and distribution lines [63]

4.2.1. Smart home concept

Emerging information and communication technologies allow our homes to become smarter. Many new software and devices suitable for this structure are being developed for smart homes which are analyzed as a sub-title of smart grids in many parts of the world and serve as a bridge between consumer and grid. The basic structure in smart homes is based on the establishment of an interactive relationship between grid operators and end-users, along with smart grid technologies [48].

By establishing communication infrastructure in smart homes, it is possible to have a two-way data flow, control and remote access to electronic devices as well as real-time pricing. In this way, the grid data will be monitored by the smart system in our homes and will regulate the operation of the electrical devices according to the grid status. As a result of this situation, peak loads in the grid will be reduced and a more efficient system will be introduced in terms of both cost and security.

Smart homes can be divided into three sections as devices equipped with sensor, two-way communication between these devices and the grid, and a user-adjustable control system [64]. It is also possible to formulate the smart home concept as a smart system card consists of a processor, sensor, Local Area Network (LAN) card and digital meter [65]. Figure 4.8shows a general scheme of the smart home.

No doubt that the smart homes may include renewable electric energy systems, electrical energy storage systems, forecasting systems, smart meters, smart plugs, smart lighting systems, charging systems for electric vehicles, as well as additional systems established to feed houses from vehicles [67, 68].

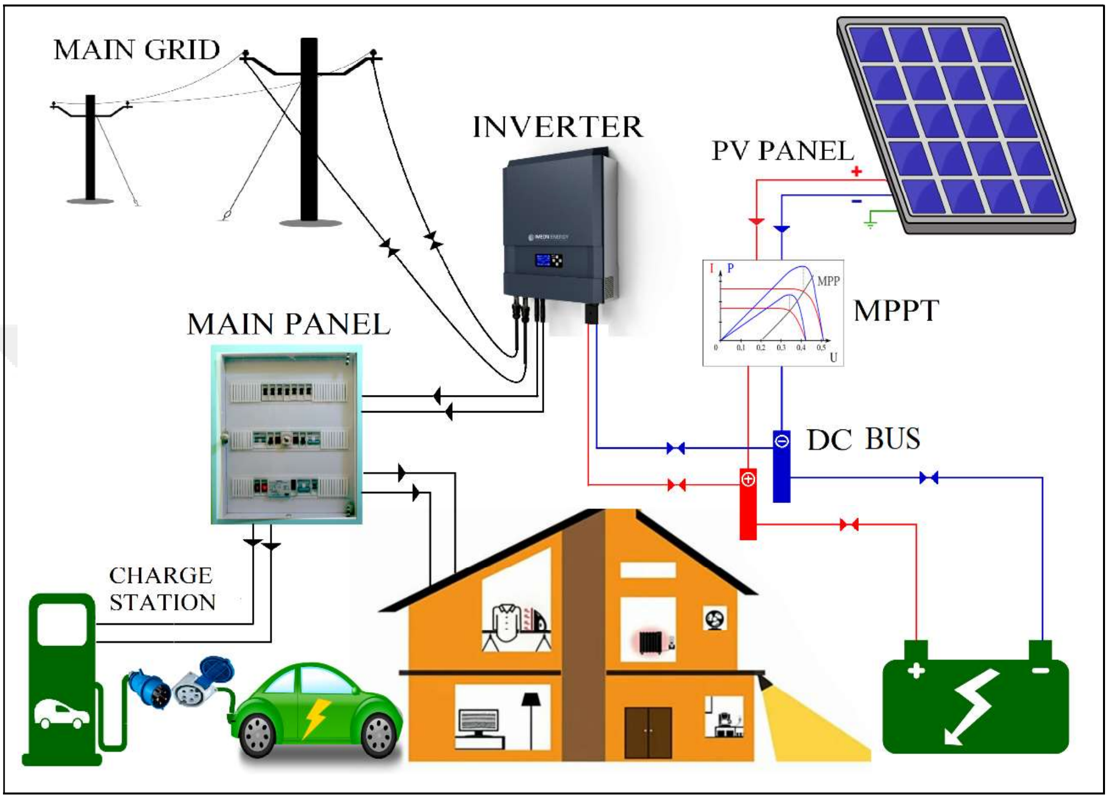

Figure 4.8. Smart home components, general scheme

4.2.2. Example of smart home in Turkey

It will be possible to create a more efficient grid by controlling and monitoring the consumption of electricity in the residential area. This is possible with smart homes. When the structure in the existing houses becomes "smart", a high level of savings and efficiency will be achieved in consumption. In this context, the Green Smart Home project was launched at Yildiz technical university as one of the first works in Turkey. Along with this project, various works related to smart grids in Turkey has been accelerated.

Under this project, the renewable energy systems are used in the smart house example to increase energy efficiency and reduce carbon emissions. Since the date of its establishment in 2012 until the end of 2015 [68], the total energy generated in

Turkey from renewable sources is 3,740,167 Wh, and thus, the carbon emissions are 2,206.7 kg.

Fig 4.9 shows an infographic of the carbon footprints of countries in Europe in 2014. This infographic uses the latest publicly available data sourced from the Emission Database for Global Atmospheric Research (EDGAR) and the US Energy Information Administration. shows the carbon footprints of countries in Europe in 2014 [69].

Since electrical energy from renewable sources is not continuous, it must be stored. In this context, a battery bank was created in the Green Smart Home project. The energy produced by renewable electric energy sources in the smart house is continuously monitored and recorded.

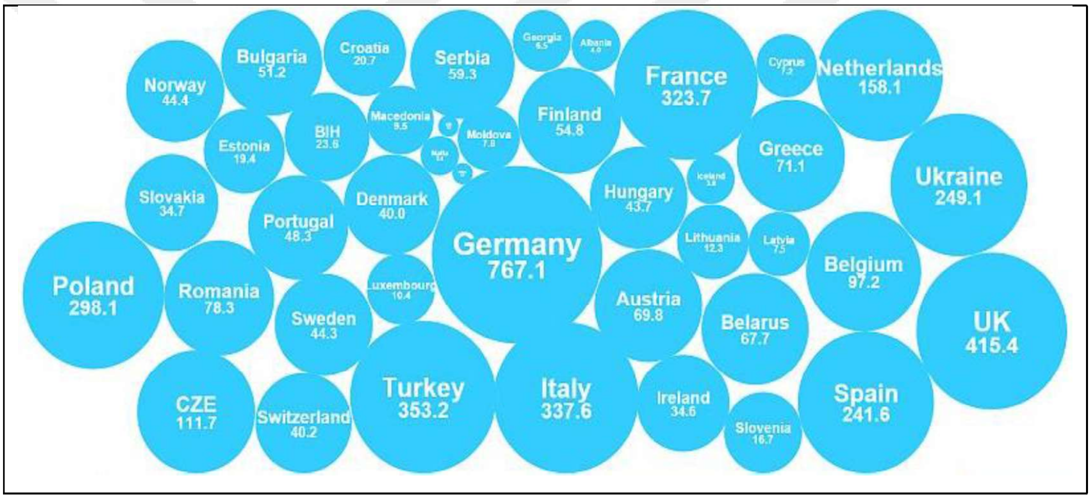

Figure 4.9. Infographic describes the carbon footprints of Europe in 2014 (in million tonnes of CO_2) [69]

At the same time, the weather station has been installed, so that forward-looking production estimates can be made and more precise energy management can be applied at home.

At the same time, weather forecast station was installed, in this way, forward-looking production can be made and more precise energy management can be applied at home. Proper inverter installation was carried out for the use of Direct Current (DC) electrical energy produced by solar panels at home.

The installed inverter also allows the home to operate independently with and without the grid. In cases where electricity generation from renewable sources is not carried out (when there is no electricity generation in the solar panel) and at peak times where the energy is expensive, an energy management algorithm has been developed that can achieve the minimum energy intake from the grid.

The load side control of energy management is carried out by means of smart plugs placed upstream the electrical appliances and which can be sampled in seconds. The smart house operational schematic is described in Figure 4.10.

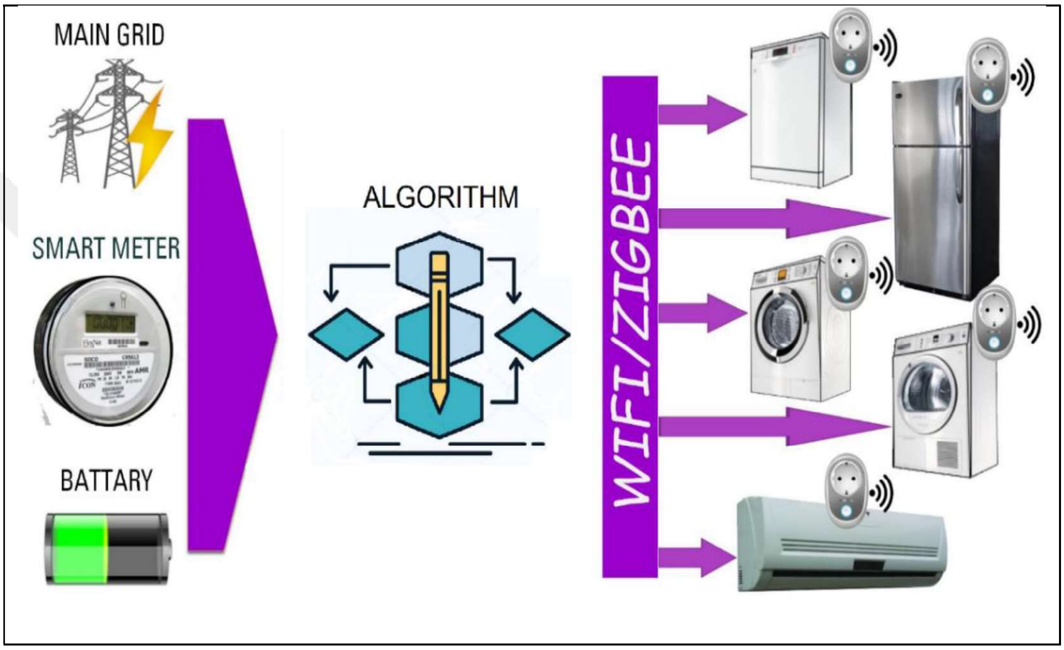

Figure 4.10. Smart home general management structure

IEEE 802.15.4 ZigBee protocol was used in the home. Smart plugs is installed in all sockets. In addition, temperature, humidity and lighting data are transferred to the central computer with the help of sensors.

Within the scope of the project, a web interface software has been developed that users can easily access to any point. This developed interface records and gethers collected wind, solar and weather forecast data, as well as in-house consumption data. In this project, the basic logic of smart houses was created by using renewable energy and energy management, and contributed to the efficiency, traceability, reliability and sustainability of energy.

With the management algorithm created with the related project, it has been shown that the electricity bill can be saved up to 25% [70].

4.3. Smart Meters and Smart Plugs

A strong infrastructure is required for our existing electricity grid to be able to monitor, secure, self-repair, bidirectional communication, as well as many other features. The most important step in the desired infrastructure is the smart meters.

4.3.1. Smart meter description and features

One of the most necessary applications to establish the relationship between the electricity grid and the consumer is the smart meters. Smart meters operate between the energy provider and the consumer as a “Smart Grid Interface” [66]. Energy consumption can be monitored remotely by using smart meters and various communication protocols. Moreover, both the distribution company and the consumer can be informed instantly via smart meters. Home Energy Management (HEM), using wireless communication in remote access (ZigBee, Bluetooth, wi-fi, etc.), reading power consumption, determining automatic bills and detecting outages all these works are recruited in smart home applications [71].

Management thinker Peter Drucker is often quoted as saying that “you can't manage what you can't measure.”. Based on this principle, energy management algorithms have been developed to control measurable(traceable) electrical energy. The energy management algorithm can be created by means of appropriate communication grids and smart applications within the house. In this way, more controllable and more efficient energy consumption can be carried out. The flexible operation and time-shifted loads become possible by energy management algorithms, thus reducing overloading on the grid side during peak times where electricity is expensive, thus avoiding energy losses, resulting in more efficient energy consumption. As a result, the emission of CO_2 gas, which is highly harmful to nature, is reduced. After a study by General Electric, “An estimated $341 million in customer cost savings and an estimated 9 million tons of CO_2 reduced since 2008” was highlighted in 2014 [72].

4.3.2. Smart meters in Turkey

smart meter works in Turkey, are carried out under the OSOS project. Within the scope of this project implemented within the body of TEİAŞ, works are carried out on the provision and installation of communication channels such as Asynchronous Digital Subscriber Line (ADSL) and General Pcket Radio Services (GPRS). By the end of 2012, 2,761 smart meters were installed in 948 different locations.

Within the scope of the project, data from these meters were read in a useful way. Web based software is developed for 349 users to see their own energy data. In the range of the "Energy Efficiency and Strategy" document, according to the energy and power quantity, subheads like "Graded Tariffs" and "Multi-time Meters" have been brought up to agenda. Multi-time Meters. is an application based on the principle of taking different prices for the electricity energy consumed at certain times of the day and certain days of the week. The weekend period (Saturday-Sunday) is not currently applied in Turkey.

4.3.3. Smart plugs

54% of the electrical energy produced in the United States is spent in buildings [73]. Almost half of Europe's electricity consumption is spent in homes, offices and commercial buildings [74]. After these information, it would be correct to say that one of the important topics in smart grids is smart homes. By providing energy efficiency in houses, it will be able to provide a high rate of efficiency in consumption. On the other hand, plug loads in residential and workplaces constitute almost 60% of total loads [75]. A certain part of this ratio is caused by the continuous plugging of the devices. To avoid this we need to create plug loads management algorithms.

The plugged electrical devices must be smart to be included in the management algorithms. In the current system, smart plugs are used because the devices are not yet smart. Smart plugs ensure that devices can be controlled and monitored. In addition, by transmitting data from smart plugs to electricity supply companies, peak demand can be reduced and consumption can be directed according to price.

4.3.4. Smart plug structure

In smart home systems, all electrical appliances within the house must be smart to be included in the energy management algorithm. The structure of the smart plugs outlined in Figure 4.11; measurement, evaluation, communication and switching are explained under 4 headings [68].

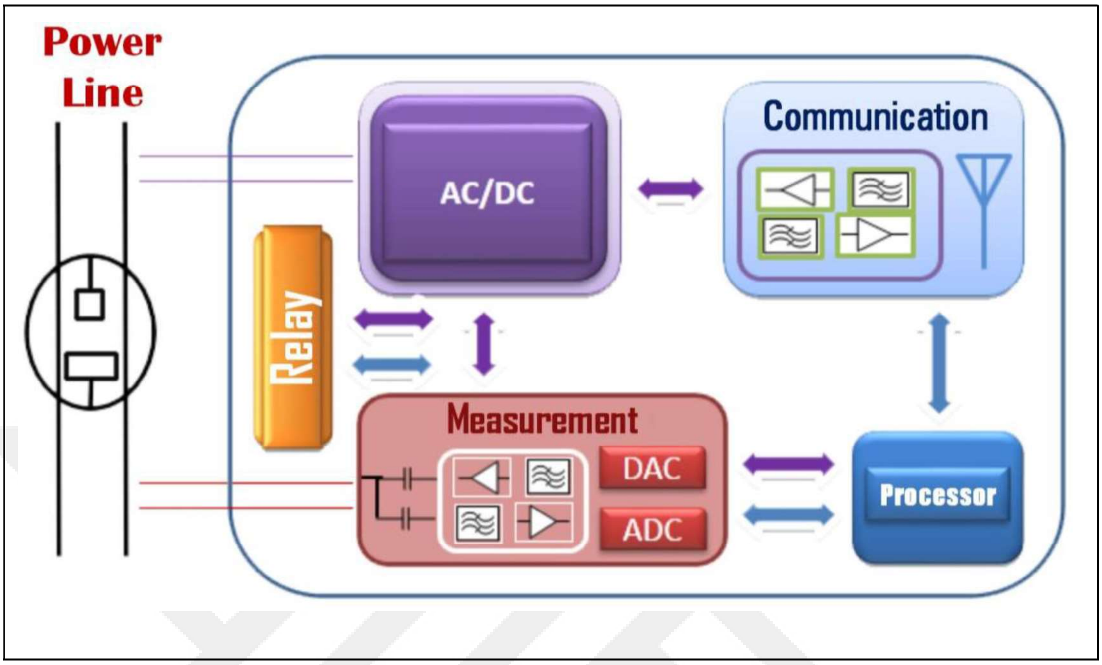

Figure 4.11. Smart plug structure [68]

4.3.4.1. Measuring

In order to save energy, we need to measure accurately. The measuring unit is one of the passive units of the smart plugs. We need to be able to read the current and voltage information accurately in the energy measurement calculation. The voltage measurement information is easily calculated by means of Analog Digital Converter (ADC). But there are several different methods for current measurement. In its simplest form, a Shunt Resistance (SR) can be used to calculate the current by taking advantage of the voltage drop on it. Although this solution is cost-effective and small in size, the voltage drop on the resistance in the case of high current, as well as the loss of heat on the resistance, adversely affect the efficiency of the system. In addition, if the load draws a high current, the results are affected by the temperature. Another method of current measurement is to use a current transformer. The current value can be read by resistance from a one-winder transformer. Although this solution has an advantage in terms of isolation, it creates instability of the system. Another solution for current measurement is to use a Hall-Effect Sensor (HES).

