T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

COST-ORIENTED ENERGY MANAGEMENT IN SMART GRID

MASTER'S THESIS

Aws Talab Ghaeb SHEBL

Engineering Management Master in English Program

AUGUST 2021

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Thesis Advisor: Asst. Prof. Dr. Koray ERHAN

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İSTANBUL GEDİK ÜNİVERSİTESİ

LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

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Enstitümüz, Engineering Management Department İngilizce Tezli Yüksek Lisans Programı (191281012) numaralı öğrencisi Aws Talab Ghaeb SHEBL'in "Cost-Oriented Energy Management In Smart Grid" adlı tez çalışması Enstitümüz Yönetim Kurulunun 16.08.2021 tarihli kararıyla oluşturulan jüri tarafından *Oy Birliği* ile Yüksek Lisans tezi olarak *Kabul* edilmiştir.

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1) Tez Danışmanı: Dr. Öğr. Üyesi Koray ERHAN

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3) Jüri Üyesi: Doç. Dr. Murat AYAZ

DECLARATION

I, Aws Talab Ghaeb SHEBL, do hereby declare that this thesis titled as "Cost-Oriented Energy Management In Smart Grid" is original work done by me for the award of the masters degree in the faculty of Engineering Management. I also declare that this thesis or any part of it has not been submitted and presented for any other degree or research paper in any other university or institution. (16/08/2021)

Aws Talab Ghaeb SHEBL

PREFACE

In completing this study, from my background in electrical engineering, and the knowledge I gained from studying engineering management, I focused on electrical loads and peak control using techniques and applications in the smart grid. All thanks to Dr. Koray ERHAN who shared his information and time with me to complete this thesis.

August 2021 Aws Talab Ghaeb SHEBL

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ABBREVIATIONS

AMI : Advanced Metering Infrastructure
AMR : Automated Meter Reading
CB : Circuit Breaker
CT : Current Transformer
DA : Distribution Automation
DER : Distributed Energy Resources
DG : Distributed Generation
DR : Demand Response
DR : Demand Response
DSM : Demand Side Management
EC : Electricity Cost
FA : Feeder Automation
FERC : Federal Energy Regulatory Commission
HEMS : Household Energy Management System
IBR : Inclining Block Rate
IT : Information Technology
LOT : Length of Operational Time
NIST : National Institute of Standards and Technology
OT : Operational Time
PAR : Peak to Average Ratio
PHEV : Plug-in Electrical Hybrid Vehicles
PHEV : Plug-in hybrid electric vehicles
PV : Photovoltaic
RE : Renewable Energy
RES : Renewable Energy Source
RTP : Real-Time Pricing
RTP : Real-Time Pricing
RU : Residential Units
SA : Service Automation
SCADA : Supervisory Control and Data Acquisition
SFC : Shared Facility Controller
SG : Smart Grid
TOU : Time-of-Use
UC : User Comfort
V2G : Vehicle to Grid
VRE : Variable Renewable Energy
VT : Voltage Transformer
WT : Waiting Time

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ABSTRACT

COST-ORIENTED ENERGY MANAGEMENT IN SMART GRID

This study focused on electrical energy, its sources of generation, and solutions to control the increase in energy demand, and manage it easily and smartly. The goal is to develop the existing electrical network using modern technologies and make it a smart network capable of managing sudden changes in the electrical power system. The stu dy was presented on the importance of these technologies in energy management. It is known that owning advanced technology is one of the most important strategic management goals in our practical life. and employing the smart grid to manage energy demand is an important factor for the product on the one hand, and on the other hand, it is an assistant part for the consumer in helping to manage energy, especially at the peak time when energy demand is higher than expected.

In this thesis, an example of the increase in demand for electrical energy was studied, monitoring the electrical loads of a particular city for a whole day, recording and studying the loads, indicating peak times and the value of loads and costs. At peak times, loads rise, which negatively affects the electrical power system and power quality, and sometimes cuts off electrical power to the consumer, to solve the problem, schedule the loads at peak time, shift them off-peak, or change the power supply to a solar power source for home units, city electrical loads were recorded for 24 hours, these loads were analyzed using Microsoft Excel, and the highest peak load was only 6 hours out of the total 24 hours. The cost was used as a key factor for controlling electrical loads and scheduling operation times for some devices in Peak Times-ON based on flexible power factor reducing the percentage of electrical loads at peak times and scheduling off-peak times, lowering the cost of the electricity bill and reduced peak loads. The study proved the use of cost in managing energy and reducing the load at peak times. The smart grid played a role in managing these loads, and the benefits of the smart grid were studied in integrating different energy sources, including renewable energy into the electric grid. In addition to urging the use of clean and environmentally friendly energies to reduce environmental pollution and global warming.

Keywords: *Smart grid, Electric energy, smart grid techniques, Energy management, Peak time.*

ÖZET

AKILLI ŞEBEKEDE MALİYET ODAKLI ENERJİ YÖNETİMİ

Bu çalışma, elektrik enerjisine, üretim kaynaklarına ve enerji talebindeki artışı kontrol etmek, kolay ve akıllıca yönetmek için çözümlere odaklanmıştır. Amaç, mevcut elektrik şebekesini modern teknolojiler kullanarak geliştirmek ve onu elektrik güç sistemindeki ani değişiklikleri yönetebilen akıllı bir şebeke haline getirmektir. Bu teknolojilerin enerji yönetimindeki önemi üzerine çalışma sunulmuştur. İleri teknolojiye sahip olmanın pratik hayatımızdaki en önemli stratejik yönetim hedeflerinden biri olduğu bilinmektedir ve enerji talebini yönetmek için akıllı şebekeyi kullanmak, bir yandan ürün için önemli bir faktördür ve diğer yandan, özellikle enerji talebinin en yoğun olduğu zamanlarda, enerjinin yönetilmesine yardımcı olan tüketici için yardımcı bir unsurdur.

Bu tezde, elektrik enerjisi talebindeki artışın bir örneği, belirli bir şehrin elektrik yüklerinin bir gün boyunca izlenmesi, yüklerin kaydedilmesi ve incelenmesi, pik süreleri ve yüklerin ve maliyetlerin değerini gösteren bir örnek incelenmiştir. Pik zamanlarda, elektrik güç sistemini ve güç kalitesini olumsuz yönde etkileyen ve bazen sorunu çözmek, yükleri pik zamanda programlamak, yoğun olmayan zamanlarda kaydırmak veya gücü değiştirmek için tüketiciye giden elektrik gücünü kesen yükler yükselir. Ev üniteleri için bir güneş enerjisi kaynağına besleme, 24 saat boyunca şehir elektrik yükleri kaydedilmiş, bu yükler Microsoft Excel kullanılarak analiz edilmiş ve en yüksek tepe yükü toplam 24 saatin sadece 6 saatinin olduğu gözlemlenmiştir. Maliyet, elektrik yüklerini kontrol etmek ve bazı cihazlar için çalışma sürelerini programlamak için önemli bir faktör olarak kullanılmıştır. Esnek güç faktörüne dayalı olarak, yoğun zamanlarda elektrik yüklerinin yüzdesini azalttığı görülmüş ve yoğun olmayan zamanları programlayarak maliyet düşürülmeye çalışılmıştır. Çalışma, enerji yönetiminde ve yoğun zamanlarda yükü azaltmada maliyetin düşmesini kanıtlamıştır. Akıllı şebekenin bu yüklerin yönetilmesinde rol oynadığı görülmüş ve akıllı şebekenin faydaları, yenilenebilir enerji de dahil olmak üzere farklı enerji kaynaklarının elektrik şebekesine entegre edilmesi de araştırılmıştır. Çevre kirliliğini ve küresel ısınmayı azaltmak için temiz ve çevre dostu enerjilerin kullanılmasını teşvik etmenin gerekliliği birkez daha ortaya çıkmıştır.

Anahtar Kelimeler: *Akıllı şebeke, Elektrik enerjisi, Akıllı şebeke teknikleri, Enerji yönetimi, Peak time*

1. INTRODUCTION

1.1 Study Topic

In general, the energy is characterized as the capability to perform a task, energy has numerous forms life, and the most significant one is the electrical energy that can be described by the ease of use and the ease of being transferred to other energy forms. The electrical, transportation operations, home heating, industrial fields, numerous household uses, and several more complicated applications. The electrical energy that is being used in the operation of electrical devices is one of the use and conversion examples of electrical energy, as electrical energy is converted from thermal, photovoltaic, mechanical, or other energy. It also has the credit for the Industrial Revolution, where the energy obtained from the fossil fuel has provided the path for an industrial revolution and resulted in massive changes for a higher quality of life. It was possibly the most radical society transformation in history. Up until now, the fossil fuels have the biggest portion (80%) in the constantly increasing energy consumption in the world, as can be seen from Figure 1.1. however, this improved life standard has its costs (Peter Pflaum, 2017), but fossil fuels have an environmental impact due to carbon dioxide emissions. Since the start of the 20-th century, numerous scientists, one of which has been the physicist Svante Arrhenius (Arrhenius, 1896,), suggested that the human-produced emissions of the CO2 can result in an effect of the global warming. From that time, numerous worldwide initiatives that aim at the reduction of global green-house gas emissions have been started, culminating in declarations for limiting the global warming to a maximum of 1.5°C at Climate Change Conference (COP 21) of UN in Paris. Taking under consideration the fact that the tendency of increasing consumption of energy is persistent (Energy Outlook, 2019).The other factor in the increase in energy consumption it is the population explosion, the population of the world had reached 7.70 billions in the middle of 2019 having added a billion people since 2007, with below a growth rate of 1.1% per year. It is expected that the population of the world will reach 8.50 billion in 2030, 9.70 billion in 2050 and 10.90 billion in 2100, as shown in Figure 1.2 (United Nations, 2019). This remarkable increases in the population of the world resulted in a big issue in the electric energy field, due to the correlation of the global population with the energy demands has been positive, meaning that the demands for the energy are going to be increased, the rate of the electricity demands exceeded the rate of the population growth (J.A.Momoh, 2012). The residential buildings are consuming about 40% of electricity in U.S., 68% in EU (A.I. Dounis ,C. Caraiscos, 2008) .With this demand increases, it has led to problems such as power outages, loss of loads and voltage instability, requiring an increase in electrical grid capacities, an increase in production and an increase in the consumption of fossil fuels, as it was observed in previous years a significant increase in fuel consumption for the world (S.M. Naseem, 2016). For example, the situation of the Energy in America and the U.S. in the past three years. Figure 1.3 depicts the production and consumption of the energy in Quadrillion Btu, while in Figure 1.4 d the consumption of the electricity by sector is demonstrated. Moreover,Figure 1.5 explains the Electricity Net Generation resources in Billion kilowatt hours. Figure 1.6 illustrates the average of electricity prices in cent/ kilowatt-hour.

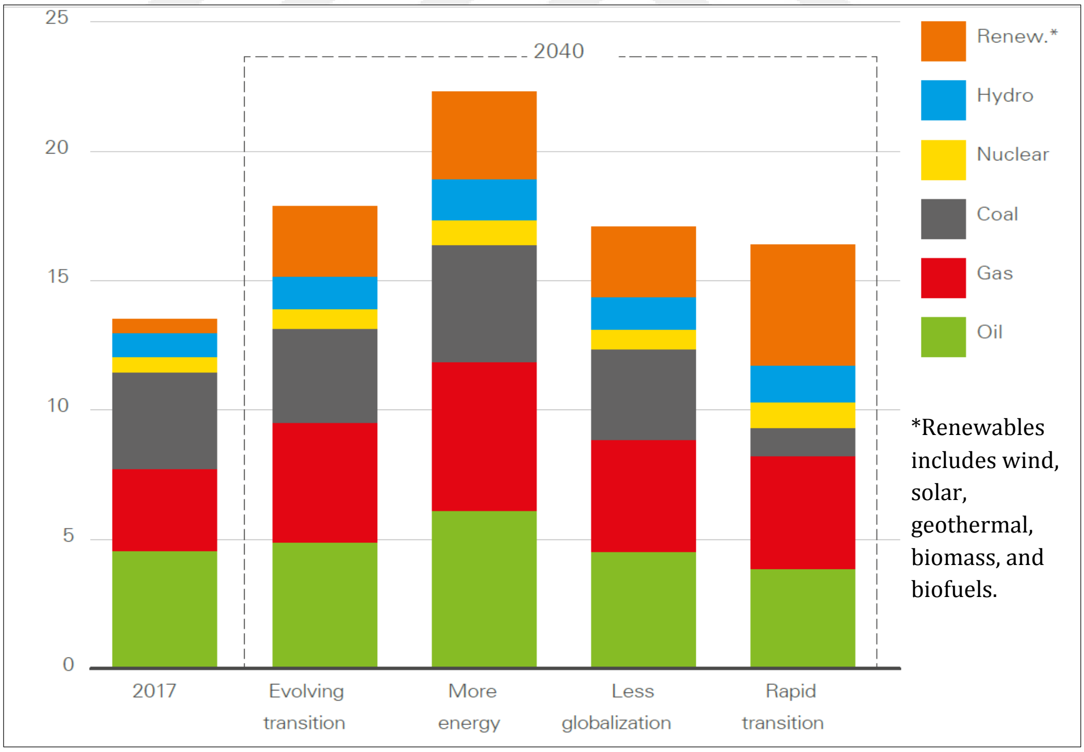

Figure 1.1: World Energy Consumption

Source: (Peter Pflaum, 2017).