Other than the aforementioned methods, Power Measurement Integral (PMI) method is used in power measurement.

Only current and voltage samples are required to be inserted in the integral input of the power measurement circuits. The power measurement integrator analyzes these inputs with delta-sigma structures and calculates the results such as active power, reactive power, apparent power, phase difference, etc. These results are also sent to the processor for processing by the evaluation unit. The measurement methods used for different application areas are given in Table 4.7 [76].

Table 4.7. Measurement methods used for different application areas [76]

Home Applications	Entertainment Applications	General Applications	Smart Grid Applications
HES, PMI	HES, PMI,	HES, PMI, SR	HES, PMI, SR

4.3.4.2. Evaluation

Having a software and communication unit is the basic element to deal with normal plugs and make them smart. The necessary evaluations in the smart plugs are made in the software side by the processors. With the software algorithms performed in the processor, it is possible to use the plug in different operating modes. With this feature, energy management algorithms can be implemented in house with smart plugs. The energy management system can simply be expressed as planning the load or demand depending on the energy price. The management system related to the plugs called HEM Systems (HEMS).

4.3.4.3. Communication

One of the most important issues in smart grids is communication. There are many options under the field of communication according to the application areas. Among these options, communication techniques of different application areas are given in Table 4.8. The communication about smart plugs is included in the internal communication system. General communication methods used in indoor areas are listed in Table 4.9.

Table 4.8. Communication methods for different application areas [76]

Home Applications	Entertainment Applications	General Applications	Smart Grid Applications
PLC, ZigBee	PLC, ZigBee	PLC, ZigBee	GSM, GPRS, WiMAX, PLC, ZigBee

Table 4.9. Communication structures used in indoor spaces and comparison [76]

Characteristics	Standard	Data Rate	Coverage Distance (m)	Operating Frequency	Power Consumption
Wi-Fi	IEEE 802.11n	72.5, 150 Mbps	Up to 100	2.4-5 GHz	Very High
ZigBee	IEEE 802.15.4g	20, 40, 250 Kbps	10-75	868, 915 MHz 2.4 GHz	Low
Z-Wave	ITU-T G.9959	9.6, 200 Kbps	Up to 30	868, 915 MHz	Medium
EnOcean	ISO/IEC 14543-3-10	120 Kbps	Up to 30	315, 868 MHz	Very Low
Dash7	ISO/IEC 18000-7-2004	27.7 to 200 Kbps	Over 100	433 MHz	Low
PLC (Narrow-Band)	IEEE 1901.2	Up to 500 Kbps	25-50	1-500 KHz	N/C

4.3.4.4. Switching

Switching in the smart plug is used as an actuator in appliances' remote control. Switching cuts off the appliance’s power via the relay. In the literature, the triac is used as a switching element besides the relay [77].

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5. ELECTRICITY PRICING SYSTEM IN TURKEY

The Electricity Market Law provides for a market structure based on bilateral agreements. The price of electricity in this market is determined by mutual agreement of buyers and sellers. Therefore, prices set by bilateral agreements are within the knowledge of the relevant parties and are not shared with the public.

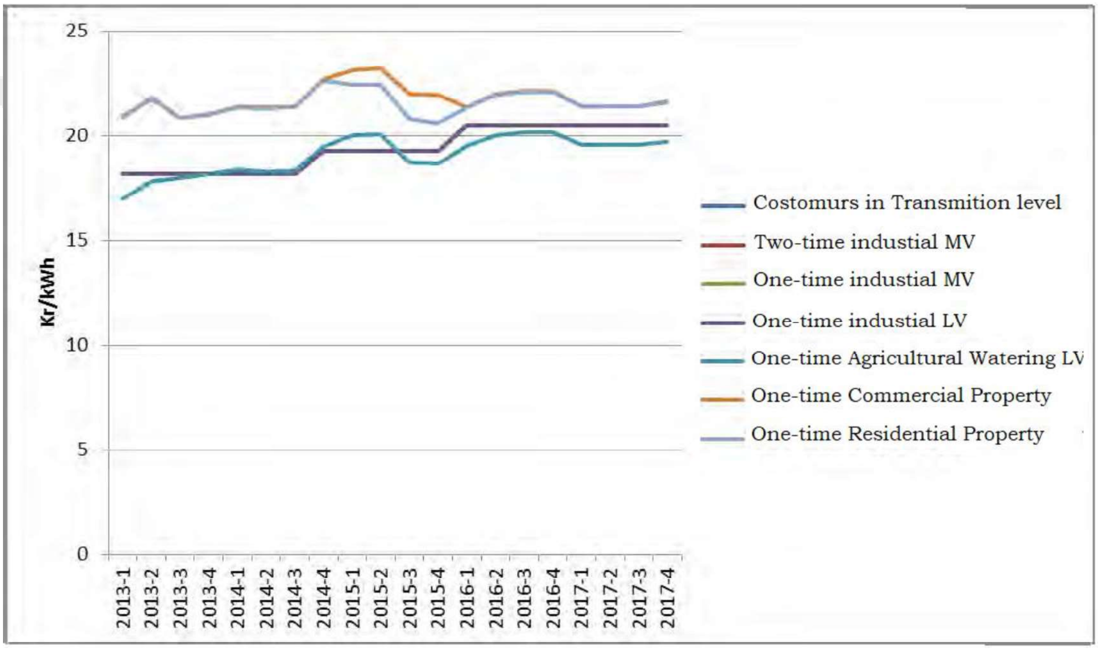

Figure 5.1. Changes in retail electricity prices in the last 5 years [78]

On the other hand, energy can be saved by applying regulated prices to a large part of consumers in the Turkish electricity market.For this reason, it is important to change the regulated prices and their components since years. In this chapter, data changes of regulated prices and its forming elements are presented over the years.

The following figure shows the changes in retail energy tariffs (including system costs and PSH(Retail Services), excluding tax and fund) for years according to tariff groups [78]. As it is known, transmission and distribution lines must be used for the transportation of energy from the producer to the consumer. The following figure shows the change in the distribution price by years.

Distribution, transmission and technical and non-technical loss costs are included in the above-mentioned amount. As a result of the addition of the distribution cost to the energy cost, the unit energy cost before tax is reached.

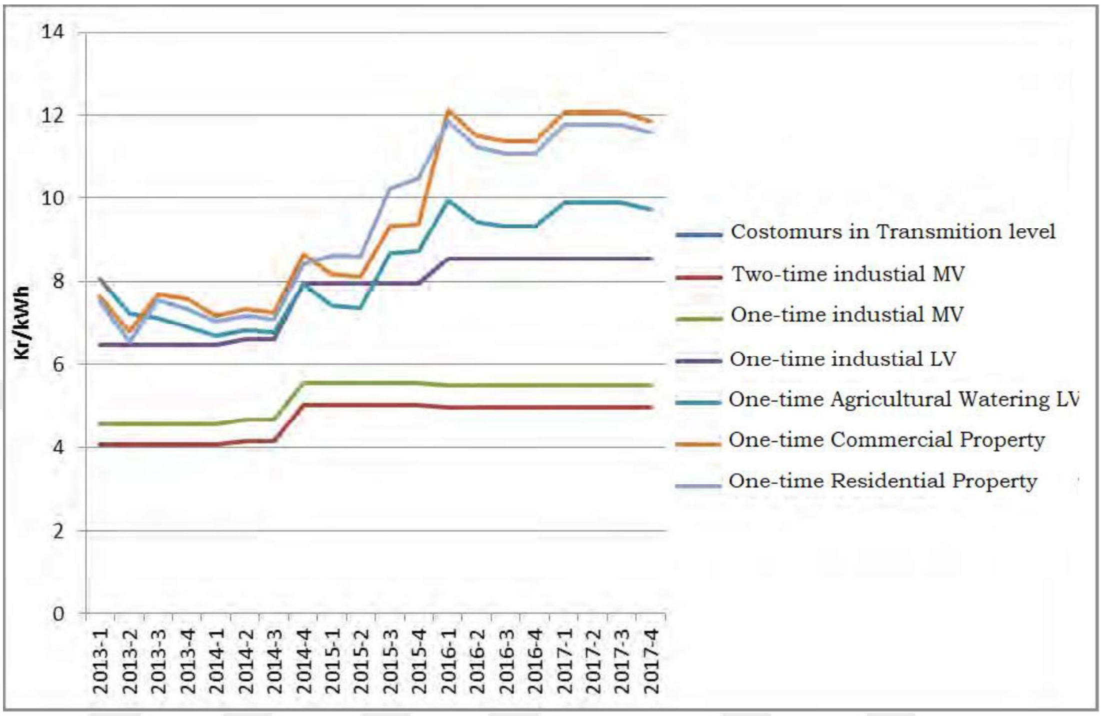

Figure 5.2. Change of grid (distribution, transmission and loss) prices by years (kr / kWh) [78]

The following figure shows the change in unit energy price by years, excluding taxes and funds (energy fund, Turkey Radio and Television (TRT) share, electricity and gas consumption tax and Value-Added Tax (VAT)).

As seen in the figure above, the consumer group, which has the highest unit energy cost before taxes and funds, is residential and commercial properties. The consumers who connected to the transmission system have the lowest unit energy cost (before tax and funds). As shown in figure 6.4, the most important component of consumer bills in the residential group - apart from the amount of retail power - is the distribution share of 29%.

Figure 6.5 shows that in the consumer bill components of the industrial group compared to the components of the consumer bill in the residential group in Figure 6.4, the share of the amount of energy sold is higher and the distribution grid share is lower.[78]

5.1. EPDK Electricity Tariffs 2018

Retail electricity sales companies sell electricity to the free consumers at the national tariff prices. Energy Market Regulatory Authority (EPDK) is the authorized public institution that regulates the prices in the electricity market. National electricity prices are updated quarterly.

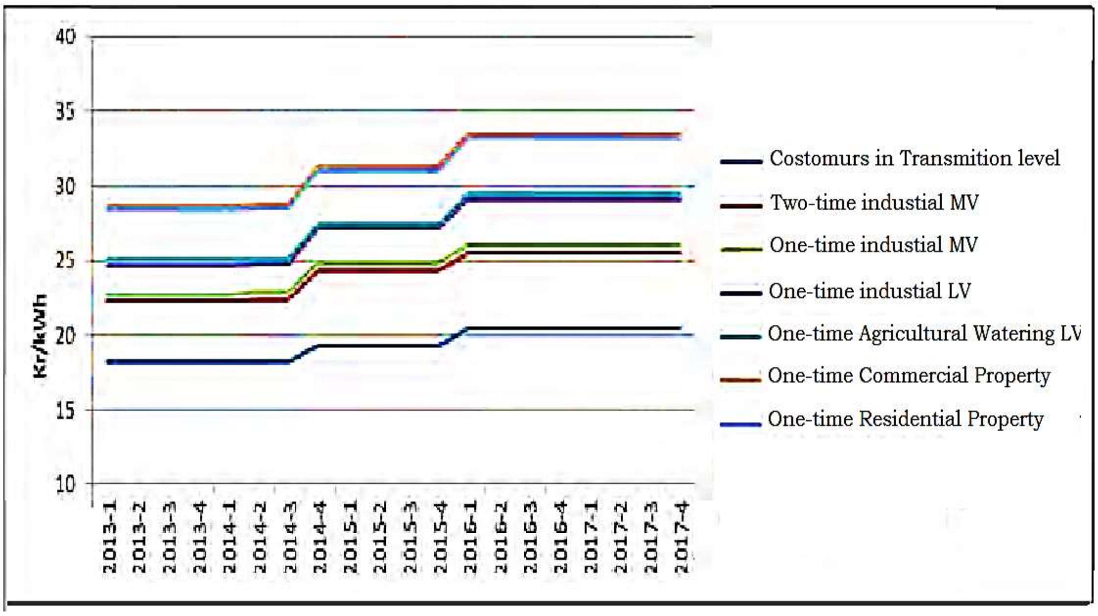

Figure 5.3. Change of final electricity tariffs before taxes and funds by years (kr / kWh) [78]

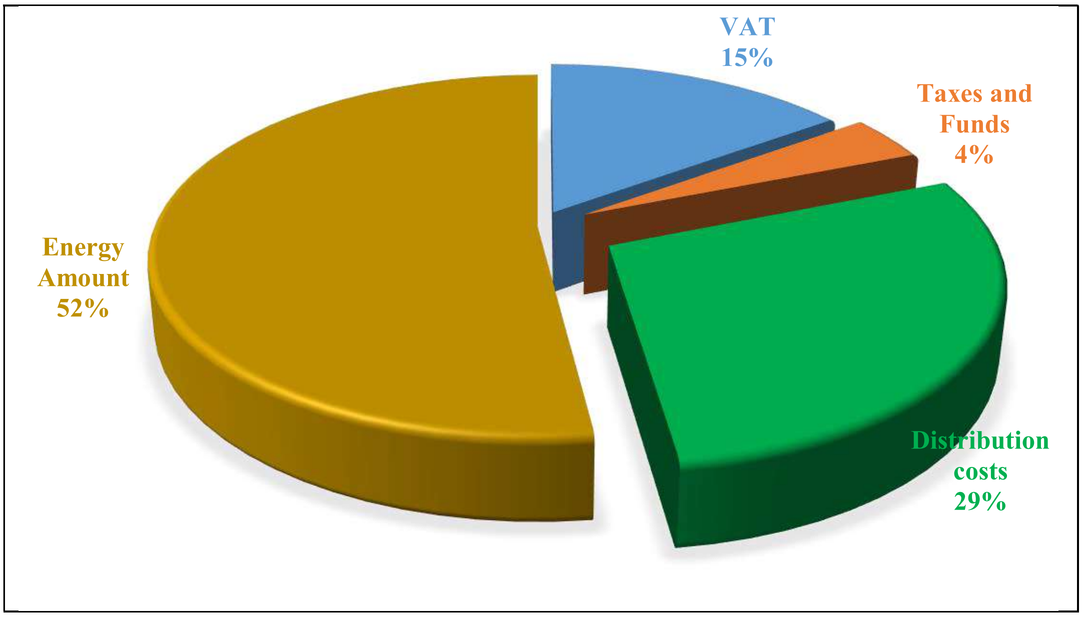

Figure 5.4. Share of fees included in residential electricity bill for 2017 (%)[78]

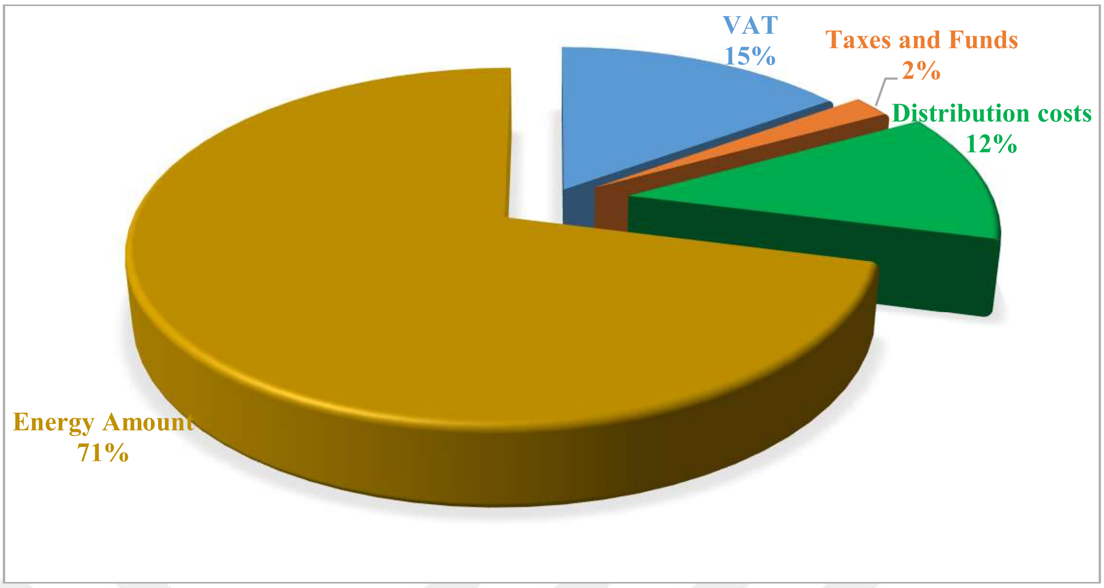

Figure 5.5. Share of costs in industrial electricity bill in 2017 (%)[78]

5.1.1. Electric kWh price 2018

National electricity prices for residential customers are regulated by the state. The independent public institution responsible for the electricity market is the Energy Market Regulatory Authority; ie EPDK. Electricity prices are a factor affecting the purchasing power of households. The price hikes in the national tariffs affect the social and economic spheres as well as inflation.

Table 5.1. By years, the raises made by epdk at the one-time residential unit price excluding tax [79]

Term	Raise rate	Term	Raise rate
2008	+%19:55	2014	+%9,00
2009	+%33,53	2016	+%6:8
2010	+%9,37	01/2017	-%3,15
2011	+9,58	10/2017	+%0:5
2012	+% 19,60	01/2018	+%6;8
2013	+%0,00	04/2018	+%5,95
		08-09-10/2018	+ 45% compared to the New Year's Day

5.1.2. Electricity prices table

The following unit prices are taken from the EPDK tariff tables in April 2018. Residential cunsomers have the possibility to choose two different tariffs. These tariffs are divided into two groups as one-time and three-time. In a one-time tariff, the unit price remains constant throughout the day, while three-time tariffs apply three units in 24 hours.[79]

Table 5.2. Residential unit prices including taxes and funds [79]

Residence	Daytime	Peak	Night
One-Time Tariff	0.46 TL		
Three-Time Tariff	0.4592 TL	0.7035 TL	0.2853 TL

Table 5.3. Commercial unit prices including taxes and funds [79]

Commercial	Daytime	Peak	Night
One-Time Tariff	0.4642 TL		
Three-Time Tariff	0.4622 TL	0.7065 TL	0.2883 TL

5.1.3. Difference between national price and discount price

It is important to distinguish between the national electricity price and the discount market price. Customers can negotiate with their chosen supplier on the market price. The market price is often referred to as discounted or cheap electricity. This is due to the fact that alternative suppliers, which are the competitors of the authorized sales companies, sell electricity by discounting the unit energy cost of EPDK.

Eligible consumers can change suppliers to serve more advantageous prices than the national price. To change the supplier, the power does not need to be cut off; because the distribution company does not change. For the same reason, there is no change in electrical quality.

5.2. Components of Electrical Unit Price

The unit price (kWh price) that the residential subscriber pays for electricity includes the energy price, the costs and the taxes related to the distribution cost.

5.2.1. Unit energy cost (active energy consumption amount)

The cost of production of electricity in power plants by using various energy sources is reflected as unit energy cost in unit price. 52% of the total bill debt, including taxes, constitutes the Active Energy Consumption Amount.

5.2.2. Non-Energy costs

5.2.2.1. Distribution cost

Costs for the stages during the delivery of electricity from the place of production to the place of use. In each new period, prices are announced by EPDK and multiplied by consumption and added to the bill. In the past, the transmission cost, the leakage cost, the retail price, and the old distribution cost is collected as a separate fee in a single item or removed by eliminating. Instead, for technical costs, only the Distribution Cost is now asked in payment. This amount constitutes 29% of the bill debt.

5.2.2.2. Taxes

In a one-time residential tariff, 19% of the unit electricity price consists of taxes.

A. Energy Fund: 1% of the energy consumption is transferred to a fund under the control of the Ministry of Energy and Natural Resources to support the research and other activities in the field of energy.
B. TRT share: It is taken as 2% of energy consumption from all subscriber groups to contribute to TRT revenues.
C. Electricity Consumption Tax (ECT): Electricity consumption tax paid by the residential customers to the municipality, is taken as 5% of the energy consumption amount.
D. VAT: Value added tax rate for electricity consumption is 18%. This percentage is applied after all taxes and charges are added to the Active Consumption Amount and added to the bill.

5.3. Electricity Price in 2018

During 2017, prices were increased, but due to inflation and increase in foreign exchange, the unit price and distribution costs increased in January 2018. As a result, we have seen an 8.8% increase in the price including taxes. In April, a hike of 5.95% in the active energy price besides the increase in taxes and costs was reflected in the bills by around 12%. Table 6.3 shows the final electricity prices of both residential and commercial tariff systems.

Table 5.4. The final tariff system for residential and commercial properties [79]

	Residence Property			Commerce Property		
Name of Tariff	Daytime	Peak	Night	Daytime	Peak	Night
Three-Time Tariff. Cheap electricity at night	0.6050 TL	0.8886 TL	0.3184 TL	0.7207 TL	1.0582 TL	0.3783 TL
One-Time Tariff. Same price all day long	0.5972 TL			0.7148 TL		

*The 2018 October's tariff was taken as basis. Daytime (06.00-17.00), Puant (17.00-22.00), Night (22.00-06.00) [79]

6. THEORETICAL APPROACH AND METHOD

In the recommended timing schedule, the operation of any device is divided into a group of serial power stages. The power stage is a nonstop secondary mission of device operation using a predefined amount of energy. these stages are sequent so that the next mission of the device cannot start until the previous one is completed (for example, the washing machine cannot start washing until its reservoir is full). The device scheduling process will be mathematically formulated as a MILP problem whose description has been given in the next chapter.

In addition to the last two criteria, each stage could have extra restrictions defined by the manufacturer. These restrictions for a particular stage involve limiting the instant power consumed (matching with the max operating power and no-action power) and achieving the max fulfillment time.

Although all stages of energy associated with a single device have to run sequentially, a delay can be placed between the stages as long as the stage arrangement is maintained (e.g. it is not recommended that the washing machine stop moving more than 10 minutes after the tank is filled).

Also, between the devices each other, there are additional sequential restrictions. For example, a certain device cannot operate before some other device finishes (e.g. washing machine and clothes dryer).

Furthermore, there is another limit relative to safety requirements called the total peak. In brief, the instant power aggregate of all devices cannot exceed this limit. Finally, there may be time preferences defined by the consumer, determining certain devices to finish their tasks at a certain time (e.g. dishes must be clean before breakfast, so the dishwasher has to run between 4 am and 6 am).

In terms to achieve these operational restrictions, the device operation schedule specifies the suitable power missions, as time functions over the implement duration.

Hence, we can define the device power profiles term as the time-based power missions and each compatible with a particular energy stage of the device concerned. The purpose of the proposed scheduling program is to find the lowest set of power profiles without overriding the needful operational restrictions.

To figure out the scheduling problem mathematically, the next section provides an introduction to the "MILP" based on the device scheduling problem.

6.1. MILP Formulation

The decision-problem which supposed to manipulate the consumed energy scheduling can be processed as MILP. Hence, to configure a problem like this, problem's setup, variables, restrictions definition is required. The mathematical description of these components is provided below.

6.1.1. Problem setup

The device operation periods will be divided into equal time intervals (exp. 30 or 60 minutes for each interval). The number of devices that subject to process is referred by N. And n_i (for i = 1,2,3…, N) indicates to energy stage for each device. Note that these stages not allowed to be interrupted. So, to avoid ambiguity, we suppose in this paper to abstract terminologically between 'device' and 'energy stage'. to demonstrate the last idea, it can be said that a device used twice a day can be processed as tow individual device.

6.1.2. Variables

The outcome of the assumed scheduling is an energy profile, denoted by K_{in}^{m}, describes assigned power to stagen of device i, during the whole time interval m. It is worth mentioning here that the energy profile K_{in}^{m} is a real continuous variable. Note, kWh is the standard unit of the variable K_{in}^{m}.

Of equal importance, a binary variable that helps to specify whether a stage is operating or not is needful. This integer variable is donated $y_{in}^{m} \in \{0,1\}$. Indeed it can be said that stage n of device i has been processed in interval m if and just if y_{in}^{m}=1.

This variable is substantially required to formulate restriction, which is responsible for energy stage successive operation.

Moreover, the problem needs another two binary variables to be solvable. If $(1\ )$is assigned to the first variable- denoted as y_{in}^{m}=1, that means stagen of device i has been already executed in time interval m. The other's usage is to indicate that device i has to move on from stage $n-1$ to n. For this reason, nranges here just from 2 to n_i (i.e., number of stages in device i minus one).

6.1.3. Electricity price function

The essential aim of proposed scheduling is to minimize device total electricity cost. this study is based on a day-ahead tariff system (TL per kWh) for cost calculation. The curve that represents the tariff system is a step function having finitely many pieces (piecewise constant). An example of a typical tariff curve is shown in Fig.7.1.

c^m presents electricity tariff in time interval m. Thus, the total electricity cost of operating devices is:

$$\sum_{m=1}^{s} c^m \left(\sum_{i=1}^{N} \sum_{n=1}^{n_i} k_{in}^{m} \right) \tag{6.1}$$

6.1.4. Restrictions

In order to facilitate, restrictions will be divided into two group – energy restrictions and timing restrictions.

6.1.4.1. Energy restrictions

A. Meeting stage energy needs: To ensure that energy stages have met their energy needs, the following restriction is imposed:

$$\sum_{m=1}^{m} k_{in}^{m} = E_{in} \qquad \forall i, n \tag{6.2}$$

Where E_{in} is taken from the Operational specification of the devices. So, E_{in} is the energy needs for stage nof device i.

B. Determining stage instant power limits: the following restriction is designed to maintain consumed power between upper and lower power limits assigned to each stage.

$$\underline{k}_{in}^{m} y_{in}^{m} \leq k_{in}^{m} \leq \overline{k}_{in}^{m} y_{in}^{m} \qquad \forall i, n, m \qquad (6.3)$$

Where $\underline{k}_{in}^{m}$ and $\overline{k}_{in}^{m}$ are the upper and lower power limits according to the device's Operational specification data. Note, if variable $y_{in}^{m} = 0$, the former restriction will turn into one simple condition which is $k_{in}^{m} = 0$.

C. Power security (overload protection): the security restriction represents the upper limit of the total consumed energy at any time interval, and can be modeled as:

$$\sum_{i=1}^{N} \sum_{n=1}^{n_i} k_{in}^{m} \leq PEAK^{m} \qquad \forall m \qquad (6.4)$$

Where $PEAK^{m}$ is the peak value during interval m. this value comes from the exterior grid operator which can be a demand response parameter.

6.1.4.2. Timing restrictions

I. Stage fulfillment time limits: to model the limits of stage implementation time, the following restriction is designed:

$$\underline{T}_{in}^{m} \leq \sum_{m=1}^{S} y_{in}^{m} \leq \overline{T}_{in}^{m} \qquad \forall i, n, m \qquad (6.5)$$

Where $\underline{T}_{in}^{m}$ and $\overline{T}_{in}^{m}$ are processing time limits of intervals number for stage n in device i.

II. Uninterruptible operation: stage operation cannot be continued after a pause; the stage is considered uninterruptible. A restriction can be designed with the help of auxiliary variable z_{in}^{m} as follow:

$$y_{in}^{m} \leq 1 - z_{in}^{m} \qquad \forall i, n, m \qquad (6.6)$$

$$y_{in}^{m-1} - y_{in}^{m} \leq z_{in}^{m} \qquad \forall i, n, \forall m = 2,3, \ldots\ldots, S \qquad (6.7)$$

$$z_{in}^{m-1} \leq z_{in}^{m} \qquad \forall i, n, \forall m = 2,3, \ldots\ldots, S \qquad (6.8)$$

According to equation (6.6), stage nof device i is already completed in time interval m, if and only if $z_{in}^{m} = 1$. Accordingly, the variable $y_{in}^{m} = 0$. Therefore, running the restriction $z_{in}^{m} = 1$ means that this stage has just been completed (i.e., the value of y_{in}^{m} has changed from zero to one). This is the case equation (6.7). Last of all, z_{in}^{m} suppose to stay unity as designed in equation(6.8).

III. Consecutive operation: Consecutive operation of stages of a device means that any stage cannot be operated if its former stages haven't completed yet. This restriction can be designed utilizing from the auxiliary binary variable z_{in}^{m} as follows:

$$y_{in}^{m} \leq z_{i(n-1)}^{m} \qquad \forall i, m, \forall n = 2,3, \ldots\ldots, n_i \qquad (6.9)$$

In the same manner, designing the consecutive operation between devices can be conducted by similar restriction as follow:

$$y_{i1}^{m} \leq z_{\tilde{i}n_{\tilde{i}}}^{m} \qquad \forall m \qquad (6.10)$$

Where $\tilde{i}$ refers to the device that has to be completed before i device can start. And $z_{\tilde{i}n_{\tilde{i}}}^{m}$ relates to device $\tilde{i}$, energy stage $n_{\tilde{i}}$ at time interval m.

IV. Delay between stages: here the binary variable t_{in}^{m} is used to calculate the number of time intervals (gaps) between device's stages. If $t_{in}^{m} = 1$ that means in time interval m device i has completed stage $n-1$ and waiting to start stage n (i.e., stage n is completed or not operated yet). The congruous restriction is :

$$t_{in}^{m} = z_{i(n-1)}^{m} - (y_{in}^{m} + z_{in}^{m}) \qquad \forall i, m \forall n = 2,3, \ldots\ldots, n_i \qquad (6.11)$$

As long a stage cannot be completed and operated at the same time, so the inequality $y_{in}^{m} + z_{in}^{m} \leq 1$ is always verified as mentioned in equation (6.6). After defining t_{in}^{m} as above, the restriction that governs lower and upper limits of the transition interval's number can be written as follow:

$$\underline{D}_{in} \leq \sum_{m=1}^{S} t_{in}^{m} \leq \overline{D}_{in} \qquad \forall i, m \forall n = 2,3, \ldots, n_i \qquad (6.12)$$

Where $\overline{D}_{in}$ and $\underline{D}_{in}$ determine delay limits(in a number of time intervals) between stage from the device specification.

V. Customer preference: the householder has the ability to determine time preference restrictions. Thus, He/She selects the time period in which a specific device operation must be done. In other word, devices cannot be work outside of preference periods. This type of restriction can be formulated as follow:

$$y_{in}^{m} \leq PP_{i}^{m} \qquad \forall i, m, n \qquad (6.13)$$

Where PP_i^m refers to the preference period. Note, that if $PP_i^m = 1$ then there isn't any stage of devicei can be made during time interval m.

6.1.5. Objective function and proposed scheduling

To gather up, the objective of this work is to find the optimum schedule that minimizes the residential devices operating cost. Scheduling problem briefly can be written as:[1]

$$\left.\begin{array}{ll} \min\limits_{k,y,z,t} & \text{Total cost (1)} \\ \text{subjected to} & \text{restrictions (2 -13)} \\ & k_{in}^{m} \in \mathbb{R}, \ \ \forall m, i, n \\ & y_{in}^{m}, z_{in}^{m} \in \{0,1\}, \ \ \forall m, i, n \\ & t_{in}^{m} \in \{0,1\}, \forall m, i, \forall n = 2, \ldots, n_i \end{array}\right\} \qquad (6.14)$$

This kind of problem can be solved by using linprog.m function that comes with the optimization toolbox of MATLAB. It employs the branch and bound algorithm. Accordingly, optimal management of total energy consumption processed as a MILP problem using MATLAB with Optimisation Toolbox which provides a solver able to address such kind of problem. Modeling and Solving in MATLAB have two kinds of Workflows:

Solver-based: Define problem using matrices and vectors according to solver syntax. Problem-based:(produced in R2017b) Define the problem using optimization variables, expressions and restrictions. It is available for linear programming and Mixed integer linear programming.

With the Problem-based workflow, we start with the optimization variables, then define the objective, and constraints in terms of those variables same to the mathematical models. Problem-based is more understandable and takes more lines of code than solver-base. But in more complex problems, it is often the case that there is a set of restriction with the same form. These can be specified with a single line code in the problem-based workflow.

The results are in much more compact and readable formulations than with the solve-based workflow. Because all the formulations are in a mathematical syntax, not matrices.

7. NUMERICAL STUDIES

All the tests in this study are implemented on a Toshiba PC with Core i3 processor and MATLAB R2018a.

7.1. Program Efficiency in Different Types of Electricity Tariffs

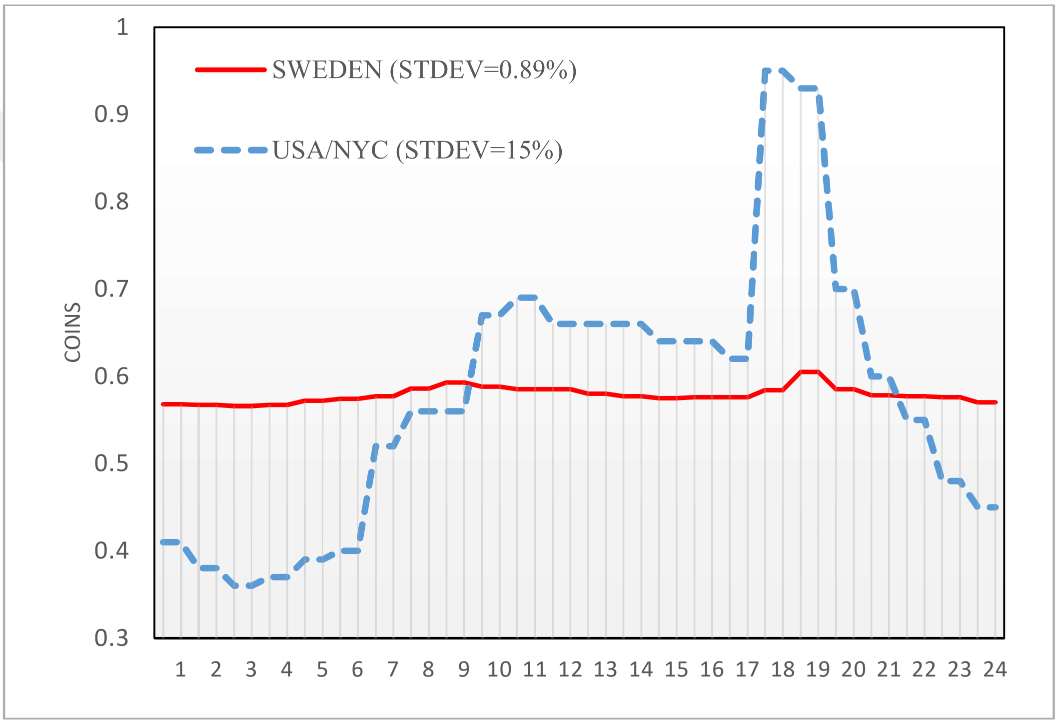

Figure 7.1. Electricity tariff system in USA/NYC and Sweden [80,81]

Two examples of household devices scheduling problem are solved by utilizing Problem-based Workflow that comes with the optimization toolbox of R2018a. The first example takes tariff samples from the USA [80] and Sweden [81].