Based on US EIA report, the Fossil fuels were the main source of the energy, which was utilized worldwide during the past century. For instance, the fossil fuels makes up a minimum of 80% of U.S. fuel since the year of 1900 (EIA, 2020). Those kinds of the sources of energy aren't renewable, it is running out daily, not environmentally friendly, pollutes the air through the increase of the emissions of the CO2, the fuel cost, the price of the fossil fuel has dramatically soared in the past 10 years. However, the renewable energy is obtained from the natural sources that aren't continuously depleted, like the water, wind, and sun that are available in almost every country. It may be produced as well from the tidal waves and movements or from the geo-thermal energy in addition to other innovations. It is fundamentally different from the fossil fuels like the coal, natural gas and oil. The renewable energy creates no environmentally dangerous fossil fuel wastes, like the ones increasing the global warming, e.g. CO2. The generation of 100% of the demand of the electricity from the renewable isn't an impossible task in the present day. For example, Norway has come first in the capacity for the generation of renewable power, in the past 10 years, 95% to 99% of their consumption of electricity has come from the renewable sources, a considerable amount portion of that percentage has come from the hydropower (A.T.Gullberg,D.Ohlhorst, M. Schreurs., 2014).

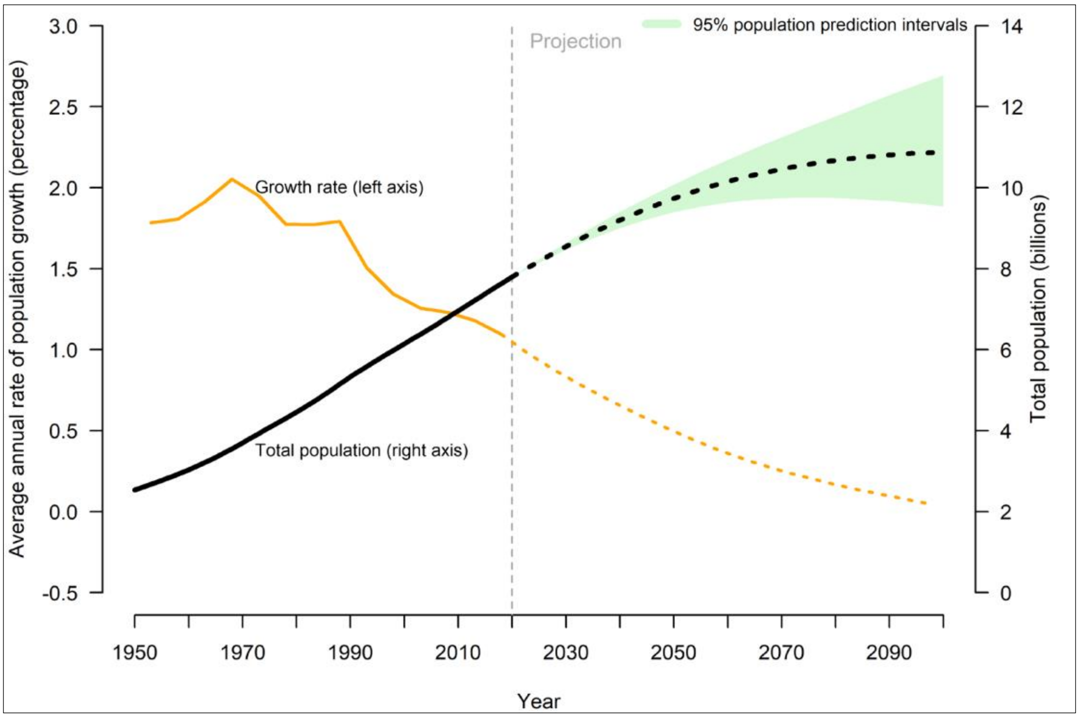

Figure 1.2: World Population Prospects 2019

Source: (Arrhenius, 1896,).

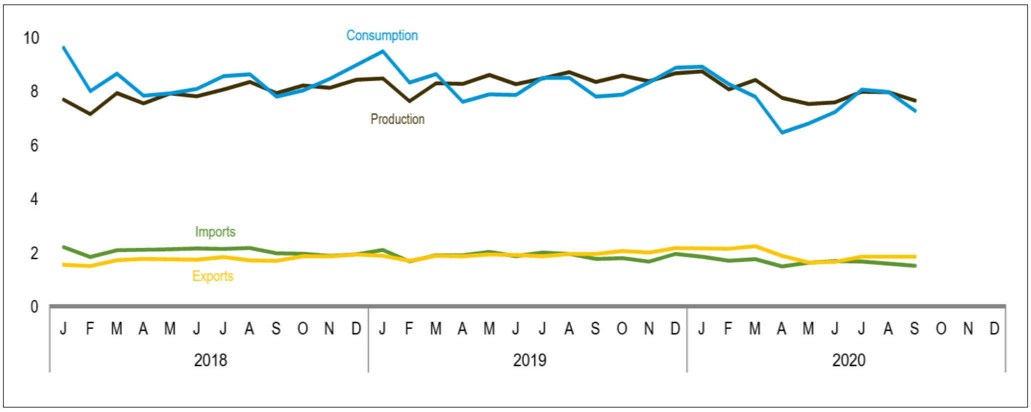

Figure 1.3: The Production and Consumption of Energy in the U.S.A.

Source: (EIA, 2020).

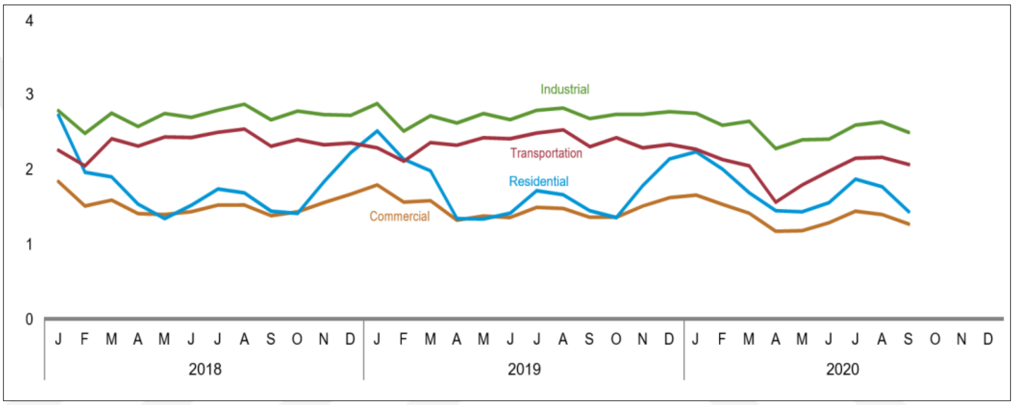

Figure 1.4: The Consumption of Electricity By Sector is Demonstrated in the U.S.A.

Source: (EIA, 2020).

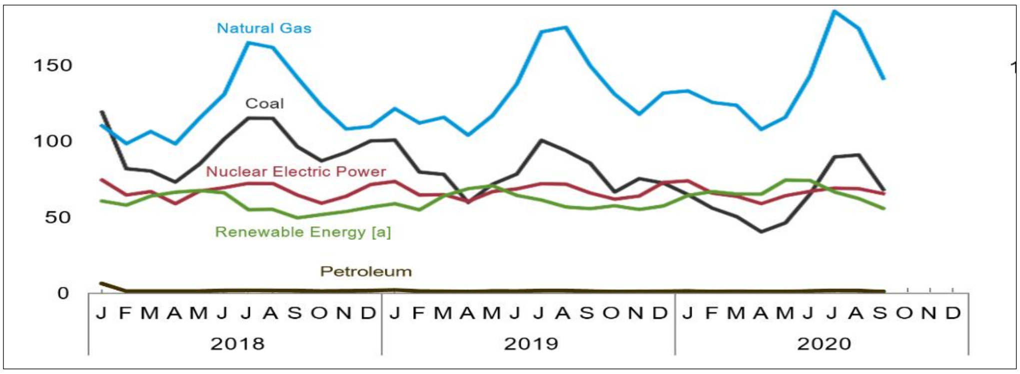

Figure 1.5: The Electricity Net Generation Resources in the U.S.A.

Source: (EIA, 2020).

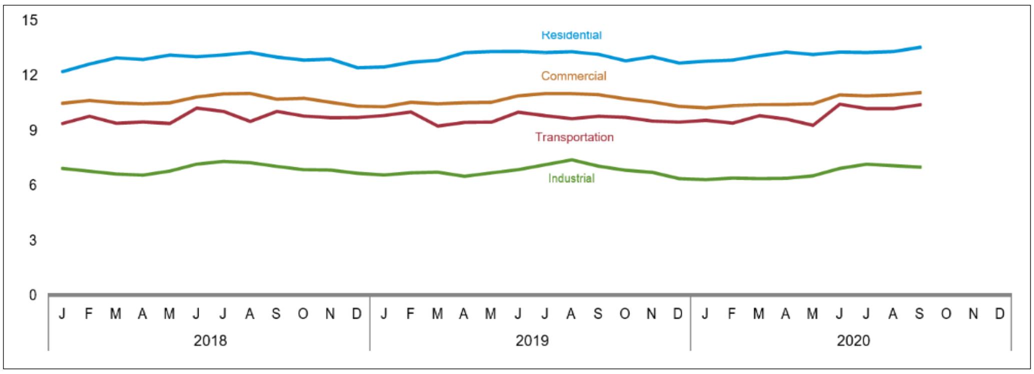

Figure 1.6: Illustrates the Average of Electricity Prices in the U.S.A.

Source: (EIA, 2020).

In (H.Sung, 2011) South Korea developed on Jeju Island in 2009 a national Smart-Grid-Roadmap for supporting large scale integrations of the sources of renewable energy with electric power system operations in a sufficient, environmentally friendly and comprehensive manner. The aim is that by 2030 the island will be supplied with a 100% renewable energy. The aim of Smart Consumers domain includes introducing systems of smart energy management that have been based upon the in-house displays, smart meter services, communication systems and distributed resources of energy that have been integrated in systems of home automation. 3,000 users of the network (administration buildings, production facilities and households,) play a role in trial operations with the dynamic tariffs as well as their real-time signalling. The systems of energy management for the households and for the large buildings production have been tailored in particular to the utilization type, has explained that smart grid represents a fundamental component for the linking of the conventional and renewable sources of energy, gradual increase of the renewable energy, and harnessing the technical factors for the success. Currently, the majority of the production of the renewable energy is generated in the hydro-electric power stations through massive dams, wherever proper places are discovered to build them on the waterfalls and the rivers, the technologies of energy generation, which are dependent upon the solar and wind energy are utilized on large scales in the developed countries and some of the developing ones. The renewable sources of energy are widespread, The potentials of the solar energy, the irradiation of the Sun on the Earth is 14000 times greater compared to the energy consumption of the whole world. Accumulated throughout 1 year, the solar irradiance energy on the Earth has been found considerably greater compared to all of the known resources of the fossil fuels, Figure 1.7 (Krauter, 2006). There are several countries that developed the plans for increasing the proportions of their renewable energy productions (C.E.Brown, 2002). From 2000 to 2010 the generating capacities of the existing renewable energy. In general 22% of the electric energy is generated presently from the renewable energies, whereas numerous countries are striving for considerably higher (D.Teichmann, K.Stark, K.Muller,G.Zottl, P.Wasserscheidc,W.Arlt, 2012). Electricity from variable wind energy and solar PV achieved high penetration levels in numerous countries in 2018. A variety of the renewable sources have met high generation shares in Denmark (51%), Ireland (29%), Uruguay (36%), Portugal (24%), and Germany (26%), and in general, at least 9 countries have produced over 20% of the electricity from Variable renewable energy in 2018 (REN21, 2019). Moreover, the sector of renewable energy in Germany has been defined as a highly successful renewable model in EU. It has supplied the country with 30% of the energy demands in 2014. In addition to that, Germany has come first in Photovoltaic arrays (PV arrays) with a 33 GigaWatt-hour installed capacity in 2012 (R.J. Bessa, A. Trindade, A. Monteiro, V. Miranda,, 2014). The reductions of the cost in the renewables and the evolutions in the digital technologies have opened massive opportunities for the transitions of energy. Wind and solar PV can provide over 50% of additional generation of the electricity by 2040 in Stated Policies Scenario and nearly all if the growth in Sustainable Development Scenario, where additional measures for incentivizing the investments in the renewables-based electricity, bio-energy, geo thermal heat, solar heat, and electrifications have pushed the renewables' share to 2/3 of the output of electricity generation and 37% of the final consumption of energy. By the year of 2040, the expected output from the wind is (8300TWh) and solar PV (7200TWh) will possibly exceed the hydro-power (6950TWh) (AGENCY, World Energy Outlook 2019, 2012).