The two countries use TOU Dynamic-Pricing system whereby tariff is fixed in specific intervals on day ahead basis, usually does not change more than twice a year. These two tariffs have been chosen in a way that they have the same mean value (considering that 1 United States Dollar (USD) ≈ 10 Sweden Krona (SEK)), but they differ in standard deviation.

Fig 7.1 shows clearly that (Peak tariff/Average tariff) ratio differs significantly between the Sweden and USA electricity tariff.

The second example is focusing on Turkish electricity tariff, shown in Fig 7.2, for both residential and commercial real estate. These two tariffs have different mean value but the standard deviation is almost the same. 20% - 24% Standard Deviation (STDIV) for residential and commercial respectively.

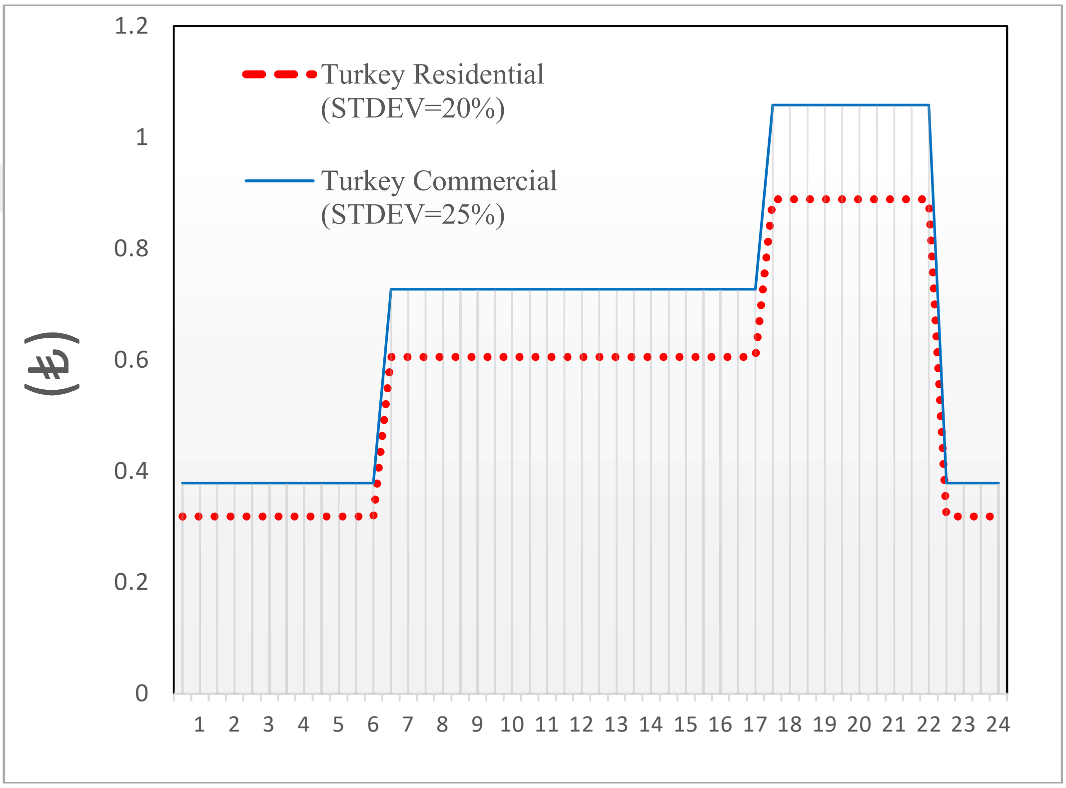

Figure 7.2. Electricity tariff system in Turkey for residential and commercial real estate

The time of every interval is 15 minutes. And by that, there are 96 intervals per a day. There are three manageable devices involved in the process: a clothes dryer, a washing machine, and a dishwasher. The householder puts the time preference restrictions (described in equation (6.13)). The dishwasher works between the 10 pm and the 6 am. The washing machine and dryer can work whenever it is suitable to achieve the largest saving.

However, All the washing machine operations ought to finish before the dryer can begin its first phase. The parameters of the operational specifications in the other restriction can be taken from the Appendix. In the end, the safety maximum value of the instantaneous power of the three devices is supposed to be set, and is always equal to 5500 Wh.

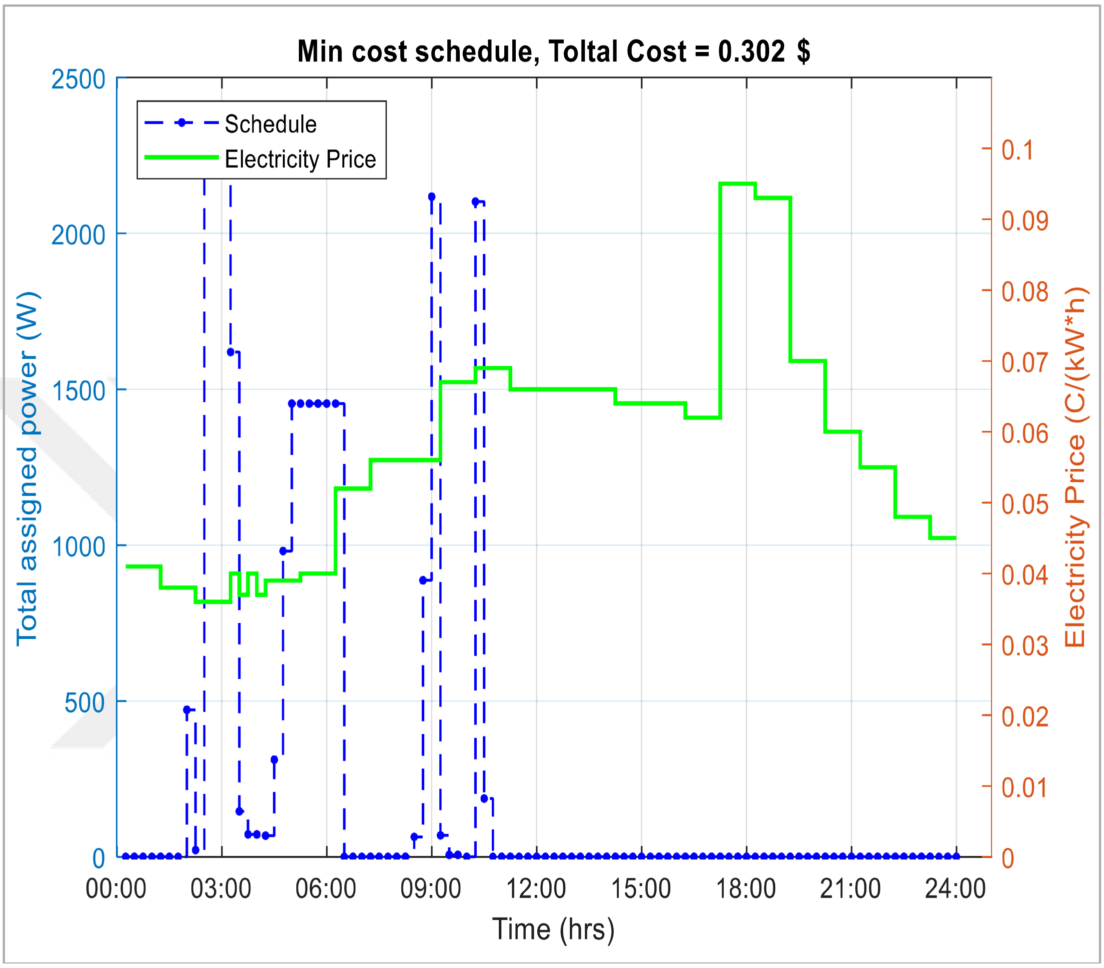

Figure 7.3. Optimal schedule for USA tariff case

After the first example is solved (with the Swedish and the USA electricity tariff price), the total energy set to all devices in every interval, and the electricity tariff, are represented in Fig 7.3 and Fig 7.4, which confirm that the scheduler specifies the electricity consumption when it is inexpensive.

The similar outcomes from solving the second example with the Turkish residential and commercial electricity tariff are shown in Fig 7.5 and Fig 7.6 respectively. The minimum cost in the USA state is $ 0.239 (about 7.17 American dollar monthly bill for the chosen devices). Furthermore, the minimum cost in the Sweden state is 3.489 SEK (about 104.67 SEK per month (≈11 USD)).

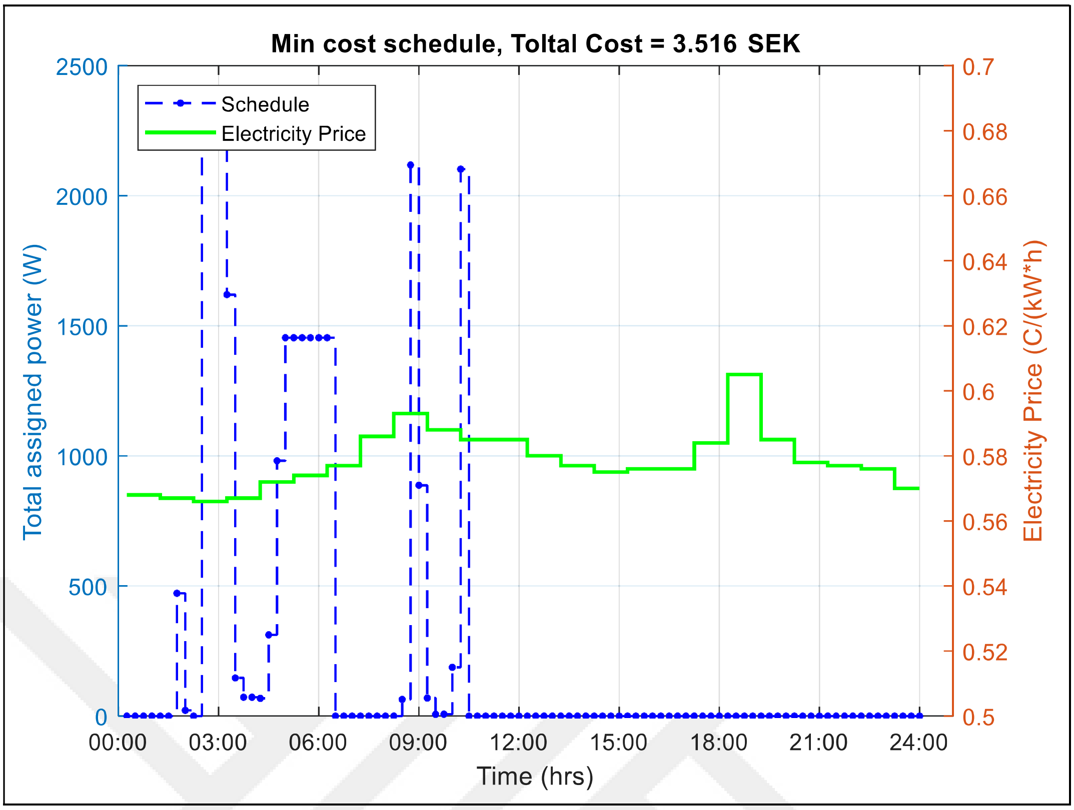

Figure 7.4. Optimal schedule for Sweden tariff case

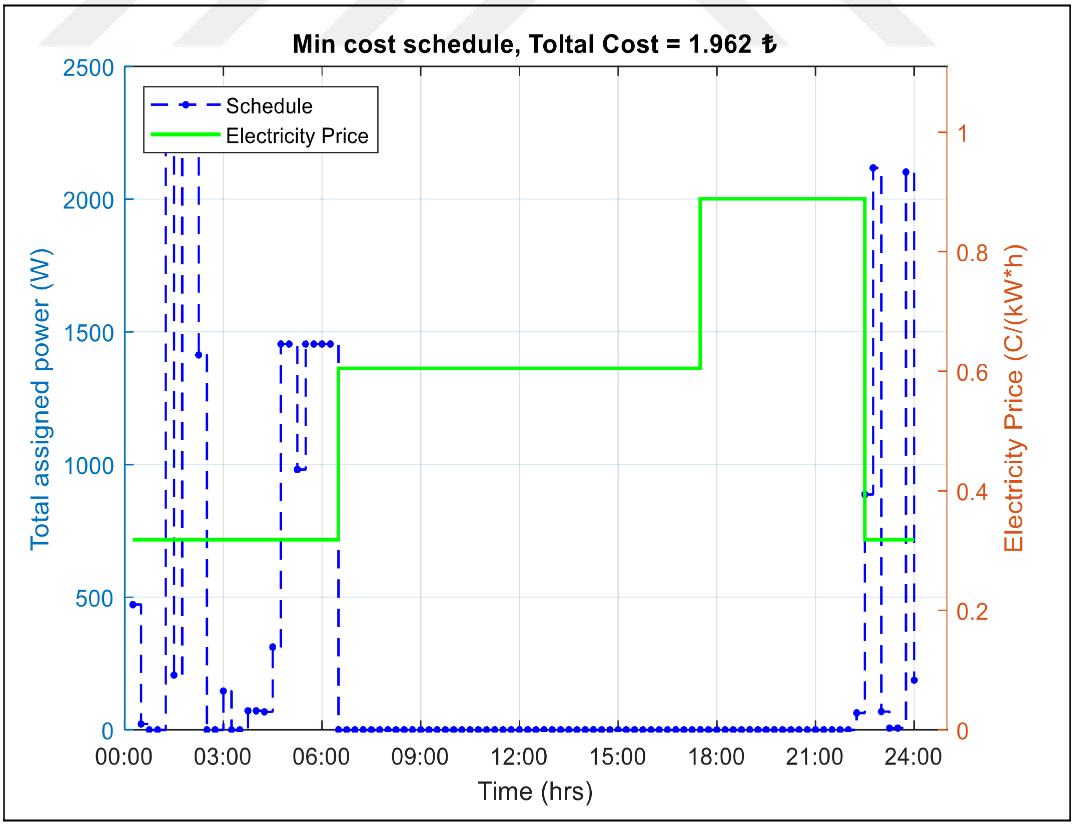

Figure 7.5. Optimal schedule for Turkish residential case

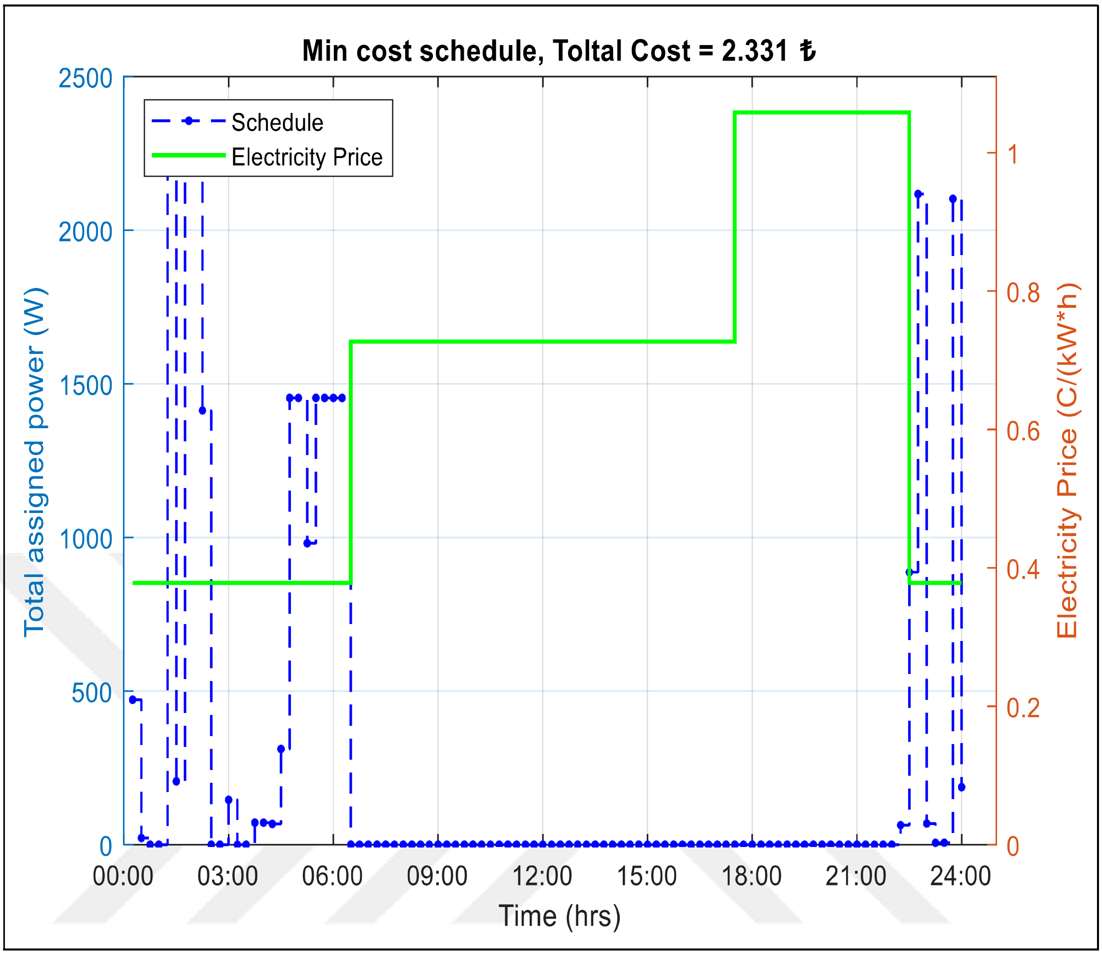

Figure 7.6. Optimal schedule for Turkish commercial case

7.2. Calculate The Maximum Cost for The Previous Cases

The best way to evaluate our results and know the maximum possible savings, is to calculate the largest energy cost by using this scheduling program. The optimization problem in equation (6.14) can be transformed into the worst scheduling scenario by modifying the objective function in equation (6.14) to maximization case instead of minimization.

Fig 7.7 and Fig 7.8 show the max costs of the scheduled devices according to the electricity tariff in the USA and Sweden respectively.

In the Sweden case, the maximum cost is 3.641 (about 3.4% Extra cost). The saving is worthless in such a pricing system. On the other hand, for the USA, the maximum is 0.518 USD (about 41% extra cost).

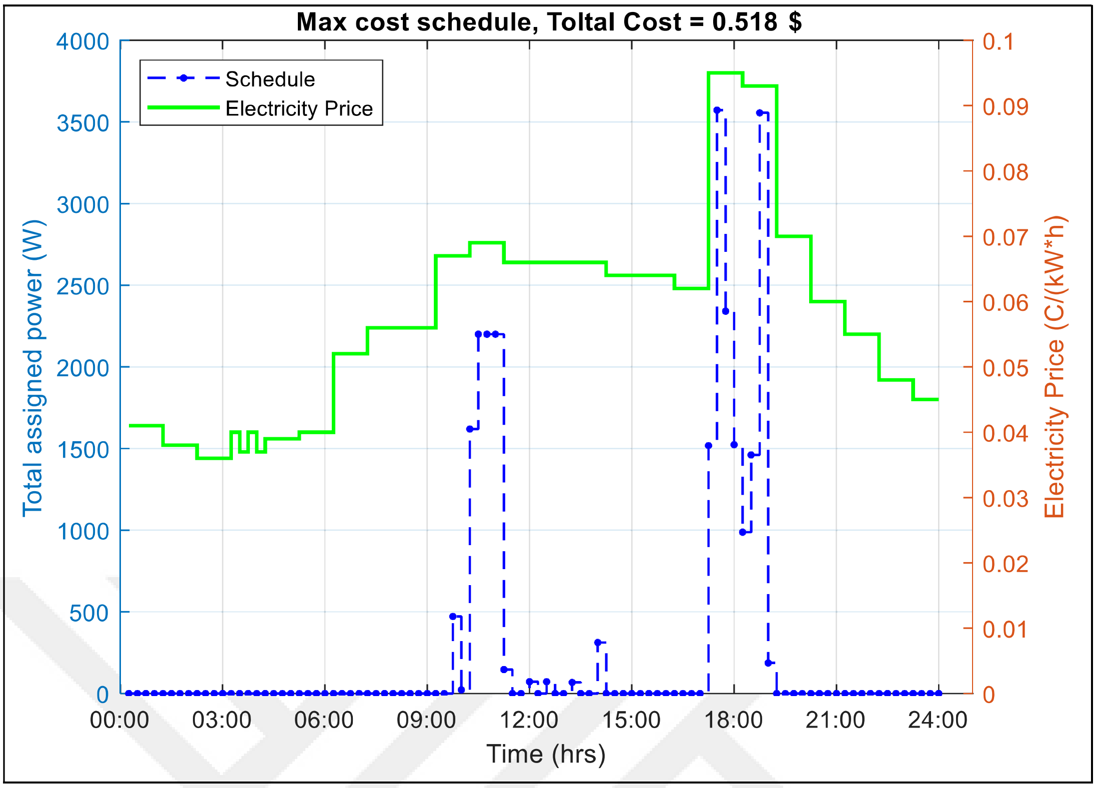

Figure 7.7. Maximum energy cost for the USA tariff

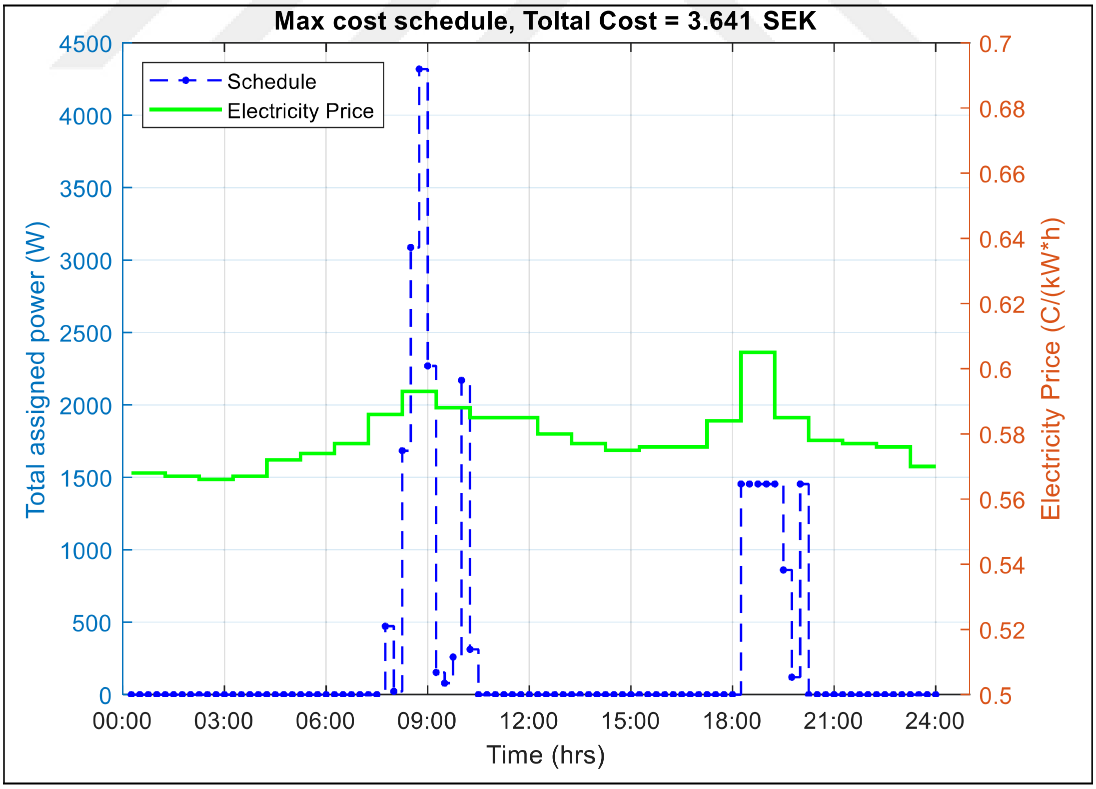

Figure 7.8. Maximum energy cost for Sweden tariff

Likewise, in the Turkish situation, calculations are made for both residential and commercial tariffs. In the residential case, the maximum cost is 5.449 TL (about 63% Extra cost). On the other hand, for the commercial, the maximum is 6.489 TL (about 64% extra cost). Fig 7.9 and Fig 7.10 show the max costs of the scheduled devices according to the Turkish electricity tariff in residential and commercial properties respectively.

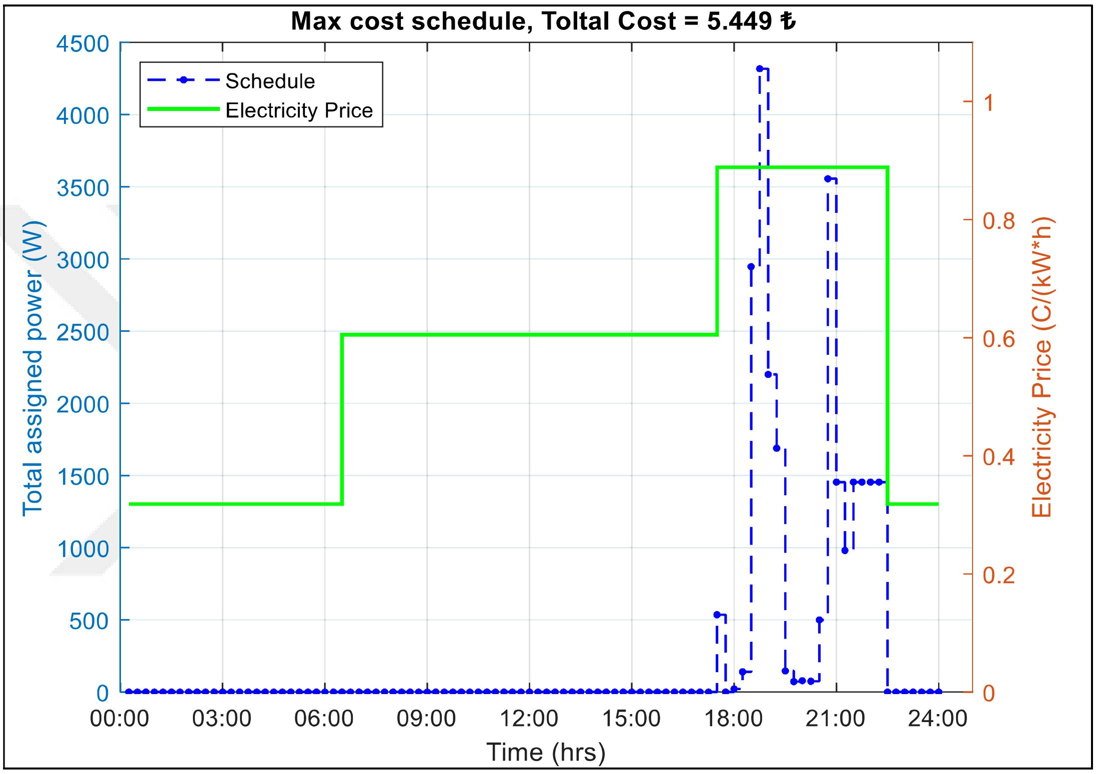

Figure 7.9. Maximum energy cost for the residential tariff

Table 7.1. Scheduling results for different tariff types

	NewYork City (USD x 10)	Sweden (SEK)	TR Residential Tariff (TL)	TR Commercial Tariff(TL)
Peak Price	0.95	0.605	0.8886	1.0582
Cheapest Price	0.36	0.566	0.3184	0.3783
Mean value	0.577083	0.578625	0.56855	0.679767
Standard Deviation	16%	1%	21%	25%
Optimal cost	0.302	3.516	1.962	2.331
Worst scenario cost	0.518	3.641	5.449	6.489
Maximum Saving	41.70%	3.43%	63.99%	64.1%

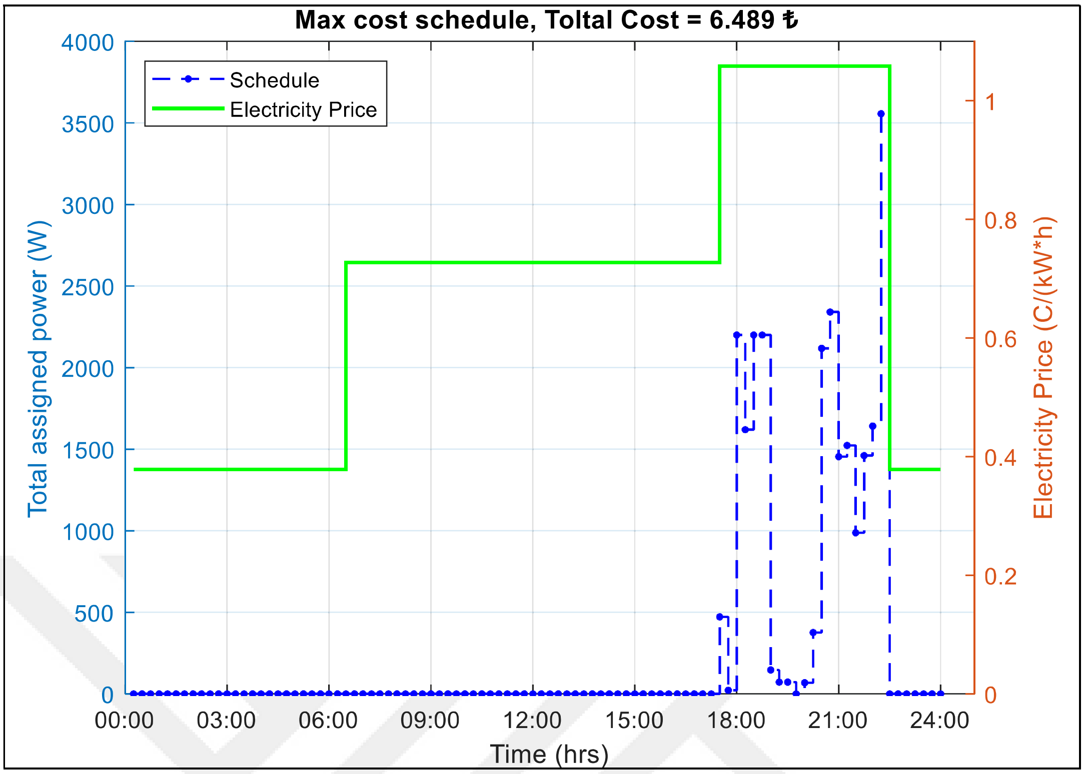

Figure 7.10. Maximum energy cost for the commercial tariff

Table 7.1 shows the final results that allow the researcher to judge the effectiveness of the proposed scheduler.

7.3. Appropriate Tariff System for Consumers in Turkey

Electricity distribution companies in Turkey offer two options for residential and commercial consumers. Here, the user is in charge to discover which option is the best to his or her consuming behavior and achieve the most bill savings. The first option was studied in the previous examples where there are three periods of electricity pricing per day (3-time tariff). The second option makes the electricity price constant throughout the day, which makes it easier to calculate the daily cost of consumed energy.

To compare the two options, the energy cost should be calculated in the one-time tariff case. This can be done by multiplying the fixed price by the daily energy consumed in all scheduled devices. The table 5.4 shows the fixed price of one-time tariff in both residential and commercial properties. The daily total energy consumed in each device can be calculated by summing the energy required to operate all phases (Required data can be found in the Appendix 1). After made calculation we found that the total energy is 3.706 kWh.

Table 7.2. Total cost in 1-time and 3-time electricity tariffs in Turkey

	Residental Tariff		Commercial Tariff	
Option	One-Time	3-Time	One-Time	3-Time
Daily Cost (TL)	2.213	1.953	2.649	2.32
Difference (TL)	0.260		0.329	

The residential customer -as shown in Table 7.2- has the ability to save about 0,26 TL per day (about 8 TL in the 30-day bill). Furthermore, the daily saving in the commercial case is 0.33 TL (i.e. about 10 TL in the bill). This finding suggests that savings with the current tariff in Turkey do not motivate customers to convert from one-time to the three-time pricing system. In other words, it is not reasonable to put restrictions on when the customers use home devices without a noteworthy saving in the bill. It is up to administrative parties concerned to develop the demand response to take the necessary measures to establish certain tariff systems that allow consumers to benefit from bill savings in return to regulate consumption.

7.4. Program's Time Response in Different Types of Tariff

If we deal with a case like individual customers, it preferred to solve the device scheduling problem as timely as possible to keep up with their time preferences. As long as the program allows the user to control some devices, so that determines the operation time, which corresponds to his daily activity, this option gives importance to studying the program's response time.

The variable which is responsible for setting priority between solving time and result accuracy is the interval length. Table 7.3 shows the details of solving the four previous examples with multiple interval lengths.Table 7.3 explain that for long interval cases like 30-20 min, there is a notable influence on solving time, however, the impact on the optimal cost is not remarkable.

Table 7.3. Solving time of optimal cost for different types of tariff

	Residential in Turkey		Commercial in Turkey		USA		SWEDEN	
Interval Length	**Elapsed Time (sec)**	**COST (TL)**	**Elapsed Time (sec)**	**COST (TL)**	**Elapsed Time (sec)**	**COST (Cent)**	**Elapsed Time (sec)**	**COST (SEK)**
30 (min) 48 interval	6.62	2.311	6.67	2.752	4.71	35	4.52	3.55
20 (min) 72 interval	12.89	2.342	17.80	2.794	8.82	31.9	10.53	3.525
15 (min) 96 interval	13.46	1.962	14.50	2.331	16.58	30.2	22.13	3.516
10 (min) 144 interval	27.74	1.953	32.95	2.32	34.83	30	40.63	3.515

On the other hand, for short interval cases like 15-10 min, there is a notable influence on both solving time and the optimal. Hence, using a short interval is preferred when the saving amount has priority. And vice versa, the long interval is preferred, when the necessity is to have a quick response.

Table 7.4. Runtime (in second) with relative error by different interval lengths (in minutes)

	30 (min) 48 interval		**20 (min)** 72 interval		**15 (min)** 96 interval		**10 (min)** 144 interval	
Tariff Type	**Runtime (sec)**	**Error %**	**Runtime (sec)**	**Error %**	**Runtime (sec)**	**Error %**	**Runtime (sec)**	**Error %**
Residential in Turkey	6.62	18.33	6.67	19.92	4.71	0.46	4.52	0.0
Commercial in Turkey	12.89	18.62	17.80	20.43	8.82	0.47	10.53	0.0
USA	13.46	16.67	14.50	6.33	16.58	0.67	22.13	0.0
SWEDEN	27.74	1.00	32.95	0.28	34.83	0.03	40.63	0.0

The above results suggest that the scheduling process in short interval case is more efficient -in the home devices programming- with real-time pricing scenario like the one in the USA.