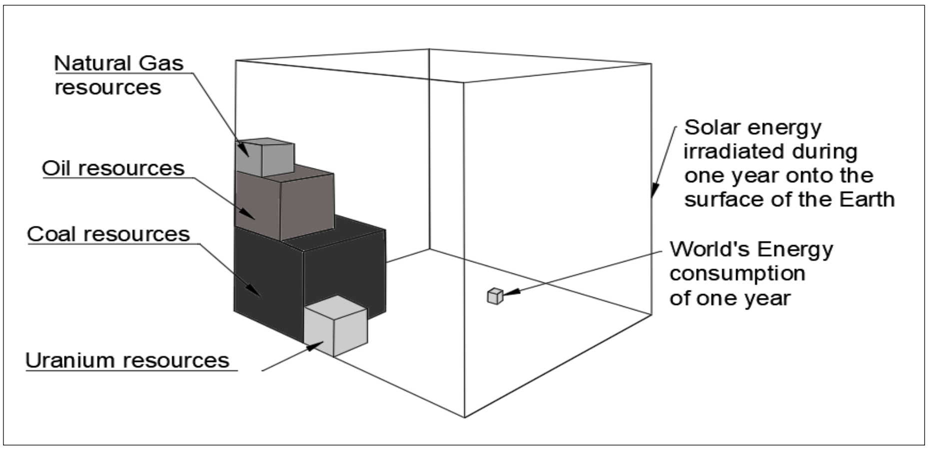

Figure 1.7: World’s Energy Consumption

Source: (Krauter, 2006)

The conclusion from the above is that there is an increase in the demand for electrical energy and an increase in the types of energy sources, and here the focus is on renewable energy sources. All energy sources must be shared on a single network to be able to manage and control them, so the current electrical network must be modernized using modern and smart technologies to create the so-called smart grid, which will be explained in the second chapter., hence the title of this thesis on energy management in the SG.

1.2 Purpose of Thesis

The diversity of these sources and their different locations has become an urgent need to link these sources with each other and with the traditional production sources using the electrical grid, but these grid suffer from fundamental problems hindering these expansions and imposing the need for a new understanding and conception to build an electric power grid that works with these sources, One of the causes of these problems is the rapid increase in demand, and this huge increase in energy demand is expected to double over the next 50 years 1980-2035. It is a factor influencing designers and managers of power transmission networks, according to Figure 1.8.(AGENCY, World Energy Outlook, 2011), Secondly, the aging infrastructure has the tendency of compromising the power supply reliability and exacerbating the losses of the energy to detriment of the economies that undergo the rapid electrifications, Thirdly, due to the fact that the share of the variable renewable energy (VRE) in the mix of the energy grows, there will be a need for increasing the flexibility of the power grid for the purpose of matching the supply and demands in the real time, for instance, the shared sources of the energy in gross German power production in 2020, Figure 1.9 (K.Appunn, Y. Haas, J. Wettengel,, 2020).

Finally, due to the increase in penetration of the distributed generation to quite high degrees in some of the areas, problems concerning the quality of the power and the bi-directional flows of the electricity arise, which can't be accurately regulated through the conventional grids. This study aims to conduct an analysis of the electrical energy demand for a specific region, where the electrical loads were monitored for a period of 24 hours during which the loads were analyzed and the Peak Time-ON for electrical energy was determined. There will be two methods for the consumer: The first is the change of time of some loads to Peak Time-OFF. The second use of a household renewable energy source (the consumer will be a producer of electrical energy). In the above two methods, the cost of electric energy will decrease and the loads decrease for the central generation sources, and this process will be through the smart grid. Our focus in this thesis will be on the smart grid, controlling Peak Time-ON in the electric power system, It will be talked about in the third chapter.

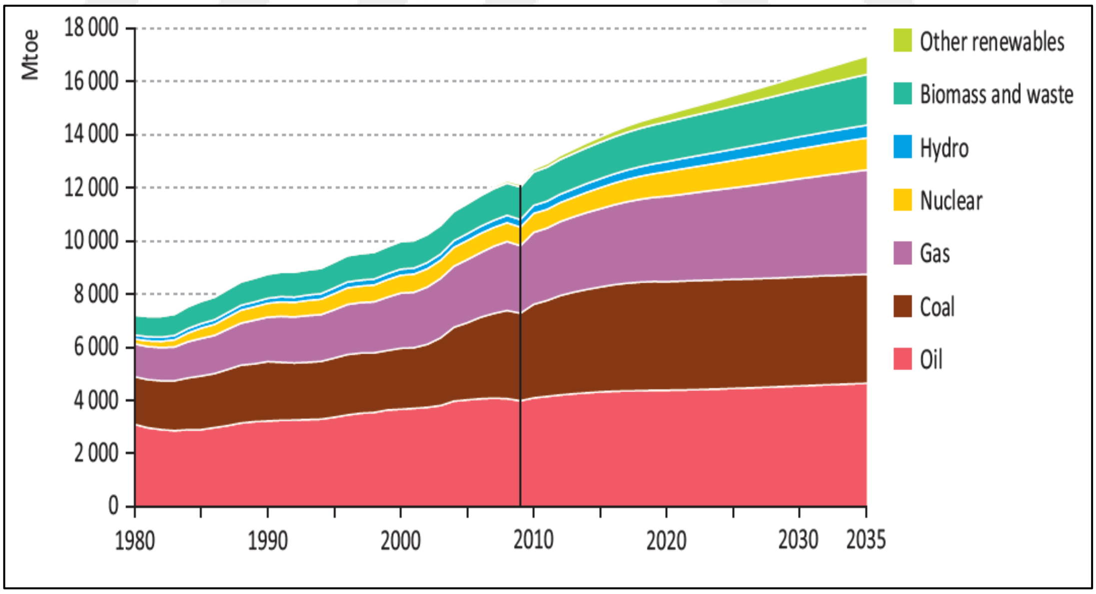

Figure 1.8: World Primary Energy Demand

Source: (AGENCY, World Energy Outlook, 2011).

1.3 Literature Review

There is a number of the research activities in Smart Grids field. In the present section, the majority of those researches especially at the level of the distribution have been discussed. Energy Management System for the electric grid by using Smart Grids (SGs), which aim at modernize conventional electric power grid toward the sufficient distribution and reliable managements of the energy in electrical domain (D.Pliatsios, P.Sarigiannidis,, 2020). The Smart Metering make the appliances smart with the use of a variety of the methods of scheduling. There's an integration of the Renewable Sources of Energy that is capable of increasing the entire system's stability. The key aim of the System of Energy Management has a variety of the parameters; Minimizing the costs of the electricity, Minimizing the load in the Peak Time-ON, Minimizing the delay, minimizing the waiting time, and Maximizing the comfort of the users

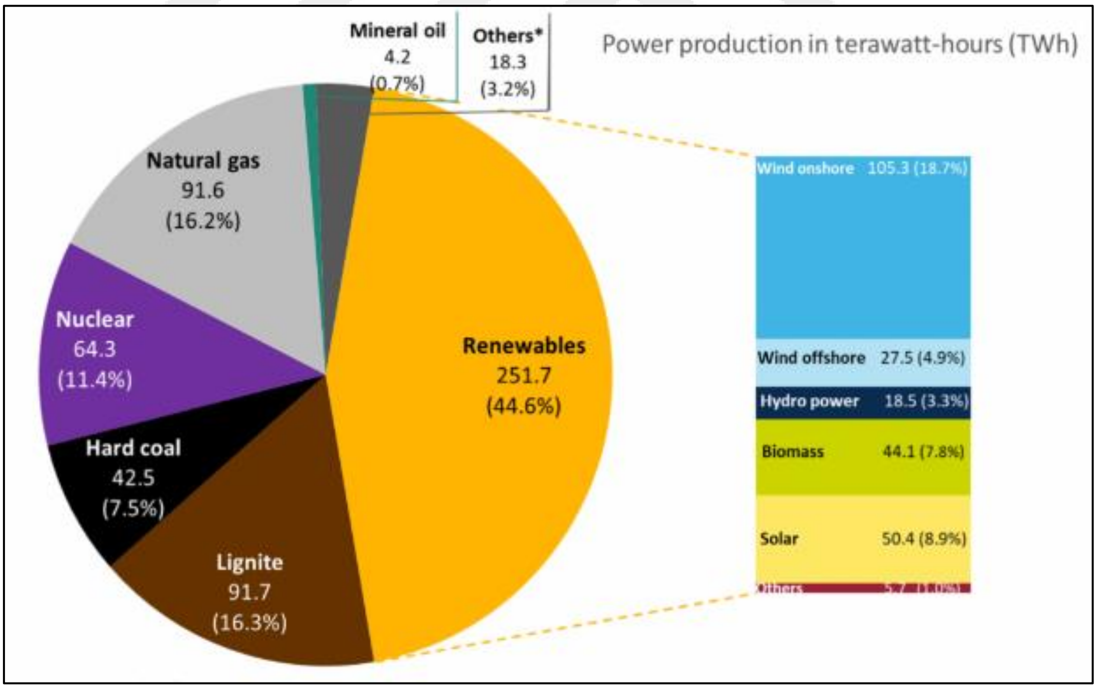

Figure 1.9: Shared of Energy Sources

Source: (K.Appunn, Y. Haas, J. Wettengel,, 2020).

A variety of the approaches and models have been suggested with the passage of time for overcoming the lacks of the energy and how the available resources are capable of fulfilling the desired consumer needs. Those approaches utilize various types of the pricing methods and various conditions elevating the users for avoiding the loads in Peak Time-OFF. The load will be shifted from Peak Time-ON to Peak Time-OFF. There is a variety of the research projects in Smart Grid fields. In the present section, some of those research projects particularly at control and distribution levels are explained in general.

“The author” (L.Tianyi. M.Dong, 2016), addressed energy management and scheduling of load with Renewable Energy integration for the purpose of reducing system cost. Optimization method like “lyapunov” handled stochastic problem of Renewable Energy. Moreover, they utilize the real time algorithm for the joint load scheduling’s and the control of the energy storage for the purpose of minimizing the general system costs in the finite time horizon. The results of the simulation demonstrate that scheme is efficient in the achievement of the desired aims within finite time horizon. On the other hand, “the authors” have ignored the cooperation amongst the RE generating consumers and appliances classificat. “the author” (R. Mohammad, 2015)author have aimed at the reduction of the cost of the consumers and Reducing the consumption of the Fossil Fuel in the smart grid with the smart houses that have been supplied by the Plug-in Electrical Hybrid Vehicles, and in addition to that, reducing the load Peak in the peak hours of the consumption and for the reduction of the fossil fuel applications. In a new approach of optimization according to the management of the demands has been presented for the purpose of reducing the costs, every one of the users for reducing the costs must certainly charge the car in the low consumption hours and saving electricity in the battery throughout the day with the use of his solar cell, and utilizing energy that has been saved by the solar cell and the PHEV at the peak hours of consumption at a time. “the author” (W. Tushar, 2014) They explained the advantages of the distributed sources of energy in a model of energy management for the smart community that consists of a Shared Facility Controller (SFC).and numerous residential units (RU) “the authors” suggested a proper system model where there is a possibility for facilitating the considered management of energy between RUs, SFC and grid through a Stackelberg game, Figure 1.10. “the author” (DTI/OFGEM Embedded Generation Working Group, 2000). The renewable energy resource installation in the networks of the distribution has several main technical implications, which are commonly researched and may be classified to 4 fundamental groups, which are: Voltage Control, Load

Flows, Network Security and Fault Levels. In this section, some researches on algorithms and Peak Time-ON time are discussed, which are the subject of our focus in this thesis. “the authors” (Z. Zhao, 2013) , (T. T. Kim, H.Vincent,, 2011) managed the load is only discussing Load, which may be managed such that there is a 2- way communication between the utility and the user for the next day energy needed and they utilize inclining block Rate (IBR) and real-time pricing (RTP) due to the fact that the RTP is more cost effective and flexible (Z. Zhao, 2013).