7.5. The Consumer Preferences Impact on The Daily Power Profile

The practical results of programming have a daily power profile form. As shown in Fig 7.11, the daily power profile is a schedule describes the operational plan of one day. Each device in this profile has a specific period to finish its tasks, furthermore, energy phases have different colors so that the assigned power and the run time of every phase can be figured out easily from the profile chart.

One of the parameters that has a significant impact on the power profile is the time preference determined by the customers. Since the customers differ in preferences, we are -as programmers- should give customers the opportunity to set time preferences themselves.

The comprehensive power profiles in which total cost reaches the minimum value in the residential case is shown in Fig 7.11.

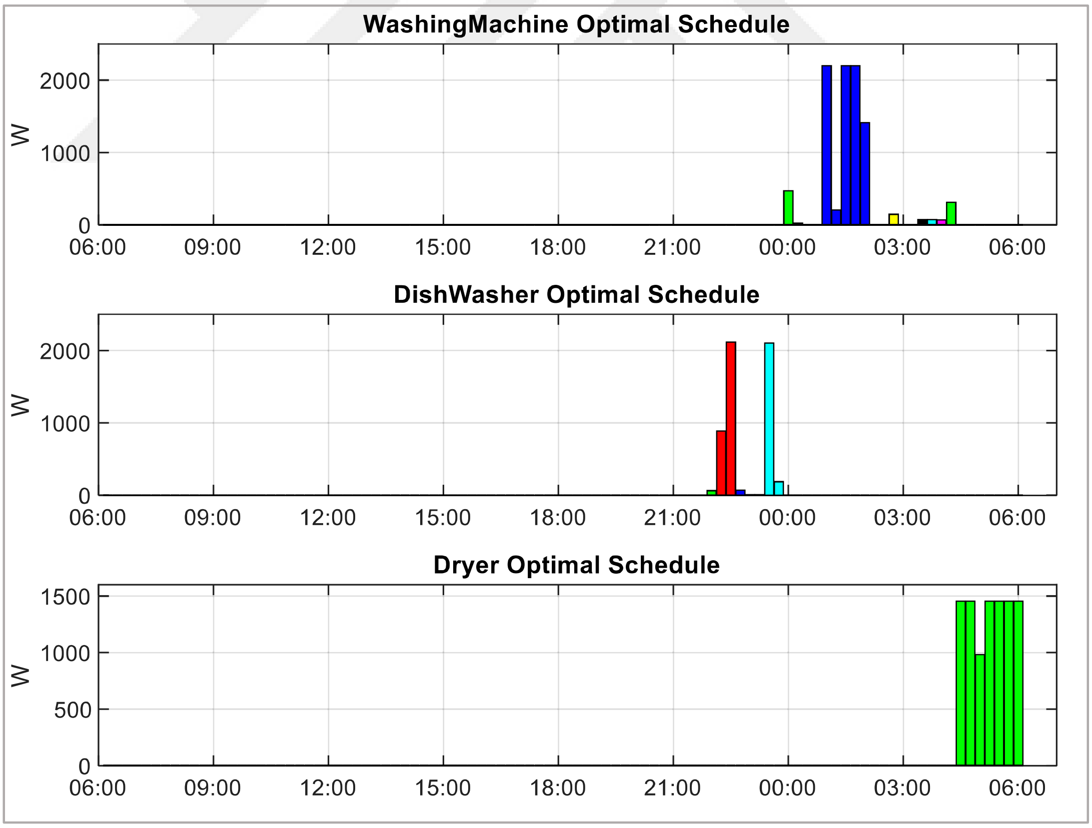

Figure 7.11. Optimal schedule for Turkish customer to meet breakfast time

It is clear that the operating periods of the processed devices - washing machine, dishwasher, and dryer - are distributed to meet the consumer preferences on one hand,

and achieve the lowest cost of energy consumption on the other hand. As we can see, the clothes dryer starts working after the washing machine is finished, and both execute their work between 12 pm and 6 am when electricity is the cheapest.

As for the dishwasher, its operation will be completed between 10 pm and 12 pm within the period set for it by the user, which is between 10 pm and 6 am. Thus, the dishes will be ready for breakfast. If the user wants the dishwasher to finish at a time so that dishes be clean for dinner, Figure 7.12 shows that.

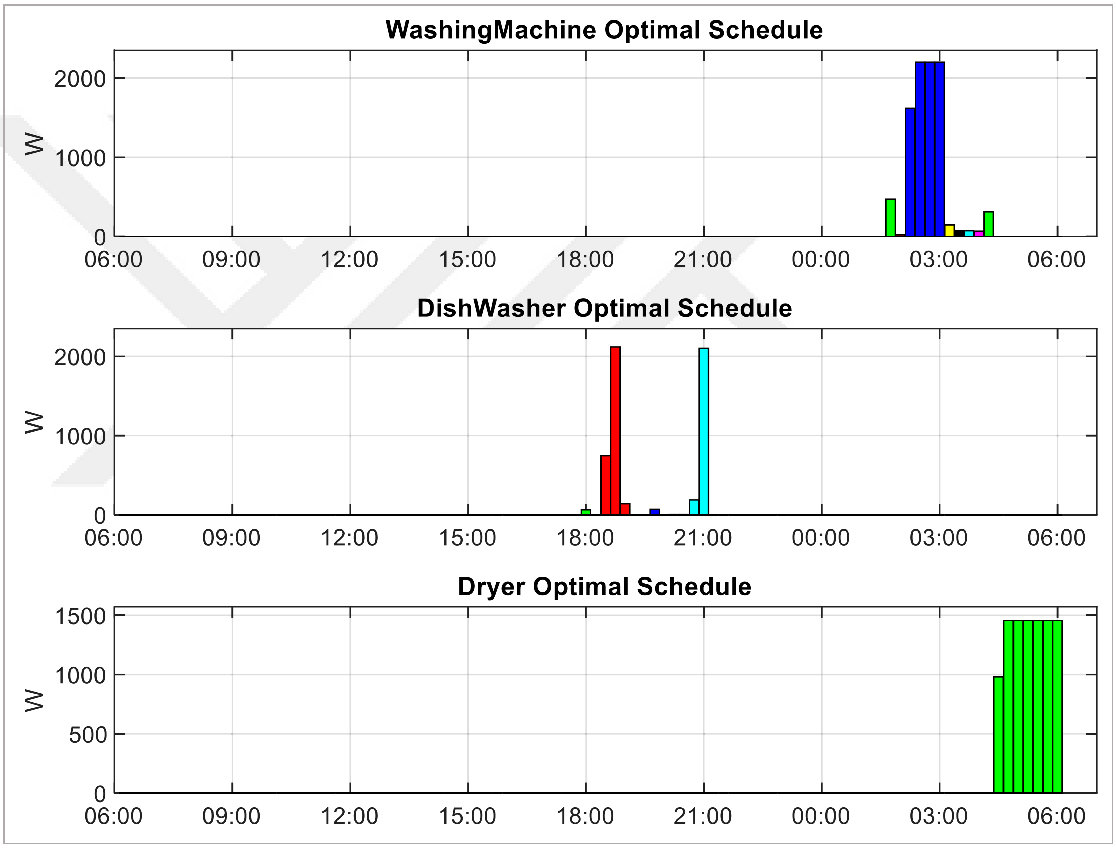

Figure 7.12. Optimal schedule for Turkish customer to meet dinner time

We note that after selecting the time range from 6 pm to 10 pm, the dishwasher starts working at 6 and ends at 9. Note that the minimum energy cost will not be achieved, in order to avoid disturbing the user's comfort and to enhance his well-being.

For users who own an electric car, the situation in principle is similar to that for the dishwasher. Because providing an opportunity to control the charging time of the car by the user is needed. that is necessary to keep up with the daily activity of different consumers. Hence, meeting the wishes of a wide range of users, including employees, night-shift workers, and many others, becomes possible.

Some users want the car to be 100% charged always before going to work in the morning. The charging period is from 11 pm to 8:30 am. Figure 7.14 shows the scheduler's response to this requirement.

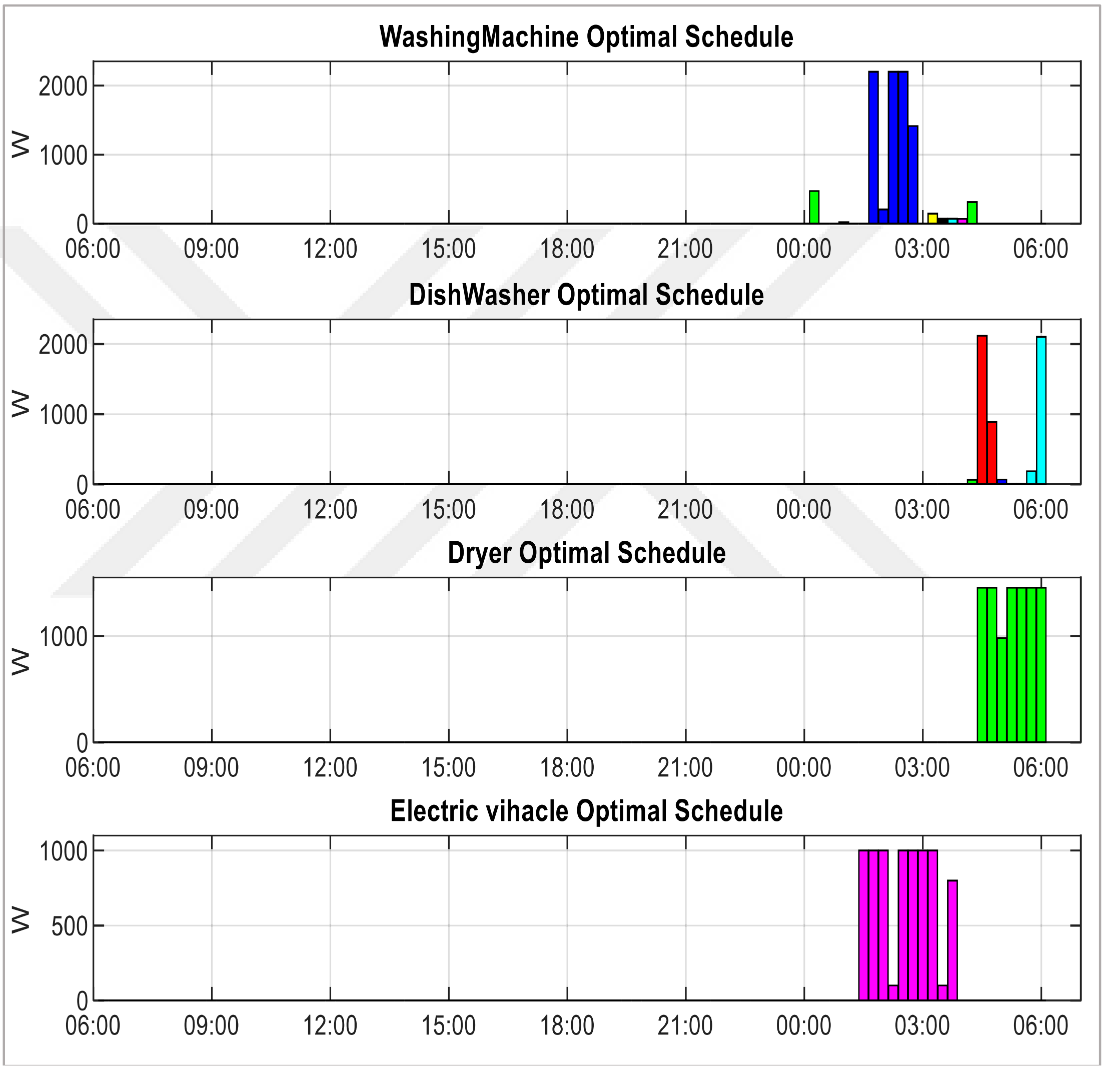

Figure 7.13. Optimal schedule with ev in on-day cases for reasidential user in Turkey.

For the night-shift worker or at weekend days, the user may want to use the car late at night due to travel or entertainment, so the best charging period, in this case, is at the day from 6 am to 12 pm. The Fig 7.14 shows the scheduler's response to this requirement.

The last case clarifies how it is easy to add a new device to the programming process (like Electric Vehicle (EV), iron, battery charger, etc).

It should be mentioned that if the consumer wants to use the same device many times a day (eg. Dishwasher twice a day), the program can address this issue by processing the frequently used device as two independent devices have the same technical specifications.

However, the operating conditions of those similar devices should be set to ensure that they do not work simultaneously (in other words, the second device starts after the first one finished). Fig 7.15 discribes s similar situation.

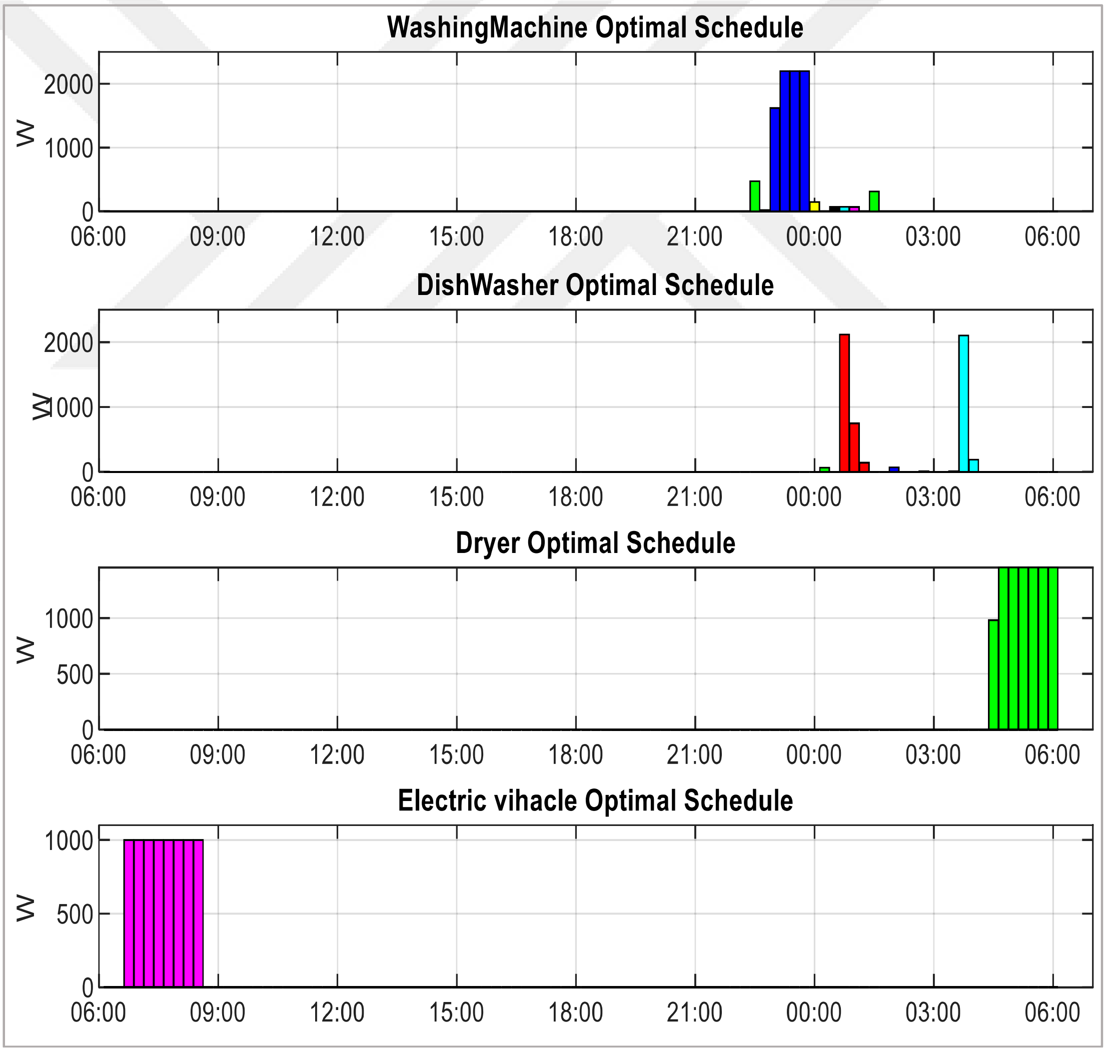

Figure 7.14. Optimal schedule with ev in the off-day cases and for night-shift worker in Turkey.