Which main aims are to minimize Peak to Average Ratio (PAR), delay time and cost of electricity. “the author” (L.Peretto, 2010) the load shifts to Peak Time-OFF from Peak Time-ON due to the charges of the electricity of the Peak Time-ON are much so when the load will be managed between Peak Time-ON and Peak Time-OFF then will be decreased as well. “the author” (G. Xiong, C. Chen, S. Kishore,, 2011) the data centres have been created for the management of load where the data has been stored and analysed for the demands and the availability for the future. “the author” (T. T. Kim, H.Vincent,, 2011) “the author” has introduced the thermostat idea that is capable of switching the appliances off in the case where they exceed desired limit that has been compromised for load in the Peak Time-ON. “the authors” (L.Peretto, 2010), (G. Xiong, C. Chen, S. Kishore,, 2011) manages the load for cost and Peak Time-ON elevation but when Renewable Energy Resources (RER) are integrated in the Energy Management System (EMS) user comfort increases due to the fact that users don’t have to be waiting for Peak Time-OFF and user comfort of systems of energy management is computed in terms of the time of waiting (A.Hamed, M.Rad,, 2010) (P.Palensky, D.Dietrich, 2011) (Z. N. Popovic,D. S. Popovic,, 2003).

And other goals of Demand Side Management (DSM) are also achieved through this RER use however Peak Time-ON cost will be same as Peak Time-OFF due to RER resources.

“the authors” (A.Hamed, M.Rad,, 2010), (P.Palensky, D.Dietrich, 2011) (Z. N. Popovic,D. S. Popovic,, 2003) use RER which can add user comfort in the form of waiting time minimization However, author (P.Palensky, D.Dietrich, 2011) there’s 2-way communication between the utility and the customers. Initially, EMC prefers the RER electricity consumption for the appliances and in the case where insufficient utility sources are utilized. RER electricity is higher compared to the requirements, then it will sell to utility company. The integrations of the resources has resulted in increasing the reliability of the system, as well as its stability and efficiency, whereas (P.Palensky, D.Dietrich, 2011) have proposed a new strategy by which the RER energy has been stored and that will be utilized in peak hours, which is why, through this mechanism, DSM is capable of achieving the Peak Time-ON load as the Peak Time-OFF that is capable of increasing the efficiency, reliability and stability. In nearly all (Z. Zhao, 2013), (A.Hamed, M.Rad,, 2010) energy and load managements have been based on PAR. Accumulative loads are managed such that the maximal load will be below PAR then there is a number of the approaches by which the load has been managed with the use of the PAR. “the authors” (L.Peretto, 2010), (A.Hamed, M.Rad,, 2010)“the authors” tried to make load less than PAR, which is why, in the case where the load is being controlled, the cost will be regulated as well. And future estimation will depend as well on the PAR value of the entire system’s EMC. Load is going to be Peak Time-ON or Peak Time-OFF load, must regulate the load such that it will become under PAR limit. “the authors” (L.Peretto, 2010), (T. T. Kim, H.Vincent,, 2011) have discussed PAR minimizations with the use of 2 methods, to make the load balance under appliance PAR. Numerous technical and scientific events were carried out and are organized with a variety of institutions that are exclusively associated with the Smart Grids. The aim of conferences was providing a forum for the discussions on the state-of-the-art innovations in the technologies of the smart grid and for offering practical near-term solutions and applications. The conference topics included Cyber and Physical Security Systems as well (i.e. outage management and intelligent monitoring), Advanced Metering Infrastructure, Smart Sensors and Standards of the Smart Grid (L.Peretto, 2010). Ultimately, the smart grid must have the ability to provide new abilities like high reliability, self-healing, real-time pricing and energy management. A wide range of the expertise and skills in the information technology, electrical engineering, control and automation, communications, nanotechnology and education will be necessary for meeting those goals, not only the fields that are strictly associated with the energy and power topics.

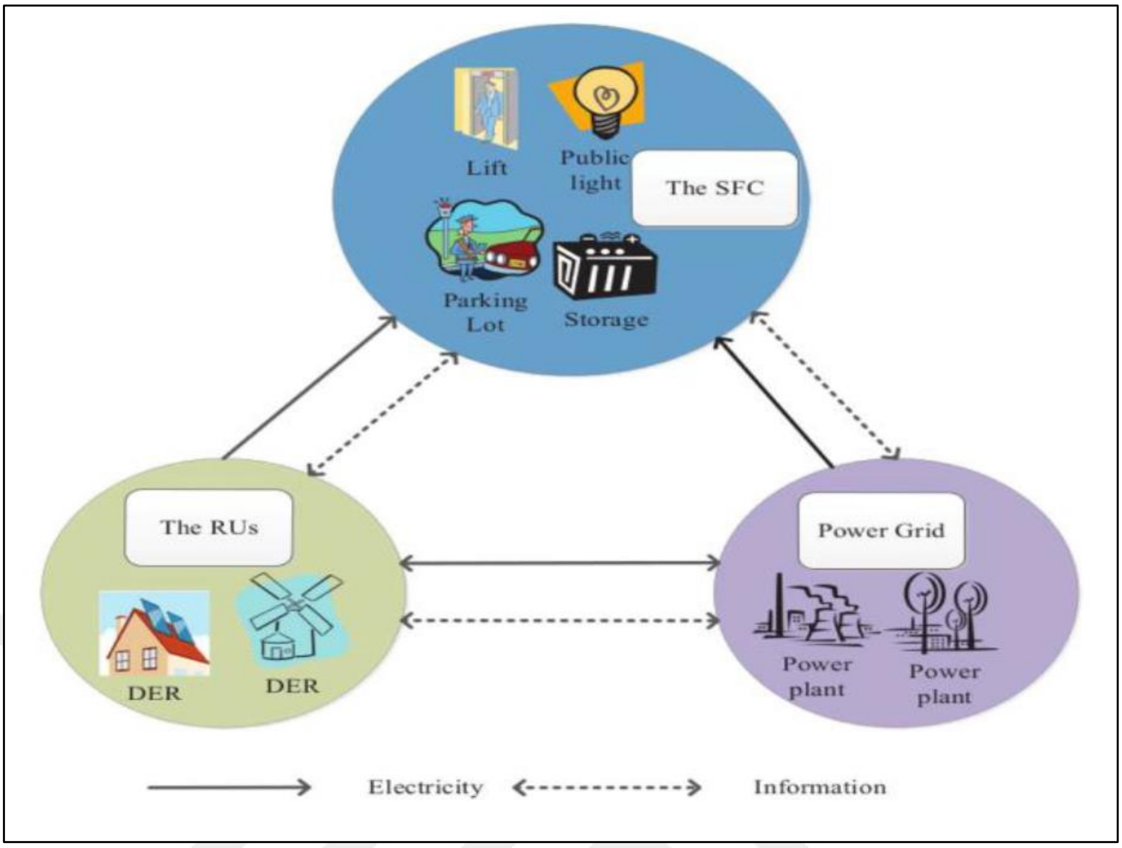

Figure 1.10: System Model for Energy Management

Source: (W. Tushar, 2014).

2. SMART GRID

2.1 Introduction

The most crucial element of power system's evolution is necessity for meeting the world's growing electricity demands, whereas decreasing the emissions of carbon for avoiding permanent changes to the environment of the planet. Therefore, all of this should be accomplished without jeopardizing the electricity supplies' reliability, on which the economies all over the world are becoming increasingly reliant. The majority of organizations and institutions were debating how to enhance and expand the power infrastructure. Lastly, it has been agreed that in order to make effective use of smart grids, one must ask the question How can such idea be implemented economically, technologically and practically, or is it even possible?" It was suggested in a report to the International Energy Agency (IEA) that implementing carefully-studied as well as designed set of policies might cause a reduction in the number of the scenarios for future of the global emissions of the carbon, yearly emissions, in 2030 from present prediction of more than 40Gt (giga-tons) carbon dioxide to only over 26Gt. Those policies attempt to keep global warming to 2^o Celsius higher than the levels of industry before which must be limiting the impacts of climate changes in order to manageable social, economical and environmental costs. One of smart grid's development trends is intelligent electricity terminal consumption. Establishing a reliable and convenient interaction between consumers and power suppliers is critical to achieving intelligent electricity consumption. Demand response (DR) is a requirement to achieve such objective. DR behaviors are defined via the IEA in 2003 as "all the factors that are accountable for variations in the levels of the power demand throughout the time, that is, total electricity consumption amount" (IEA, 2004). Smart grid is extended by household energy management system (HEMS). Users can participate better in DRprojects and may be scheduling a use of house-hold appliances by using HEMS (H. Shareef, M. S. Ahmed, A. Mohamed, and E. S. Al Hassan,, 2018). The major aim of implementing smart grid is maximizing the management and use of power transfer and capacity. This might be realized if supply and demand devices were managed automatically and intelligently. To improve the power grid's availability, flexibility, and efficiency while reducing the requirement for utility infrastructure construction.

2.2 Definition of Smart Grid

A modern concept that originated when talking about renewable energy, its sources, and its integration with the electrical grid and controlling loads, atom time and costs. It also refers to the network that includes renewable energy sources in addition to conventional sources. Smart means the use of information and technological capabilities. Figure 2.1.

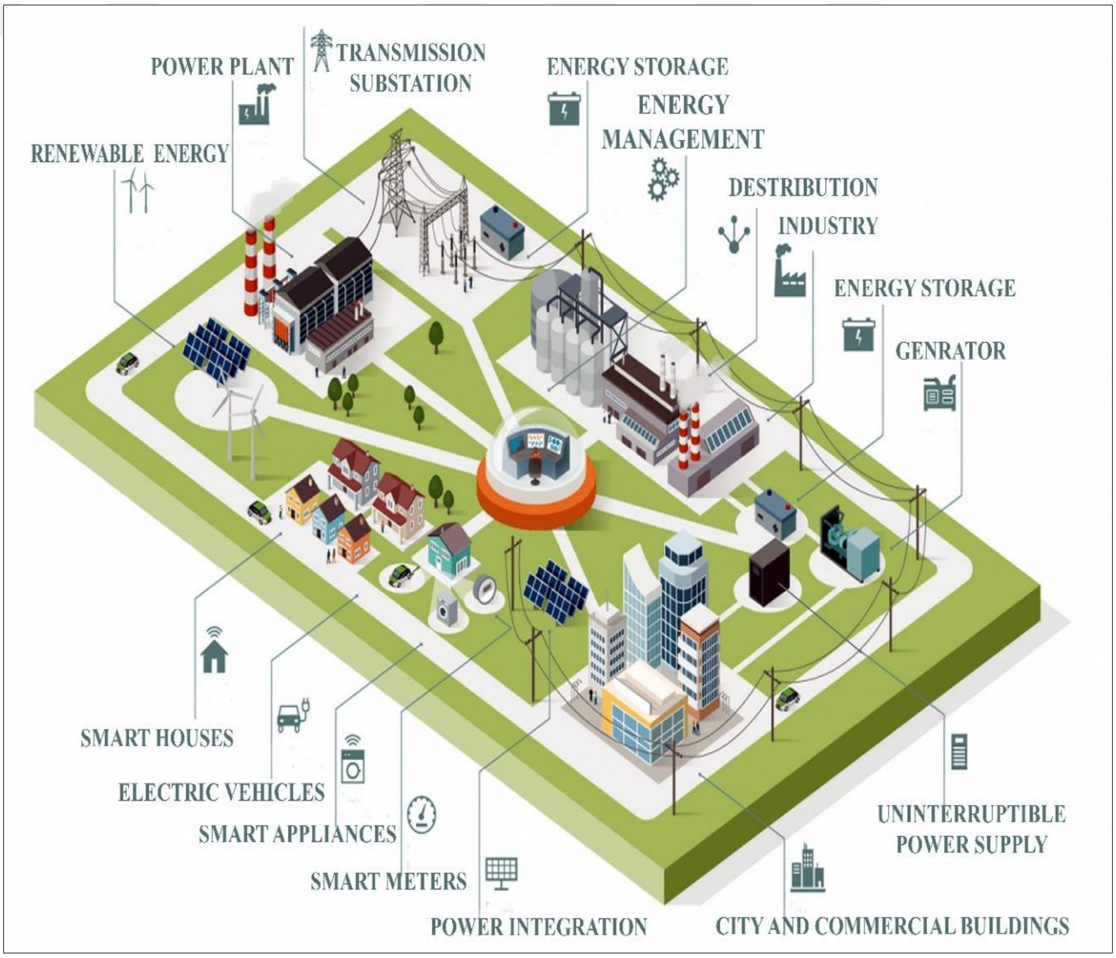

Figure 2.1: Smart Grid

Source: (Commission, 2018.)**.**

The European Technology Platform (ETP) (ETP, 2013) defines Smart Grids as:

Smart grids are electricity networks that might integrate (intelligently) actions regarding all the users that are connected to it, including consumers, generators, and the ones who do the two, for delivering sustainable, efficient, and secure electricity supplies. Innovative services and products are combined with control, communication, intelligent monitoring, self-healing technologies to create a smart grid. Developing smart grids should take into account not just technology, commercial and market considerations, regulatory framework, environmental impact, standardization usage, ICT and strategy of migration, yet as well government edicts and societal needs.