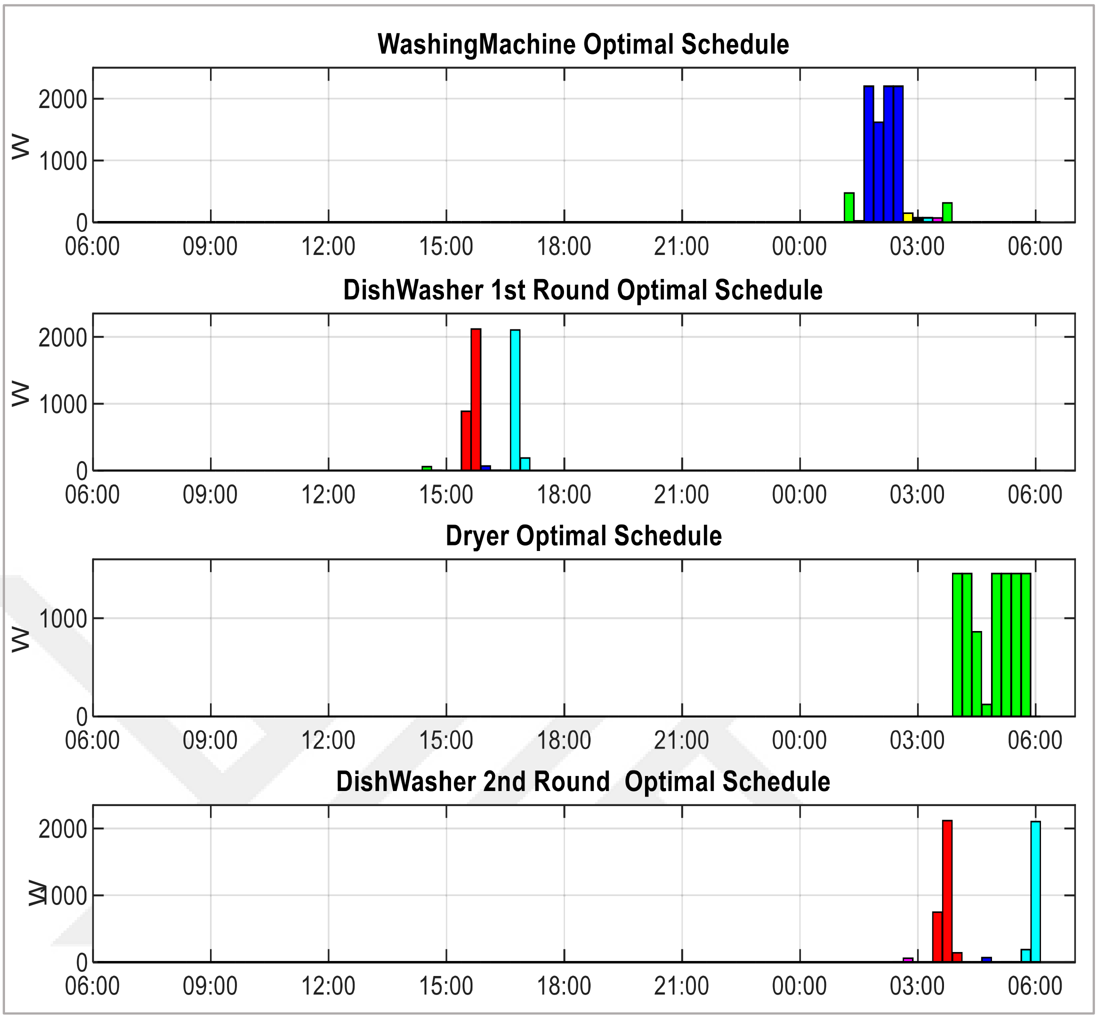

Figure 7.15. Optimal schedule for Turkish customer needs diahwasher twice a day

8. CONCLUSIONS AND FUTURE WORK

The maximum saving is gained when the scheduling process carried out with high-change tariff systems during the day (e.g. Turkey case). And that makes sense because of, the higher the on-peak price compared to the off-peak one, the more efficiency of load shifting according to the optimal schedule, and vice versa. In the low-change tariff cases, there will be no worthy difference in the total cost between scheduled and non-scheduled consumption. (e.g. Sweden case)

For Turkey, we note that the tariff system encourages consumers to regulate their consumption of electricity. There is a graet inducement for the consumers to modify their consumption pattern. In other words, the more the price fluctuates along the day, the greater the savings achieved by the scheduling process like in the Turkey state. In conclusion, the economic benefits are worthy enough to convince the customers in Turkey to schedule their appliances and transfer to the multi-time tariff system.

The time response study of the proposed program helps us to choose the interval wide wisely. Because it became understood that short interval is preferred when the saving amount has priority. And vice versa, the long interval is preferred, when the necessity is to have a quick response.

The study results were obtained in time (two minutes at most) short enough to demonstrate that the demand management project was applicable in real-time pricing circumstances. A computer equipped with an Intel Core-3i processor is used, and the computing time will certainly be reduced if a computer with the greater powerful specifications is used (e.g. Intel Core-i7 processor and larger RAM capacity).

The study was confined to three different household appliances; the results showed that it is easy to add a device to the scheduling process as in the case of the electric vehicle. In other words, in the future, the number of devices subjected to the scheduling process can be increased to include the whole area of smart homes.

Farthermore, the device scheduling can be performed with many dynamic pricing models such as Feed-In Tariff (FIT) that provide energy selling back to the main grid; and that is if the home generation exists (e.g. PV panels on the roof or a mini wind mill in the garden). Hence, at times when the demand is less than the power generated from the PV panel, the surplus energy will be sold to the main grid according to FIT system. This will bring greater savings on the bill and valuable profits to the consumer from selling energy.

The future works could include several home units rather than a single house, aiming to confirm the effectiveness of this approach in a micro smart grid covering a large area with several houses. The cost of solar panels decreases over time. Hence, the self-return calculating and cost-benefit analysis is needed to convence the customers to adopt the scheduling policies while taking into account the carbon footprint reduction when using this green energy.

The future research can include renewable energy source such as the PV panel combined with an energy storage system. Under this idea, the smart home can be equipped with an off-grid system so that there is a battery management system to store and reserve the energy to be used during the later part of the day or when the appliances need to be operated during on-peak hours. Cost-efficiency of both types of on-grid and off-grid PV panel can be studied to formulate a comprehensive backup energy resource at home. It is to be noted that the off-grid system is very expensive to own and operate, mostly due to the cost of batteries.

REFERENCES

[1] Sou K.C., Weimer J., Sandberg H., Johansson K.H., Scheduling Smart Home Appliances Using Mixed Integer Linear Programming, *Proceedings Of The IEEE Conference On Decision And Control*, Orlando, FL, USA, 12–15 December 2011.

[2] Law Y.W., Alpcan T., Lee V.C.S., Lo A., Marusic S., Palaniswami M., Demand Response Architectures And Load Management Algorithms For Energy-Efficient Power Grids: A Survey, *2012 Seventh International Conference On Knowledge, Information And Creativity Support Systems*, Melbourne, Australia, 8–10 November 2012.

[3] Merkert L., Harjunkoski I., Isaksson A., Säynevirta S., Saarela A., Sand G., Scheduling And Energy – Industrial Challenges And Opportunities, *Comput. Chem. Eng.*, 2015, **72**, 183–198.

[4] Öztemür M., Soysal B., Smart Meters On The Path Leading To Smart Grid, *Akıllı Şebekeler Ve Türkiye Elektrik Şebekesinin Geleceği Sempozyumu*, ANKARA, 26--27 April 2013.

[5] Bektaş Z., Power Demand Side Management Using Bayesian Game Approach Case With Three Consumers, Master Thesis, Istanbul Tachnical University, Graduate School Of Science And Engineering, Istanbul, Turkey, 2015, 389454.

[6] Uzunoğlu M., Erdinç O., *Akıllı Şebekelere Giriş*, 1st ed., Nobel Akademik Yayınevi, Türkiye, 2013.

[7] URL-1: https://www.epdk.org.tr/TR/Dokuman/7292, (Accessed in: February 12, 2018).

[8] Flanigan T., Hadley S., Analysis Of Successful Demand-Side Management At Publicly Owned Utilities, *Oak Ridge National Laboratory*, 10184615, 25–29, 1994.

[9] United States Government, Energy Policy And Conservation Act, https://legcounsel.house.gov/Comps/EPCA.pdf, (Accessed in: May 3, 2019).

[10] Anjali Sastry M., Gadgil A.J., Bombay Efficient Lighting Large-Scale Experiment (Belle): Blueprint For Improving Energy Efficiency And Reducing Peak Electric Demand In A Developing Country, *Atmos. Environ.*, 1996, **30**(5), 803–808.

[11] McCarthy C., Lehmann P., Derwent H., Robinson A., A Review Of The Energy Efficiency Standards Of Performance 1994 - 2002, *Ofgem and the Energy Saving Trust*, 35–41, 2003.

[12] Weisbrod G., Tribble M., Deshpande V., Learning From India: Defining Profitable Demand-Side Management And Energy Service Company Programs For A Utility, *Electr. J.*, 1999, **12**(9), 31–39.

[13] Hossain M.R., Oo A.M.T., Ali A.B.M.S., Smart Grid, Editors: A B M Shawkat Ali.*Smart Grids*, Springer, London, 23–44, 2013.

[14] Lampropoulos I., Kling W.L., Van Den Bosch P.P.J., Ribeiro P.F., Van Den Berg J., Criteria For Demand Response Systems, *IEEE Power And Energy Society General Meeting*, Vancouver, Canada, 21–25 July 2013.

[15] Mohsenian-Rad A.H., Wong V.W.S., Jatskevich J., Schober R., Leon-Garcia A., Autonomous Demand-Side Management Based On Game-Theoretic Energy Consumption Scheduling For The Future Smart Grid, *IEEE Trans. Smart Grid*, 2010, **1**(3), 320–331.

[16] Roos J.G., Lane I.E., Industrial Power Demand Response Analysis For One-Part Real-Time Pricing, *IEEE Trans. Power Syst.*, 1998, **13**(1), 159–164.

[17] Paracha Z.J., Manager P., Conservation E., Rd H., et al., Load Management, *International Conference On Energy Management And Power Delivery*, Singapore, Singapore, 5–11 March 1998.

[18] Chen C., Kishore S., Snyder L. V., An Innovative RTP-Based Residential Power Scheduling Scheme For Smart Grids, *2011 IEEE International Conference On Acoustics, Speech And Signal Processing (ICASSP)*, Prague, Czech Republic, 22–27 May 2011.

[19] Gelazanskas L., Gamage K.A.A., Demand Side Management In Smart Grid: A Review And Proposals For Future Direction, *Sustain. Cities Soc.*, 2014, **11**, 22–30 2210-6707.

[20] Gottwalt S., Ketter W., Block C., Collins J., Weinhardt C., Demand Side Management-A Simulation Of Household Behavior Under Variable Prices, *Energy Policy*, 2011, **39**(12), 8163–8174 0301-4215.

[21] Yang P., Tang G., Nehorai A., Optimal Time-Of-Use Electricity Pricing Using Game Theory, *2012 IEEE International Conference On Acoustics, Speech And Signal Processing (ICASSP)*, Kyoto, Japan, 25–30 March 2012.

[22] Palensky P., Electric Load Management And Information Technology, *AFRICON 2009*, Nairobi, Kenya, 23–25 September 2009.

[23] Strbac G., Demand Side Management: Benefits And Challenges, *Energy Policy*, 2008, **36**(12), 4419–4426 0301-4215.

[24] Shaw R., Attree M., Jackson T., Kay M., The Value Of Reducing Distribution Losses By Domestic Load-Shifting: A Network Perspective, *Energy Policy*, 2009, **37**(8), 3159–3167.

[25] Roos J.G., Lane I.E., Industrial Power Demand Response Analysis For One-Part Real-Time Pricing, *IEEE Trans. Power Syst.*, 2002, **13**(1), 159–164.

[26] Eissa M.M., Demand Side Management Program Evaluation Based On Industrial And Commercial Field Data, *Energy Policy*, 2011, **39**(10), 5961–5969.

[27] Makina Mühendisleri Odası, Dünyada Ve Türkiye'de Enerji Verimliliği Oda Raporu, TMMOB, http://www1.mmo.org.tr/resimler/dosya_ekler/a551829d50f1400_ek.pdf, (Accessed in: August 9, 2018).

[28] Erol E., Erdener-Akınç H., Atasoy T., Güreç O., Erçin Ö., Benli O., Akıllı Şebekelerde Karar Destek Sistemleri Ile Talep Tarafı Katılımı, *2. Uluslararası İstanbul Akıllı Şebekeler Kongre Ve Fuarı*, istanbul, 8–9 May 2014.

[29] Şanlı B., Alanyalı M., Türkiye Elektrik Piyasasında Talep Katılımının Tasarımı, *TOBB Ekonomi ve Teknoloji Üniversitesi*, 1654189, 1–13, 2013.

[30] Su W., Huang A.Q., A Game Theoretic Framework For A Next-Generation Retail Electricity Market With High Penetration Of Distributed Residential Electricity Suppliers, *Elsevier Ltd*, 2014, **119**, 341–350.

[31] Goswami Y., Kreith F., Pepper D.W., *Energy Efficiency and Renewable Energy Handbook*, 2nd ed., CRC PRESS, New York, USA, 2016.

[32] AYAN O., Demand Side Management And Energy Efficiency In Residential Area Within Smart Grids, Master Thesis, Istanbul Technical University, Graduate School Of Science And Engineering, Istanbul, Turkey, 2017, 467061.

[33] Albadi M.H., El-Saadany E.F., A Summary Of Demand Response In Electricity Markets, *Electr. Power Syst. Res.*, 2008, **78**(11), 1989–1996.

[34] Kathan D., Aldina R., Sporborg P., Tita M., Wight D., Wilkerson A., Assessment Of Demand Response And Advanced Metering-Staff Report, *Federal Energy Regulatory Commission*, 21–49, 2012.

[35] Aalami H.A., Moghaddam M.P., Yousefi G.R., Demand Response Modeling Considering Interruptible/Curtailable Loads And Capacity Market Programs, *Appl. Energy*, 2010, **87**(1), 243–250.

[36] Saebi J., Taheri H., Mohammadi J., Nayer S.S., Demand Bidding/Buyback Modeling And Its Impact On Market Clearing Price, *2010 IEEE International Energy Conference*, Manama, Bahrain, 18–22 December 2010.

[37] Tiptipakom S., Lee W.J., A Residential Consumer-Centered Load Control Strategy In Real-Time Electricity Pricing Environment, *39th North American Power Symposium, NAPS*, Las Cruces, NM, USA, 30 Sep-20 October 2007.

[38] Datchanamoorthy S., Kumar S., Ozturk Y., Lee G., Optimal Time-Of-Use Pricing For Residential Load Control, *2011 IEEE International Conference On Smart Grid Communications (SmartGridComm)*, Brussels, Belgium, 17–20 October 2011.

[39] Herter K., Residential Implementation Of Critical-Peak Pricing Of Electricity, *Energy Policy*, 2007, **35**(4), 2121–2130.

[40] Allcott H., Real Time Pricing And Electricity Markets, Master Thesis, Harvard University, Graduate School Of Science And Engineering, Harfard, USA, 2009, .

[41] Edward J., Policy P., Assessment Of Customer Response To Real Time Pricing , Master Thesis, State University of New Jersey, Bloustein School Of Planning And Public Policy, New Jersey, 2005, .

[42] Yao R., Steemers K., A Method Of Formulating Energy Load Profile For Domestic Buildings In The UK, *Energy Build.*, 2005, **37**(6), 663–671.

[43] Mansouri I., Newborough M., Probert D., Energy Consumption In UK Households: Impact Of Domestic Electrical Appliances, *Appl. Energy*, 1996, **54**(3), 211–285.

[44] Finn P., O'Connell M., Fitzpatrick C., Demand Side Management Of A Domestic Dishwasher: Wind Energy Gains, Financial Savings And Peak-Time Load Reduction, *Appl. Energy*, 2013, **101**, 678–685.

[45] Zhang P., Li F., Bhatt N., Next-Generation Monitoring, Analysis, And Control For The Future Smart Control Center, *IEEE Trans. Smart Grid*, 2010, **1**(2), 186–192.

[46] Amin M., Wollenberg B., Toward A Smart Grid, *Power & Energy Magazine*, 2005, **3**(5), 34–41.

[47] Staschus K., Standardization And Network Codes, *European Conference On Smart Grid Standardization Achievements*, Brussels, Belgium, 28 January 2013.

[48] URL-2: http://smartgrid.gov/the_smart_grid, (Accessed in: October 2, 2018).

[49] Farhangi H., The Path Of The Smart Grid, *IEEE Power Energy Mag.*, 2010, **8**(1), 18–28.

[50] URL-3: http://www.sgiclearinghouse.org, (Accessed in: October 15, 2018).

[51] Yuexin L., Haoqing X., Hanwu L., Ningxi S., Investment-Benefit Analysis And Evaluation Model Of The Smart Grid, *China International Conference On Electricity Distribution*, Nanjing, China, 13–16 September 2010.

[52] URL-4: http://opencourses.emu.edu.tr/course/view.php?id=46, (Accessed in: September 3, 2017).

[53] Bartels G., Global Smart Grid Federation 2012 Report, *The Global Smart Grid Federation*, 16–40, 2012.

[54] TMMOB, Türkiye' Nin Enerji Görünümü 2018, Makina Mühendisleri Odası, https://www.mmo.org.tr/sites/default/files/EnerjiGorunumu2018_1.pdf, (Accessed in: April 25, 2018).

[55] TEİAŞ, 2017 Yılı Faaliyet Raporu, http://www.teias.gov.tr/sites/default/files /2018-06/2017 TEİAŞ Faaliyet Raporu.pdf, (Accessed in: May 19, 2018).

[56] Enerji Verimliliği Kanunu, T.C Resmî Gazete, Sayı: 26510, http:// www.resmigazete.gov.tr/eskiler/2007/05/20070502-2.htm, (Accessed in: April 16, 2019).