Based on U.S. Dept. of Energy (Department of Energy, U.S. (2009), 2013):

Smart grids employs digital technology for improving the electrical system's security, reliability, and efficiency (both energy and economic) from large generation to electricity consumers, as well as an increasing number of the storage and distributed-generation resources.

(IEEE, 2015) the definition of the IEEE for the SmartGrid is that "smart grid is one of the revolutionary undertakings that entail new control capabilities and communications, generation models, energy sources, and adherence to the cross jurisdiction regulatory structures."

In Smarter Grids: Opportunity (Department of Energy and Climate Change, UK (2009) Smarter grids, 2013), SmartGrid can be defined as:

Smart grids are enabling electricity grids to be noticeable (capable of being measured and visualized), automated (capable of self-healing and adapting), controllable (capable of being manipulated and visualized), and fully integrated using sensing, embedded processing, and digital communication (which is entirely interoperable with the current systems and with a capacity for the incorporation of a wide variety of the sources of energy). Smart grids are seamless, transparent, and direct 2-way information delivery, energy, and enabling industry of electricity for excellently managing the transmission and delivery of the energy while also empowering consumers to be having more control on the decisions that are related to the energy, according to afore-mentioned definitions. Smart grid are combining the advantages of innovative communications and information technology for delivering real-time data and enabling electrical grid to maintain a near-instantaneous balance of demand and supply. One important difference between current's utility grid and smart grids is the 2-way information exchange between the consumer and the utility grid. For instance, a smart thermostat could receive a signal about the electricity expenses as well as adjust temperatures in response to high demands (and high price values) on the grid of the utility, saving costs of consumers, whereas maintaining the comfort. Which is why, the definition will be that: “SmartGrids can be described as advanced digitized 2-way power system of power flow, which has the ability of the adaptive, self- healing, sustainable and resilient with the foresight for the predictions under a variety of the uncertainty cases. It has been supplied for the inter-operability with the future as well as the present standards of the devices, components, and systems which have been cyber-secured towards the malicious attacks.”

2.3 Need for Smart Grid

The opportunities for benefiting from the enhancements in the technology of electronic communication for resolving the costs and limitations of the electrical grid have become evident, concerns regarding the environmental damages from the fossil-fired power stations, the quickly dropping expenses of the point of the renewable-based sources to one of the main changes from centralized grid topology to the topology that has been highly-distributed.

2.4 Characteristics of Smart Grid

The smart grids are using novel services and products, in addition to communication, intelligent control, selfhealing and monitoring technologies. (K.Moslehi, 2010) (R.F.Arritt, 2011) (S.R. Kuppannagari, R.Kannan,V.K. Prasanna,, 2018) .The literature has suggested the next Smart Grid attributes.

2.4.1 Reliability

Consumers have a more sufficient choice of supply with Smart Grid, and the information allows them to help optimize the system's operation. It enables the DR (i.e. demand response) and DSM (i.e. demand side management) via incorporating smart meters, electricity storage, smart appliances, microgeneration, and consumer load, as well as offering consumers with energy usage and pricing information. Consumers will be given incentives and information to change their consumption patterns for the purpose of overcoming a small number of constraints in power system and improve reliability and effectiveness.

2.4.2 Flexibility

It intermittent generation and accommodates storage devices while allowing the connections and operation of the generators of a variety of the technologies and sizes. It can support and accommodate all forms of renewable DERs, residential microgeneration, storage options and DGs, significantly decreasing overall environmental impacts of the system of electricity supply. It enables microgenerators to be operated ‘plug-and-play,' increasing flexibility.

2.4.3 Load blancing

Smart grid enables creation of balanced electrical grid without affecting consumer behavior, such as storing energy in only Peak Time-OFF periods, which allows energy to be easily secured during Peak Time-ON periods. key idea is to ‘shifting’ the loads away from high demand periods.

2.4.4 Sustainability

The flexibility relateod the smart grids allows sharing sources of renewable energy, and since the infrastructure of traditional grid does not allow many generation points with different capacities, the smart grids is a required condition for increasing the electrical energy generated from sources of the renewable energy in the grid.

2.5 Comparison between Existing Grid vs Smart Grid

Various factors are contributing to the conventional grid's inability for meeting the demands for reliable power supply. The properties of conventional grid and the required Smart Grid are compared in Table 2.1.

Table 2.1: Comparison Between Existing Grid and Smart Grid

Feature	Existing Grid	Smart Grid
Equipment	Electromechanical	Digital
Information Flow	1-way communication	Two-way communication
Generation	centralized generation	Distributed generation

Grid Topology	Radial	Interconnected
Sensors	Sensors are not widely used	Sensors are widely used
Observing Ability	Lack of monitoring only manual	Digital self-monitoring

Table 2.1: Cont.) Comparison Between Existing Grid and Smart Grid

Feature	**Existing Grid**	**Smart Grid**
Outage Recovery	Manual	Automatic
Protection Ability	Complicated	Easy
Control Type	Passive Control	Active Control
Testing	Manual check	Remote check
Pollution	High	Low
Overall Efficiency	Low	High
Control Ability	Limited control	Pervasive control
Customer Preference	Few customer choices	Many customer choices

Source: (R. Ma,, Y.-R. Huang, W. Meng, and H.-H. Chen, 2013).

2.6 Advantages of Smart Grid

2.6.1 For grid

According to the U.S. DOE's Modern Grid Initiative (U.S. Department of Energy (DOE)'s, 2007), (S.Paul, 2014), a Smart Grid is expected to reveal the following main characteristics:

- The Power Quality: offers power free of sag, disturbance, interruptions and spikes.
- Self-Healing: responds and detects to the routine issues and is rapidly recovered in the case where they take place, reducing the financial loss and downtime.
- Motivating and including consumers: visibility in Realtime pricing and can afford them an opportunity for choosing the consumption volume as well as the price, which is most suitable for their requirements.
- Can accommodate all the options of generation and storage: "plug & play" interconnections to distributed and multiple sources.

- Enables the markets: can support the energy markets, encouraging both investment as well as innovations.
- Optimizing the assets and operating effectively: develop less new infrastructures, transmitting more power via current systems; thus, spending less for operating and maintaining the grid.

2.6.2 For the consumer

- Offers the newest information concerning their energy utilizations.
- Multiple consumer options for electric energy prices according to time and cost.
- Enable the smart appliances, electric cars, as well as other smart devices to be charged then programmed for running throughout the Peak Time-OFF hours to lower bills of the energy.

2.6.3 For the stakeholders

- Reducing the inefficiency in the delivery of the energy, quick restoration of the power following the outage.
- Integrating renewable energy sources more sufficiently to grid.
- Improving the distributed energy resource management, which includes the operations of the generation and storage.
- Increasing the resiliency and reliability of the grid and reducing power outages.
- Levelling of the demand curve (Peak reduction)
- Reduction of carbon emissions.

2.7 Components of Smart Grid

Figure 2.3 depicts an architectural framework divided to sub-systems and layered with layers of intelligence, technology, innovation, and novel tools. The electric power system's bulk power generations, distribution, transmissions, and consumer levels are all involved. The following are the functions of each component: (S. Rahman, 2009).

Figure 2.2 shows the main features of the Smart Grid.

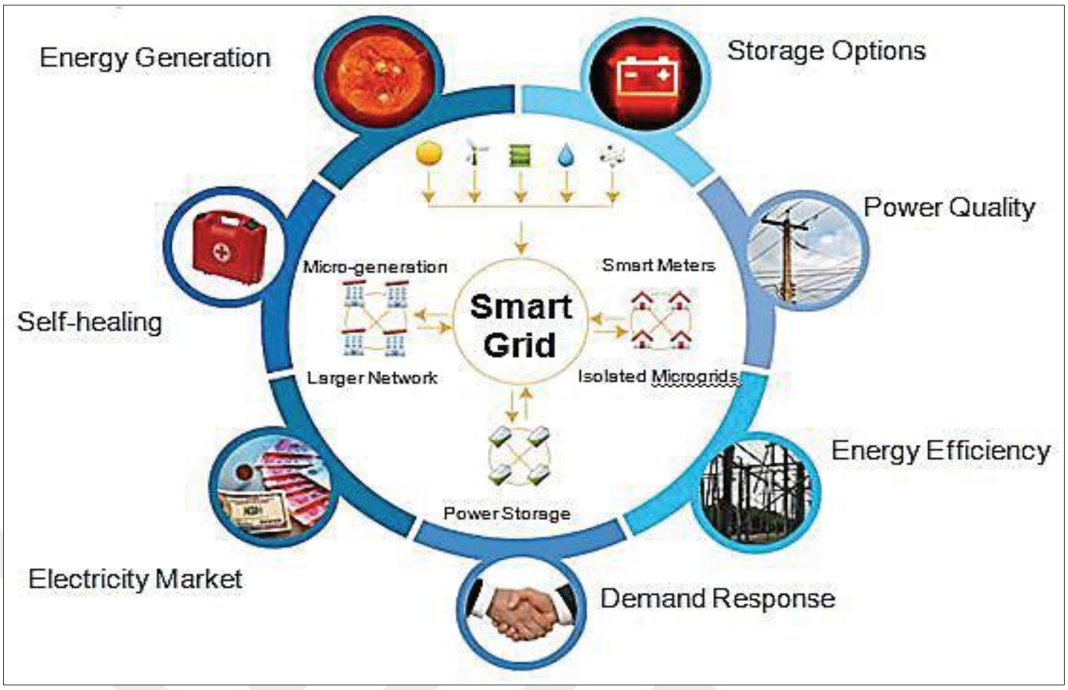

Figure 2.2: Key Features of Smart Grid

Source: (A.Jain1, R.Mishra, 2016).

2.7.1 Smart devises interface

Smart devices can be defined as electronic devices which are typically connected to other networks or devices through various wireless protocols and might operate autonomously and interactively. Smart devices for control and monitoring are part of components of the real-time information process generation. Both centrally distributed sources and DERs should be easily integrated in their operations. Smart cars, smart fridges, smart doorbells, smart thermostats, smart bands, phablets and tablets, smart locks, smart keychains, smartwatches, smart speakers, smartphones, and other smart devices are just a few examples.

2.7.2 Storage

Because of RES inconsistency and the mismatch between peak availability and peak consumption, finding ways for storing the energy for future uses is critical. The component of the storage enhances the resiliency and reliability of the utility grid and electricity consumers. Flow batteries, flywheels, ultracapacitors, pumped-hydro, superconducting magnetic energy storage, and compressed air are examples of energy storage technologies.

2.7.3 Transmission sub-system

An integrated power system's backbone is the transmission system, which connects all major load centers and substations. The ultimate goal of transmission operators and planners is to achieve efficiency and reliability at reasonable costs. Transmission lines must be able to withstand contingency and dynamic changes in load without disrupting services. Specific standards are required to ensure supply quality, performance, and reliability. The design of analytical tools and advanced technologies are among the approaches for achieving Smart Grid performances at the transmission levels. Performance analysis is carried out using advanced technologies that include intelligence, such as market simulation tools and reliability, real-time stability assessments, robust state estimations and dynamic optimal power flows. Transmission sub-systems intelligent enabling tools for the development of the functionality of the smart transmission include real-time monitoring on the basis of state estimators, communication and sensors technologies.

2.7.4 Control and monitoring technologies

Devices for self-healing, self-monitoring, adaptability and predictability of the generations, smart grid, and devices that are capable of handling issues of reliability, instability, and congestion make up the control and monitoring technology component. Such new flexible grids must be able to withstand shock (durability & reliability), as well as providing real-time changes in its uses. Inbuilt control and monitoring capabilities are built into smart energy, efficient utilization of the devices and distributed smart DER. These devices have been found self-aware and might take independent actions on the basis of the situational awareness.

2.7.5 Intelligent Sub-system of the grid distribution

The network of the distribution can be defined as the final power transmission stage to the consumer. Industrial, residential and commercial consumers are served by secondary and primary distribution feeders. Intelligent support schemes at the level of the distribution will have automation monitoring abilities by means of links of communication between consumers and utility controls, AMI, energy management components and smart meters. Self-learning modules regarding fault detection, automatic billing, feeder reconfiguration, restoration, load transfer and voltage optimization, and real-time pricing (RTP) will be included in the automation function.