[57] Demirci T., Kalaycıoğlu A., Küçük D., Salor O., et al., Nationwide Real-Time Monitoring System For Electrical Quantities And Power Quality Of The Electricity Transmission System, *IET Gener. Transm. Distrib.*, 2011, **5**(5), 540 – 550.

[58] URL-5: http://www.ritm.gov.tr/aboutUs/ritm.php, (Accessed in: February 25, 2018).

[59] URL-6: https: //www. simula. no/ research /projects /pronet -protection - power- electronically- interfaced- lv-distributed- generation, (Accessed in: November 1, 2018).

[60] T.C Cumhurbaşkanlığı, Dokuzuncu Kalkinma Plani Stratejisi (2007-2013) Hakkinda Karar, http://www.resmigazete.gov.tr/eskiler/2006/05/20060513-2.htm, (Accessed in: February 14, 2019).

[61] Sanayi ve Ticaret Bakanliği, Sanayi Stratejisi Belgesi, https:// www.tobb.org.tr/AvrupaBirligiDairesi/Dokumanlar/MevzuatveDokumanlar/Sanayi_Stratejisi_Belgesi_2011_2014.pdf, (Accessed in: January 18, 2019).

[62] EPDK (Enerji Piyasasi Düzenleme Kurumu), Elektrik Piyasası Sektör Raporu Ağustos/2017, https://www.epdk.org.tr/Detay/DownloadDocument?id=GWHnLpVA2qk=, (Accessed in: April 21, 2019).

[63] TEİAŞ, Annual Development Of Electricity Generation- Consumption And Losses In Turkey 1993-2017, https://www.teias.gov.tr/tr/iii-elektrik-enerjisi-uretimi-tuketimi-kayiplar-0, (Accessed in: March 24, 2018).

[64] Saul-Rinaldi K., Lebaron R., Caracino J., Making Sense Of The Smart Home, *National Home Performance Council*, 1–33, 2014.

[65] Shahid B., Ahmed Z., Faroqi A., M.Navid-ur-Rehman R., Implementation Of Smart System Based On Smart Grid Smart Meter And Smart Appliances, *2nd Iranian Conference On Smart Grid*, Tehran,lran, 23–24 May 2012.

[66] Al-Ali A.R., El-Hag A.H., Dhaouadi R., Zainaldain A., Smart Home Gateway For Smart Grid, *2011 International Conference On Innovations In Information Technology*, Sharjah, UAE, 25–27 April 2011.

[67] Lee J.I., Choi C.-S., Park W.-K., Han J.-S., Lee I.-W., A Study On The Use Cases Of The Smart Grid Home Energy Management System, *ICTC 2011*, Seoul, South Korea, 28–30 September 2011.

[68] KIRAL G.E., Development Of Smart Plug For Energy Management System In Smart Grid, Master Thesis, Yıldız Technical University, Graduate School Of Science And Engineering, Istanbul, Turkey, 2014, 411543.

[69] URL-7: https://www.dailymail.co.uk/sciencetech/article-3584523/The-world-s-carbon-footprint-revealed-Graphic-shows-countries-guilty-producing-emissions-UK-20.html#i-3587c6c69e304f01, (Accessed in: May 3, 2019).

[70] Boynuegri A.R., Yagcitekin B., Baysal M., Karakas A., Uzunoglu M., Energy Management Algorithm For Smart Home With Renewable Energy Sources, *4th International Conference On Power Engineering, Energy And Electrical Drives*, Istanbul, Turkey, 13–17 May 2013.

[71] Byun J., Hong I., Park S., Intelligent Cloud Home Energy Management System Using Household Appliance Priority Based Scheduling Based On Prediction Of Renewable Energy Capability, *IEEE Trans. Consum. Electron.*, 2012, **58**(4), 1194–1201.

[72] URL-8: https://www.ge.com/sites/default/files/GE-smart-meters-8_new.pdf, (Accessed in: January 5, 2019).

[73] Zhu T., Mishra A., Irwin D., Sharma N., Shenoy P., Towsley D., The Case For Efficient Renewable Energy Management In Smart Homes, *Proceedings Of The Third ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings*, Washington, USA, 1–2 November 2011.

[74] Koen Kok, Karnouskos S., Nestle D., Dimeas A., et al., Field-Testing Smart Houses For A Smart Grid, *21st International Conference On Electricity Distribution*, Frankfurt, Germany, 6–9 June 2011.

[75] Roberson J.A., Webber C.A., Mcwhinney M.C., Brown R.E., Pinckard M.J., Busch J.F., After-Hours Power Status Of Office Equipment And Inventory Of Miscellaneous Plug-Load Equipment, *Ernest Orlando Lawrence Berkeley National Laboratory University of California*, 5–27, 2004.

[76] Elmenreich W., Egarter D., Design Guidelines For Smart Appliances, *10th International Workshop On Intelligent Solutions In Embedded Systems*, Klagenfurt, Austria, 14–19 June 2012.

[77] Morsali H., Shekarabi S.M., Ardekani K., Khayami H., et al., Smart Plugs For Building Energy Management Systems, *Iranian Conference On Smart Grids*, Tehran, Iran, 24–25 May 2012.

[78] EPDK (Enerji Piyasası Düzenleme Kurumu), Elektrik Piyasası 2017 Yılı Piyasa Gelişim Raporu, *Strateji Geliştirme Dairesi Başkanlığı*, 1–88, 2017.

[79] URL-9: https:// akillitarife.com/ rehber/ elektrik-fiyatlari-2018, (Accessed in: May 12, 2019).

[80] URL-10: https://www.nyiso.com/real-time-dashboard, (Accessed in: March 2, 2018).

[81] URL-11: https:// www. nordpoolgroup. com/ Market- data1 /#/ nordic /table, (Accessed in: February 15, 2018).

APPENDIX

Appendix A

Table A.1. Operational specifications of dishwasher [1]

Energy Phase	Pre-Wash	Wash	1st Rinse	Drain	2nd Rinse	Drain and Dry
Energy (Wh)	16	751.2	17.3	1.6	1.7	572.3
Min Power (W)	6.47	140.2	10.28	2.26	0.2	187.3
Max Power (W)	140	2117.8	132.2	136.2	52.3	2143
Nominal Opperating Time (Min)	14.9	32.1	10.1	4.3	2.3	52.4

Table A.2. Operational specifications of washing machine [1]

Energy Phase	Movement	Pre-Heating	Heating	Maintenance	Cooling	1st Rinse	2nd Rinse	3rd Rinse
Energy (Wh)	118	5.5	2054.9	36.6	18	18	17	78
Min Power (W)	27.231	5	206.523	11.035	10.8	10.385	9.903	23.636
Max Power (W)	2100	300	2200	200	500	700	700	1170
Nominal Op.Time (Min)	26	6.6	59.7	19.9	10	10.4	10.3	19.8

Table A.3. Operational specifications of dryer [1]

Energy Phase	**Drying**
Energy (Wh)	2426.3
Min Power (W)	120.51
Max Power (W)	1454
Nominal Opperating Time (Min)	120.8

Table A.4. Operational specifications of electric vehicle [1]

Energy Phase	**Charging**
Energy (Wh)	2000
Min Power (W)	1000
Max Power (W)	100
Nominal Opperating Time (Min)	120

Appendix B

MATLAB FILE PROGRAMING CODE

```
clear all
peak=5500;
DWpreferenceS=12;
DWpreferenceF=15;
load Price.mat;
v={'06:00','09:00','12:00','15:00','18:00','21:00','00:00','03:00','06:00'};
nHours = numel(TR96Evsel);
Time = 24/nHours:24/nHours:24;
figure
hold on
stairs(Time,TR96Evsel)
hold off
xlim([0,25])
ylim([0.0,1.1])
xlabel('Price per kWh at each period')
set(gca,'XTick',0:3:96,'XTickLabel',v)
disp(WashingMachine)
disp(DishWasher(:,1:6))
disp(Dryer(:,1))
nAppliances = 3;
nPhase=8;
Energy = [WashingMachine{1,1:nPhase};DishWasher{1,1:nPhase};Dryer{1,1:nPhase}];
Minpower = [WashingMachine{2,1:nPhase};DishWasher{2,1:nPhase};Dryer{2,1:nPhase}];
Maxpower =[WashingMachine{3,1:nPhase};DishWasher{3,1:nPhase};Dryer{3,1:nPhase}];
Nomoptime = [WashingMachine{4,1:nPhase};DishWasher{4,1:nPhase};Dryer{4,1:nPhase}];
TSL=24*60/nHours;
```

Variables for Solution:

```
k = optimvar('k',nHours,nAppliances,nPhase,'LowerBound',0);%,'LowerBound',minpower,'UpperBound',maxpower );
```

```
y =
optimvar('y',nHours,nAppliances,nPhase,'Type','integer','LowerBound',0,'UpperBound',1);
z =
optimvar('z',nHours,nAppliances,nPhase,'Type','integer','LowerBound',0,'UpperBound',1);
t = optimvar('t',nHours,nAppliances,nPhase-1,'Type','integer','LowerBound',0,'UpperBound',1);
```

Constraints

Energy Constraints

Energy phase energy requirement

```
Energyconst = optimconstr;
for ii = 1:nAppliances
  for jj = 1:nPhase
   Energyconst(ii,jj)= sum(k(:,ii,jj)).*(TSL/60) == Energy(ii,jj);
   end
end
```

Instantaneous energy phase power assignment bounds

```
for kk=1:nHours
  for ii=1:nAppliances
      for jj=1:nPhase
      minpower(kk,ii,jj)= Minpower(ii,jj);
      end
   end
end
lowerboundsconst= minpower.*y <= k ;
for kk=1:nHours
   for ii=1:nAppliances
      for jj=1:nPhase
      maxpower(kk,ii,jj)= Maxpower(ii,jj);
       end
   end
end
upperboundsconst= maxpower.*y >= k ;
```

Power safety:

```
Peak=repmat(peak,nHours,1);
```

peakconst= sum(sum(k,3),2)<=Peak;

Timing Constraints:

Energy phase process time limits:

```
lowertimelim= floor(0.8*Nomoptime/TSL);
 uppertimelim= ceil(1.2*Nomoptime/TSL);
 for ii = 1:nAppliances
   for jj = 1:nPhase
       lowertimecont(ii,jj)= sum(y(:,ii,jj)) >= lowertimelim(ii,jj);
   end
 end
%
  for ii = 1:nAppliances
   for jj = 1:nPhase
       uppertimecont(ii,jj)= uppertimelim(ii,jj) >= sum(y(:,ii,jj))  ;
   end
  end
```

Uninterruptible operation:

```
uninterrupa= y <= 1-z;
for kk=2:nHours
   for ii=1:nAppliances
       for jj=1:nPhase
          uninterrupb(kk,ii,jj)= y(kk-1,ii,jj)- y(kk,ii,jj) <= z(kk,ii,jj);
          uninterrupc(kk,ii,jj)=z(kk-1,ii,jj)<=z(kk,ii,jj);
       end
   end
end
```

Sequential Processing:

```
for kk=1:nHours
   for ii=1:nAppliances
       for jj=2:nPhase
          sequentconst(kk,ii,jj)= y(kk,ii,jj) <= z(kk,ii,jj-1);
       end
   end
end
```

User sequence preference:

```
userseqconst= y(:,3,1)<= z(:,1,8);
```

User time preference:

```
DwdelayS= nHours*DWpreferenceS/24;
DwdelayF= nHours*DWpreferenceF/24;
usertimeconstDW= [ x (1:DwdelayS-1,2,:); x(DwdelayF+1:end,2,:)]<=0;
```

Between-phase delay:

```
for kk=1:nHours
   for ii=1:nAppliances
      for jj=2:nPhase
         W(kk,ii,jj-1)= z(kk,ii,jj-1)-(y(kk,ii,jj)+z(kk,ii,jj));
      end
   end
end
t=W;
Delay=0.5*nHours/24;
delayconst=sum(t)<=Delay;
```

PROBLEM SOLVING:

Define Objective:

```
c=repmat(TR96Evsel,1,nAppliances,nPhase);
schedule=sum(sum(sum((TSL/60).*c.*k)));
```

Solve the Problem:

```
energyprob = optimproblem('ObjectiveSense','minimize');
energyprob.Objective                    = schedule;
energyprob.Constraints.Energyconst          =Energyconst ;
energyprob.Constraints.Lowerboundsconst     = lowerboundsconst;
energyprob.Constraints.Upperboundsconst     = upperboundsconst;
energyprob.Constraints.Peakconst           = peakconst;
energyprob.Constraints.Lowertimecont        = lowertimecont ;
energyprob.Constraints.Uppertimecont        = uppertimecont;
energyprob.Constraints.Uninterrupa          = uninterrupa ;
energyprob.Constraints.Uninterrupb          = uninterrupb;
energyprob.Constraints.Uninterrupc          = uninterrupc;
energyprob.Constraints.Sequentconst         = sequentconst ;
```

```
energyprob.Constraints.Userseqconst         = userseqconst ;
energyprob.Constraints.UsertimeconstDW     = usertimeconstDW ;
energyprob.Constraints.Delayconst          = delayconst ;
%
options = optimoptions('intlinprog','Display','final');
options.CutGeneration='basic';
%
tic;
[Energysol,TotalCost,exitflag,output] = solve(energyprob,'options',options);
toc
```

Examine the Solution

Ploting phases with colors

```
figure
subplot(3,1,1)
hold on
bar(Time,Energysol.k(:,1,1),.95,'green')
bar(Time,Energysol.k(:,1,2),.95,'red')
bar(Time,Energysol.k(:,1,3),.95,'blue')
bar(Time,Energysol.k(:,1,4),.95,'yellow')
bar(Time,Energysol.k(:,1,5),.95,'black')
bar(Time,Energysol.k(:,1,6),.95,'cyan')
bar(Time,Energysol.k(:,1,7),.95,'magenta')
bar(Time,Energysol.k(:,1,8),.95,'green')
xlim([0,25])
ylabel('Wh')
title('WashingMachine Optimal Schedule','FontWeight','bold')
set(gca,'XTick',0:3:96,'XTickLabel',v)
box on
grid on
hold off
%
subplot(3,1,2)
hold on
bar(Time,Energysol.k(:,2,1),.95,'green')
```

```
bar(Time,Energysol.k(:,2,2),.95,'red')
bar(Time,Energysol.k(:,2,3),.95,'blue')
bar(Time,Energysol.k(:,2,4),.95,'yellow')
bar(Time,Energysol.k(:,2,5),.95,'black')
bar(Time,Energysol.k(:,2,6),.95,'cyan')
bar(Time,Energysol.k(:,2,7),.95,'magenta')
bar(Time,Energysol.k(:,2,8),.95,'green')
box on
grid on
xlim([0,25])
ylabel('Wh')
set(gca,'XTick',0:3:96,'XTickLabel',v)
title('DishWasher Optimal Schedule','FontWeight','bold')
hold off
%
subplot(3,1,3)
hold on
bar(Time,Energysol.k(:,3,1),.95,'green')
bar(Time,Energysol.k(:,3,2),.95,'red')
bar(Time,Energysol.k(:,3,3),.95,'blue')
bar(Time,Energysol.k(:,3,4),.95,'yellow')
bar(Time,Energysol.k(:,3,5),.95,'black')
bar(Time,Energysol.k(:,3,6),.95,'cyan')
bar(Time,Energysol.k(:,3,7),.95,'magenta')
bar(Time,Energysol.k(:,3,8),.95,'green')
xlim([0,25])
ylabel('Wh')
set(gca,'XTick',0:3:96,'XTickLabel',v)
title('Dryer Optimal Schedule','FontWeight','bold')
box on
grid on
hold off
a=sum(sum(Energysol.k,3),2);
figure
```

```
box on
grid on
hold on
yyaxis left
L1=a(1:(numel(Time)*18/24)-1);
L2=a(numel(Time)*18/24:end);
L=[L2;L1];
stairs(Time,L,'Color','blue','Marker','*','MarkerSize',3,'LineStyle','--','LineWidth',1)
ylabel('Total assigned power (W)')
yyaxis right
K1=TR96Evsel(1:(numel(Time)*18/24)-1);
K2=TR96Evsel(numel(Time)*18/24:end);
K=[K2;K1];
stairs(Time,K,'Color','g','LineWidth',1.5)
ylim([0.0,1.1])
hold off
title(sprintf('Min cost schedule, Toltal Cost = %.0f {e-03 coin}%',[[],TotalCost]))
ylabel('Electricity Price (C/(kW*h)')
xlabel('Time (hrs)')
b={'00:00','03:00','06:00','09:00','12:00','15:00','18:00','21:00','24:00'};
set(gca,'XTick',0:3:96,'XTickLabel',b)
legend('Schedule','Electricity Price','Location','northwest')
```

PERSONAL PUBLICATIONS AND WORKS

Alhamad S., Demand Side Management – Household Load Optimization by using Mixed Integer Linear Programming, *International Marmara Science and Social Sciences Congress,* April 26-28, 2019 Kocaeli, Turkey

CURRICULUM VITAE

Saria Al Hamad was born in 1987 in Damascus. He completed his high school education at Ibn-Rushd High School. In 2005, he entered Aleppo University, Electrical Power Systems Engineering Department and graduated in 2011 with first place. After that, he worked in the Syrian Petroleum Company for 3 years as a senior maintenance engineer. In 2015, he started his master's degree as a scholarship holder at Kocaeli University, Department of Energy Systems Engineering. In his master's degree, he has studies on DSM and energy optimization for smart home.