2.7.6 Demand side management (DSM)

DSM can be defined as a key component of smart grids which allow customers to control their electricity usage patterns. DSM is a critical component of smart grid energy management. It is specified as the change in user consumption patterns that results in the required changes in power system load curves. Rather than installing new generating capacity or reinforcing the distribution and transmission corridor, it focuses on using dynamic electric tariffs, power saving strategies, and incentive-based DR programs for reducing the peak load. DSM as well as options of energy efficiency have been created for the modification of the consumer demands in order to reduce operation costs via decreasing the uses of costly generators and postponing the capacity additions. DSM options help decrease emissions and improve generation reliability. The utility load curve will be affected by such options. It's critical to have a standard protocol with regard to consumer delivery using 2-way information highway technologies. Consumer interfaces and demand side meters for higher energy efficiency will be in place, as will smart homes and smart energy buildings, clean air requirements, and plug-and-play. The goals of DSM are to use RESs, reduce utility power consumption, maximize economic benefit, and reduce peak load. Because power demands are steadily increasing, new-generation units may be needed in the future to meet the needed power. The DSM addresses this problem by lowering peak load. As a result, one can safely postpone the new installations for some years. To maintain a balance between supply and demand, consumers must act wisely through shifting their power consumption from Peak-Time-ON to Peak-Time-OFF (Z.Wu, H.Tazvinga, X.Xia, 2015).

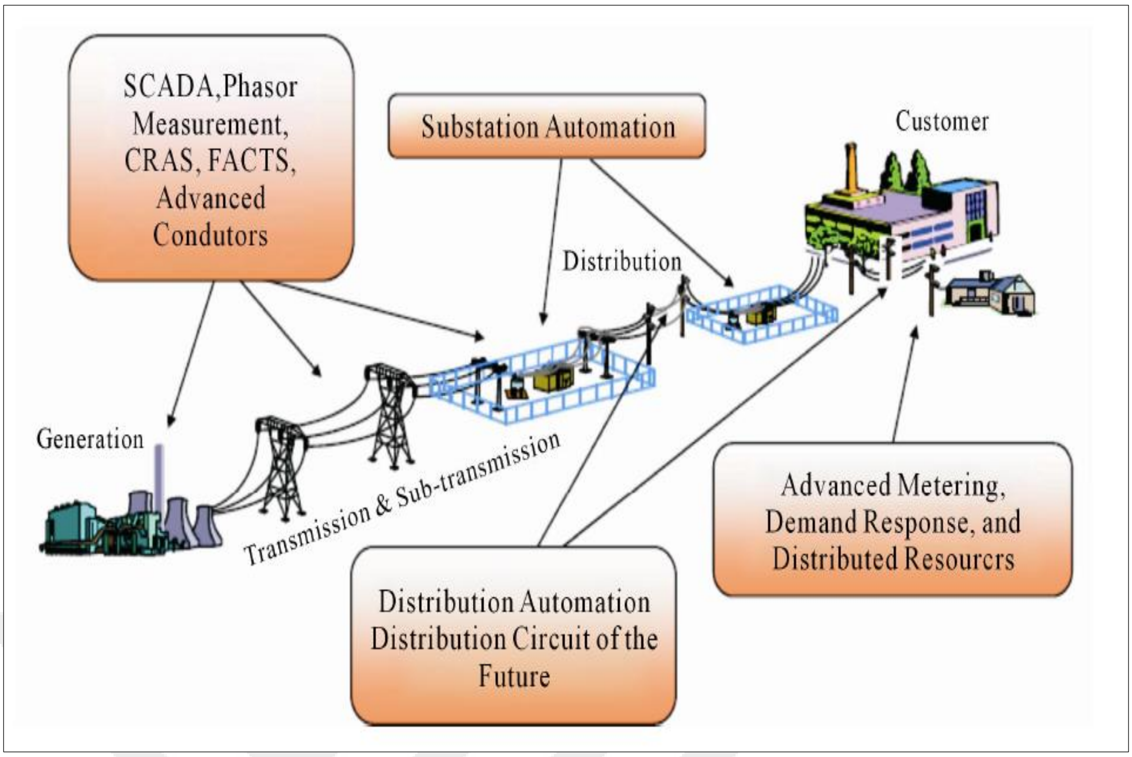

Figure 2.3: Components of Smart Grid

Source: (T.Vijayapriya, D.P.Kothari, 2011)**.**

DSM assists utility companies in flattening load profiles and lowering peak loads for their customers. This helps to make the grid more sustainable while also lowering overall operational costs. There is a sudden spike in demands throughout peak consumption hours. Instead of burdening new installations and generation capacities to meet demand, it solves the problem via decreasing the consumption of power throughout peak hours. As a result, DSM attempts to balance power system supply and demand. (N.N.Sithara, V.Saminathan, 2014).

2.8 Smart grid technologies

The traditional electric grid can be transitioned into a Smart Grid via using some technologies. In the following sections, we'll look at the Smart Grid technologies that can help with the transition.

2.8.1 Smart meters

Smart Meter can be defined as one of the distinctive features of Smart Grid technology that makes it the most reliable instrument for data measurement in power generation and consumption, Figure 2.4. Smart metering is the use of advanced meters along with communication systems to enable customers to track their energy usage in real-time (S.Paul, 2014).

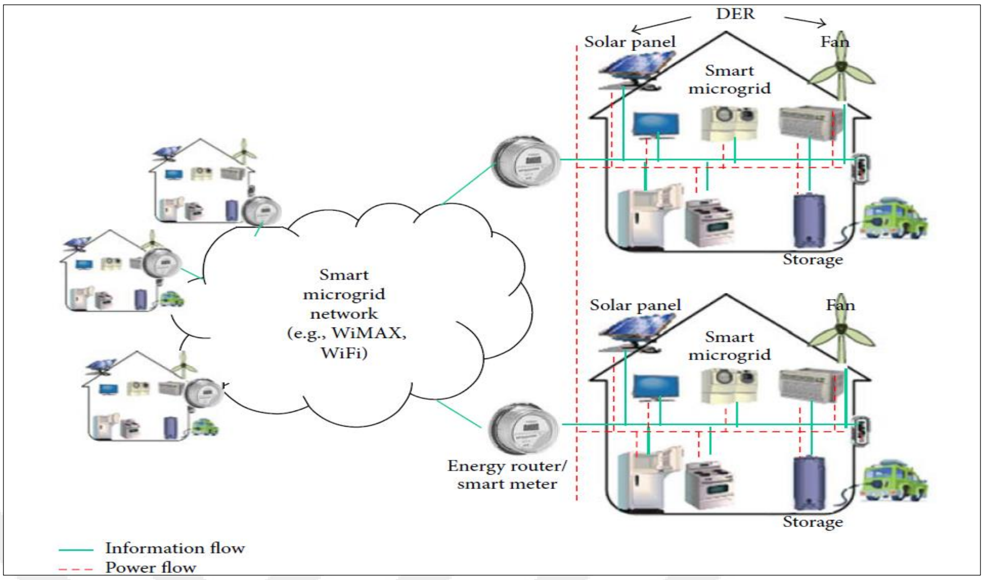

Figure 2.4: Smart Meter
Source: (G,Mukesh, A.Datta,P.Mohanty., 2013).

A common Smart Meter assists consumers in understanding billing procedures and electricity usage so that they might manage their electricity usage within their required billing limit/budget. Smart meter measurement, however, aids suppliers in calculating accurate bills for consumers who use electricity from the grid.

2.8.2 Automated meter reading (AMR)

AMRs allow utilities for remotely reading the meters, eliminating any need for a worker to read every one of the meters individually (Q.Liu,B.Zhao,Y.Wang, 2009). While they do provide some 2-way communications, their functionality has been found limited and doesn't improve the utility grid's reliability or efficiency. They don't have any built-in home displays for showing the consumer their pattern of energy consumption, so the consumer is unaware of their energy usage. As a result, utilities are unable to communicate with customers regarding their energy consumption, preventing customers from reducing their consumptions during the peak hours and therefore saving energy. AMRs in a distribution network allows utilities to remotely read status of consumers' homes, alarms, and logs of the usage. Because of its 1-way system of communication, the capabilities of the AMR are limited to meter data reading (L. Li, H. Xiaoguang, H. Jian, H. Ketai,, 2011). It doesn't allow utilities to take corrective actions on a basis of the information that has been received from the meters. Put differently, AMR systems cannot be used to transition to Smart Grid because pervasive controls at all the levels isn't doable with AMR alone (J.D. Lennox, 1992). AMR is considered as the process of remotely collecting consumption data from consumers such as smart meters and electric meters and processing the data for generating a bill with the use of power-line, radio frequency, telephony, or satellite communications technologies. A block diagram of an AMR system is shown in Figure 2.5. Each block's functions are described below.

(1) Reading unit: Essentially, the reading unit performs two significant tasks. First, the readings from the analogue meters are converted to digital. Data is then processed and sent to the unit of the communication for the transmissions.

(2) Unit of Communications: Which can be defined as one of the major difficult and crucial aspects of the system. Because data is most significant component of the system of meter readings and billings, this section is difficult. Data transmissions must be as effective as possible, with no data loss.

(3) Unit of data acquisition and processing : This unit receives and processes data from the unit of communication for the future use.

(4) System of Billing: The billing system, which takes the meter number and generates the bill of this meter, is the final AMR step. It makes use of database information gathered from meter readings across all of the system's units. The system might also be used to conduct an analysis of each meter's electricity usage.

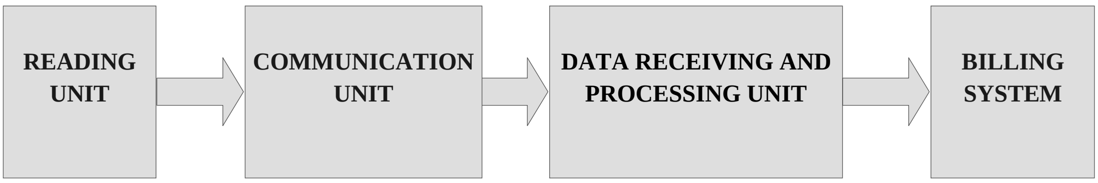

Figure 2.5: Block Diagram of AMR System

Source: (J.D. Lennox, 1992).

2.8.3 Vehicle to grid (V2G)

Plug in hybrid electric vehicles (PHEV) and Electric vehicles are another component of Smart Grid systems. Vehicle to grid power uses electric drive vehicles to supply power to specific electric markets (M. Ghofrani, A. Arabali,, 2012) (H. Tangiuchi, Y. Ota, K.M. Liyanage, T. Nakajima,J. Baba, A. Yokoyiama,, 2010). Battery, fuel cells or hybrid of them has been utilized for storing the energy in the vehicles. There have been 3 major versions of V2G, which are:

- A fuel cell vehicle hybrid,
- A solar vehicle.
- A plug-in or battery-powered hybrid vehicle.

And all of the above include on-board battery.

Figure 2.6 depicts the connections between utility grid and vehicles. Electricity flows in 1-way from generators to the electricity users via grid. Electric vehicles have a two-way flow. When the grid requires energy, a control signal is required for communicating with electric vehicles. A vehicle that can provide energy back to the utility grid is known as a V2G vehicle. In addition, V2G gives the grid system operator the option of using the vehicle as a distributed source of energy. Electricity flows from generators to consumers throughout the utility grid, while unused flows of the energy back and forth from the electric vehicle. A battery electric vehicle might be charging throughout Peak Time-OFF and Peak Time-ON. PEVs, on the other hand, can participate in the services market. Due to the fact that the aggregative V2G model appears as a major prospective, many researches were conducted for defining the framework's tasks and role.

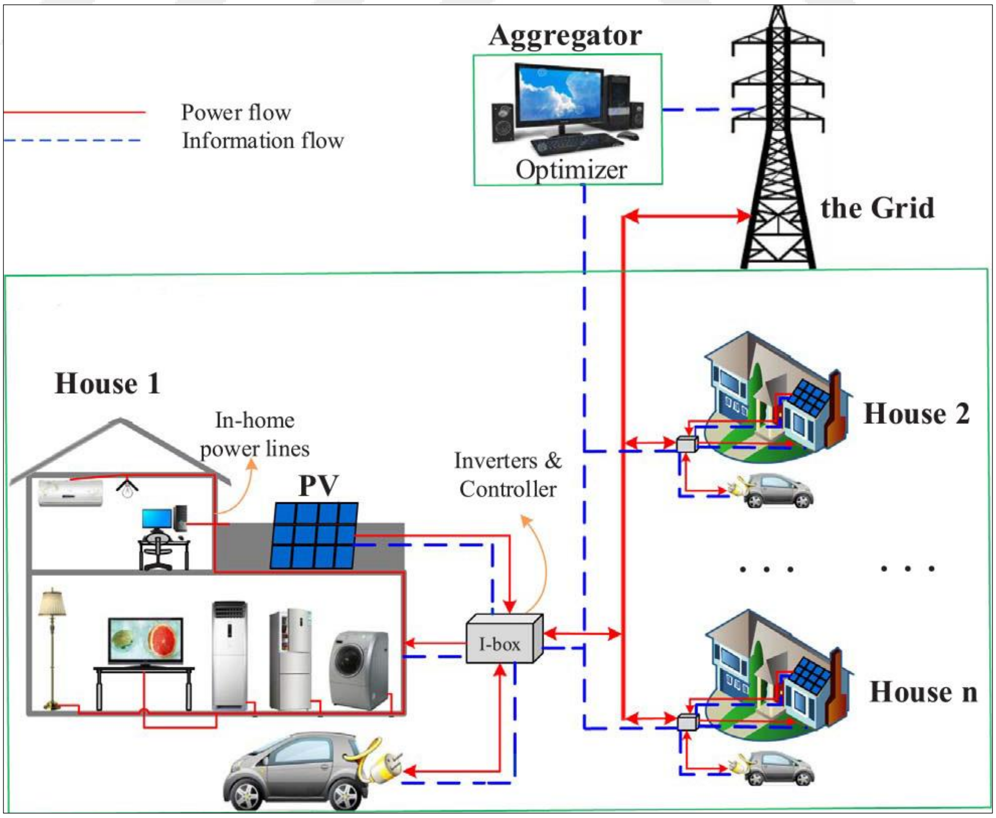

Figure 2.6: The Connections Between Vehicles and the Smart Grid

Source: (B.Zhanga, Q.Lia,L.Wangb, W.Fengc, 2018).

Furthermore, smart parking for electric and hybrid vehicles might play a significant role in energy sharing, as it serves as an intermediary between every one of system operators and electric vehicle owner, with tasks such as assembling a specific number of electric vehicles and adequately coordinating their shipment, with the advantages of providing energy marketing services (K.Erhan, M.Ayaz, Y.Icer, 2018).

2.8.4 Smart sensor

Many parameters, like current, voltage, phase and temperature, should be measured in smart grids for detecting any fluctuation of the parameter in near real-time as well as managing corrective actions to ensure grid reliabilities during the fault conditions. Also, measured data should be readable via intelligent appliances and include a time-stamp and sensor location to aid smart grid decision supports (N.Kayastha, D.Niyato, E.Hossain. Z.Han., 2014). Sensors which offer analog signal processing regarding the recorded signals, data and address transfer via a bi-directional digital bus, digital representation of analogue signal, computation and manipulation of sensor-derived data are referred to as smart sensors (P. Wang, H. Hou, X. He, C. Wang, T. Xu, Y. Li,, 2015). Smart sensors are performing more functions, along with those needed for accurately displaying the sensed quantity. It is made up of a number of processing components that are all integrated into the sensor on one chip. Has intelligence of some of the forms and provides value-added functions beyond the passing of the raw signal, leveraging of the communication technologies for the remote reporting/operation and telemetry. Smart sensors' goals include maintaining and integrating a distributed system of sensors that measures smartly and intelligently, creating an overall platform for computing, control, yield cost-effectiveness, and communications towards one common goal, and interfacing various sensor types. In conjunction with smart sensors, reliable, automated, off-line and online analysis systems are needed to support the Smart Grid diagnostics and monitoring applications. Transformers, relays, circuit breakers, capacitors, cables, bushings and switches are among the major substation and line equipment that can be monitored and diagnosed using smart sensors. The basic block diagram of a smart sensor is shown in Figure 2.7. The changes in parameters are sensed by a sensing unit, which is after that conditioned and converted into a digital signal by a unit of signal conditioning and digitalizations.

2.9 Smart Grid Functions

Forecast and monitoring of the supply demand balance might be achieved for maintaining the balance of demand and supply in energy production and consumption the smart grid (J.Medina, N.Muller,I.Roytelman, 2010).

Smart Grid functions are:

- Exchanging data on electrical generators, grids and consumers via Internet and processing such data using IT.
- Balancing the fluctuations out in the yields of the electricity arising due to using the renewable energy.
- Integrating many new and small facilities of electricity generations.
- Utilizing time communications, information processing and synchronized sensors.
- Via the communications, information processing, sensors, and actuators which allow a utility for using high degree of network coordination for the reconfiguration of the system and preventing fault currents from going beyond the damaging degree.
- Real time determinations of the ability of the element for carrying load on the basis of environmental and electrical conditions.
- Adjustable protective relay setting (voltage, current, equipment and feeders) which might change in real-time on the basis of signal from central control system or local sensors.
- The use of flexible systems of the AC transmission, series capacitors, PARs transformers, and very low impedance super-conductors.
- Automatic isolations and reconfigurations that are related to the faulted segments of the distribution feeders or the lines of the transmission through controls, sensors, communications systems and switches.
- Online analysis and monitoring of equipment, its efficiency, and operating environments for detecting abnormal conditions.

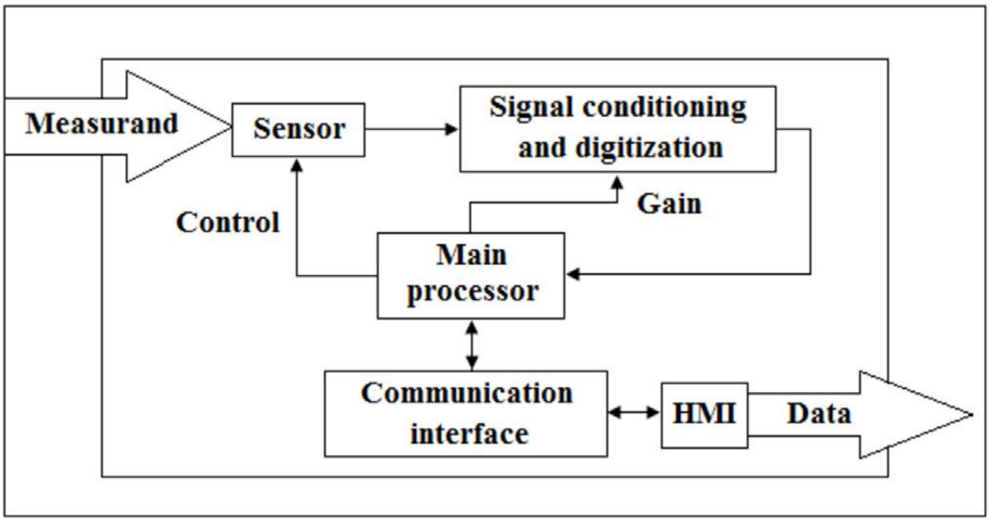

Figure 2.7: Basic Components of a Smart Sensor

Source: (N.Kayastha, D.Niyato, E.Hossain. Z.Han., 2014)

- Through the coordination of the reactive power resource operation, like voltage regulator, transformer load-tap changers, capacitor banks, DG (i.e. distributed generation) with controls, sensors, and communication systems.
- Real time measurements regarding customer consumptions as well as the managements of the load via AMI systems and embedded devices controllers which help the customer in making informed energy utilization decisions through real-time price signals, service options and the rates of the time-of-use (TOU).
- High accuracy and more discriminations of fault type and location with coordinated measurements amongst a number of the devices.
- Real-time feeder reconfigurations and optimizations for the relieving of the load on equipment, enhancing asset utilizations, improving the efficiency of the distribution system, and enhancing the efficiency of the system.
- Customers have been supplied by the information for making educated decisions concerning their electricity utilization.
- Inform the consumer, through smart devices and applications, of peak times and electric energy bill rates.

2.10 Smart Grid Reference Architecture

The Smart Grid reference model from NIST is made up of many domains and sub-domains, every one of them contains a variety of the application and actor types (E.U.Ogbodo,D.G.Dorrell, 2017). Actors include computer systems, devices, and software programs, among other things. Actors are capable of making decisions and sharing the information with the other actors via the interfaces of the network. Applications are tasks which are carried out via the actors in the domain. A group of actors or a single actor work together to carry out applications. The actors form domain clusters in order to find commonalities that will define the interfaces. For the purpose of enabling the functionality of the Smart Grids, the actors in one of the domains are usually interacting with the actors in the other domains. In addition, the domains in Smart Grid are depicted in Figure 2.8.

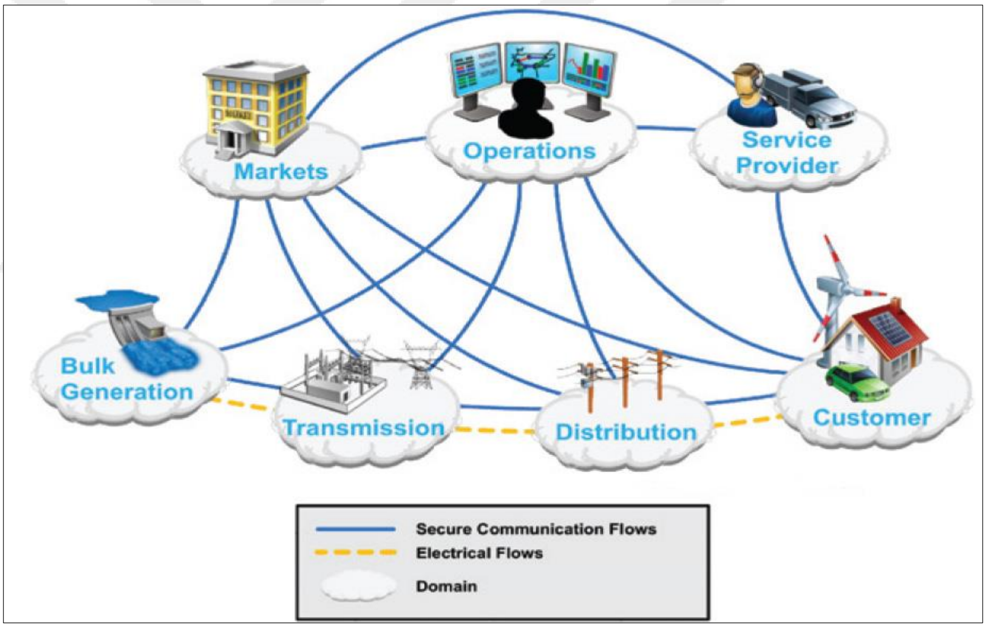

Figure 2.8: Smart Grid Conceptual Model by NIST

Source: (Y.Cunjiang, Z.Huaxun, Z.Lei, 2012).

The conceptual model can be defined as regulatory and legal model that includes requirements and policies that can be applied to a variety of applications, actors, and interactions. Various aspects of Smart Grid are governed by regulations that have been adopted via the FERC and via public utility commissions at local as well as state levels. Electric rates must be reasonable and fair, while reliability, security, privacy, safety, and other requirements of the public policy have to be satisfied. The conceptual model is aimed to be one of the significant tools for the regulators at all of the levels in determining how to optimally reach public policy goals, which, in conjunction with the business aims, motivate the investments in building a clean energy economy and modernization of nation's infrastructure of the electric power.

2.11 Smart Grid Evolution

The current electricity grids are the result of the rapid urbanizations as well as infrastructure development in a variety of parts in the world over the last 100 years. Generally, the companies of the utility have used comparable technologies, despite the fact that they exist in various geographies. Yet, the political, economic, and geographic factors which were distinctive to each one of the utility companies have impacted the growth of electrical power systems. Despite these differences, the current electrical power system's basic topology remains unaltered. The power industry has been operating with clear demarcations between its transmission, distribution and generation sub-systems since its inception, and as a result, each silo had shaped various levels of evolution, transformations and automation. The present electricity grid has been considered as strictly hierarchical system, as shown in Figure 2.9, with the power plants at top of the chain, which ensures power delivery to the loads of the customers at the bottom. This system is a 1-way pipeline, with the source having no real time knowledge of the termination points' parameters of service.

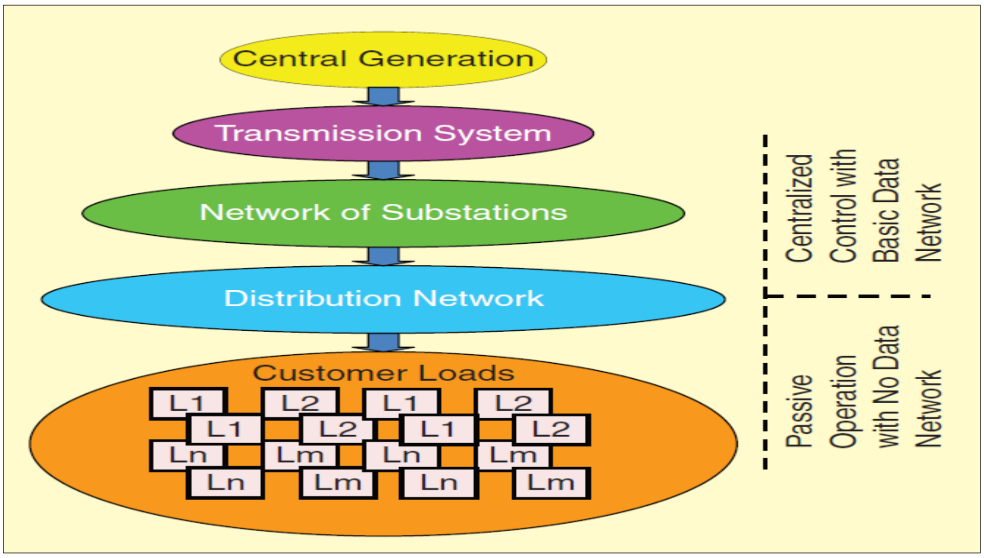

Figure 2.9: The Existing Grid

Source: (H.Farhangi, 2010).

Utility companies have only limited controls over the upstream functions, and distribution network is out of their hands in real-time. And this image is nearly the same all over the world. For example, in the U.S. that have one of the major developed electrical power systems worldwide, only about a quarter of distribution net is equipped with communications and information systems, and distribution automation penetration at system feeder level has been estimated to be only (15-20) %. (H.Farhangi, 2010).

The evolutions of the electric grid might be stated as follows: (a) nerves, (b) brains, (c) bones, and (d) muscles. The addition to the nerves necessitates installation of sensory devices at both consumer levels and utility grid. The main goal is to feed data from smart choice to the whole system. AMI and smart meters have been characterized as the Smart Grid’s nerve system at the consumer level. At the distribution and transmission level, advanced visualization technologies are used for providing utility grid operators with more real time, wide-area awareness of the grid status. Such ability will be allowing better power generation, distribution optimization, and transmission, in addition to faster problem responses. Advanced visualization technology is demonstrated by synchro phasors, which are used to measure current and voltage readings in transmission lines. Adding brains indicates to efficiently using and processing the data sensed via Smart Grid nerves. As shown in Figure 2.10, the convergence of the information and communication technologies with the power system engineering, provided with an array of the new methodes, technologies, and applications, results in enabling current grid from the traversal of complicated, however, staged path of protocols, models, and standards toward smart grid.

2.12 Smart Grids’ Metering and Communication

In the power system’s real time operations, the communications are critical. Smart Grids are going to be an interactive and dynamic mega infrastructure for the real time exchanges of the power and information thanks to fully integrated, high-speed, 2-way communication technologies. This technology is critical to the Smart Grid's performance because it monitors, measures, and transfers real time data for control purposes. Formalized protocols and standards are required for a secure transmissions of the highly-sensitive data over a network of communications. Present measuring, monitoring, and control technology appears to be of high importance in the Smart Grid network as well (P.P. Parikh, M.G. Kanabar, T.S. Sidhu,, 2010) (K.S. Reddy, M. Kumar, T.K. Mallick, H. Sharon, S. Lokeswaran,, 2014).

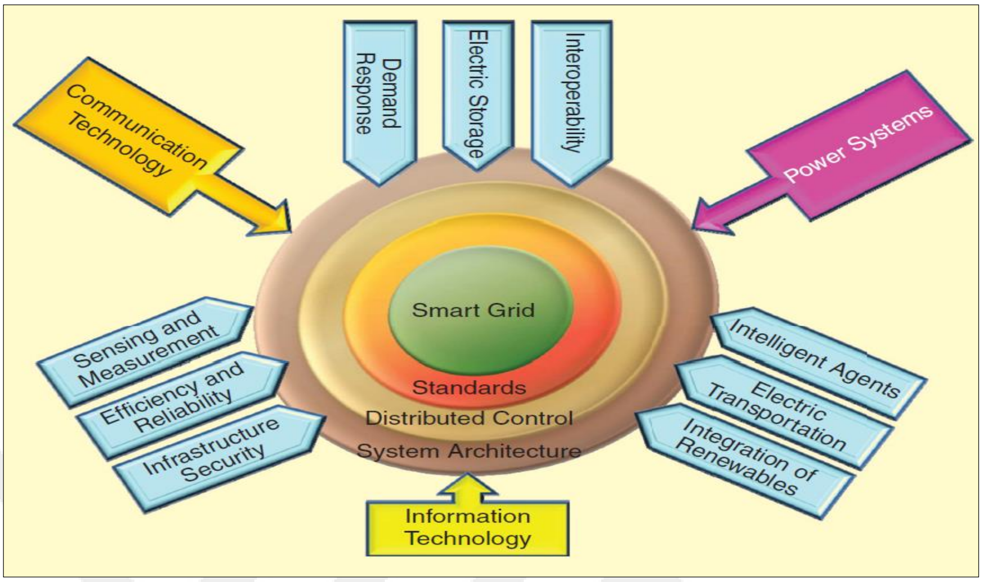

Figure 2.10: Basic Smart Grid Ingredients

Source: (H.Farhangi, 2010).

2.12.1 Advanced metering infrastructure (AMI)

AMI has been described as a collection of technologies that offers an intelligent connections between consumers and utilities (G. L_opez, J.I. Moreno, H. Amarís, F. Salazar, 2015). The communication infrastructure, utility grid, and supporting information infrastructure are all converged in AMI. Implementation guidance and industry security requirements are the major motivations for the development of network centric AMI. Various needs, standards, and best practices from the telecom and cable industries are applicable (directly) to AMI implementations. The deployment of an AMI has been found as a fundamental step in the modernizations of the electrical grid. AMIs provide the consumers with the information they need to make informed decisions, as well as the capability to put such decisions into action and a variety of options that result in considerable benefits. Refining utility operations and asset management processes on the basis of AMI data might greatly enhance consumer service. AMI provides a significant link between utility grid, generation, storage, consumers, and their loads by combining a variety of technologies (like integrated communications, smart metering, data management applications and unifying software interfaces) with asset management processes and present utility operations. Initially, the technologies of AMR were used for enhancing the meter reading accuracy and lower the costs. AMI evolved from AMR due to the advantages of 2-way interactions between the consumers, utilities, as well as their loads.

2.12.2 Intelligent electronic devices

SCADA systems are majorly used to control and monitor power systems, and they rely on data that has been obtained and fed from the RTUs that have been located in the sub-stations. The RTUs are wired to the CB links in a substation switchyard, and any changes in CB status contacts triggers an alarm to the operators. Analog measurement data is also collected by RTUs via instrument transformers (VTs & CTs) and connection of the transducers. In the case where measured analogue value exceeds the threshold, it will either be considered as one of the operator measurements or as alarms (F.Espinoza, M.Mar, E.Ramirez ,J.Noel, 2016).

2.12.3 Cloud architecture of smart grid

Because of its flexibility and scalability, as well as its capability in handling large amounts of data, cloud computing is a good approach for Smart Grids. Large-scale real time computing abilities are required in the SmartGrid's construction for coping with communication and storage of massive amounts of the transferable data (M. Yigit, V.C. Gungor, S. Baktir,, 2014). However, once the required entities are in place, cloud computing will unload the Smart Grid via allowing automatic updates, remote data storage, and reduced IT system maintenance while saving money, energy, and manpower. An overview regarding the cloud-integrated smart grid architecture, which provides access to virtually unlimited storage and computational resources. Through secure communication channels, the grid operator and consumers exchange encrypted data with cloud-based services. To ensure data privacy during storage, homomorphic data encryption techniques are used Figure 2.11.

2.13 Smart Grid Applications

Building and home automation, feeder automation and substation automation are all possible with Smart Grid technologies. In addition, Smart Grid technologies allow for the detection of faults, efficient use of devices and the isolation of faulty equipment and devices as needed.

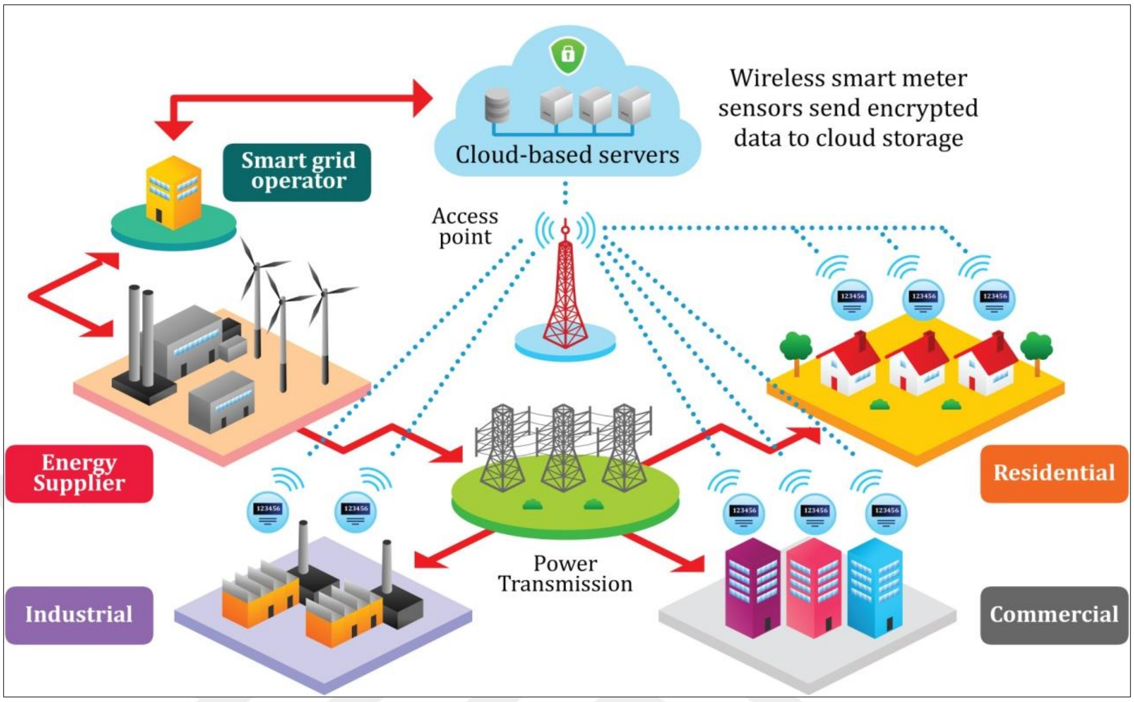

Figure 2.11: Cloud Architecture of Smart Grid

Source: (A.Alabdulatif, H.Kumarage, I.Khalil, M.Atiquzzaman,X. Yi, 2017).

2.13.1 Home and building automation

The Smart Grid networks include building and home automation; a smart building or home is one that has been automated (R. Missaoui, H. Joumaa, S. Ploix, S. Bacha,, 2013). Smart homes have energy and appliance sources which are controlled and coordinated in such a way that the aims of the Smart Grid are met to the best of their ability. Smart energy controllers with smart metering capabilities are required for the development of smarter homes.

2.13.2 Smart substation

Protection relays, CBs, CTs and VTs are all wired together with the use of copper cables in a traditional substation (W. Ling, D. Liu, D. Yang, C. Sun,, 2015). With advancements in communications, digital technology, and standards, the smart substation is now becoming a reality, with devices of protection, workstations, and low-level transducers that are all connected via a backbone of the optical fibre communications. In addition, architecture of the substation system has been split to 3 levels: first, station level in which engineering functions, operations and reporting occur, second, bay level in which the control functions and system protection take place and third, the process level in which signals from the CTs, VTs and other transducers have been transmitted (H.Li, L.Wang, 2011).

2.13.3 Feeder automation (FA)

FA can be defined as the capability for remotely monitoring and controlling the distribution network, as well as collecting and providing significant information to consumers (K. P. Schneider, 2009). FA is referred to as distribution automation (DA) by a few utilities, whereas it is referred to as service automation (SA) by others. FA automates feeder switchings, equipment health monitoring, reactive and voltage power management, and outage with the use of the digital sensors and the switches with the innovative communications and control technology. FA serves as a foundation for distribution system control, monitoring, and protection. The definition of FA varies from utility to utility. Interoperability and rapid automation implementation are key features of FA products. These products have a SCADA interface and can be used for FA without or with communication. The products of the FA help strengthening current distribution systems and provide solid foundations for the future development of a fully implemented feeder scheme. Products of the FA have been defined as one of the most effective tools for cutting cost and enhancing customer service. Solutions should fulfill the requirement for less tangible benefits as well as advantages that are measurable to bottom line (decreased maintenance and operating costs, increased kWh sales, eliminated or deferred capital expenditures). Within the products of the current utility feeder infrastructures, FA and system solutions might be incorporated incrementally and then scaled (Ya-ning, 2018).

3. ENERGY MANAGEMENT

3.1 Introduction

The integration regarding highly-fluctuated distributed generation, like wind turbines, photovoltaic (PV), energy storage systems and electric vehicles poses a threat to the power and distribution systems' stability. The major reason for this is that the demand and supply power ratios might not be balanced. A shortfall or excess in power consumption of generation can disrupt the network and cause serious issues, like voltage drop/rise and, in extreme cases, blackouts. The systems of energy management are used for increasing the supply-demand balance in a cost-effective manner and for reducing peak load throughout unexpected periods. There are 2 major categories of energy management. The 1st is on supplier's side, like electric utility, where a few generators are turned on and off in response to load demand fluctuations. Demand-side management is the 2nd category, which is aimed at consumers. Consumers are managing their energy consumption to match the provided power from generation side in demand-side management. The major aim of employing energy management is to lower the costs of operating and consumption, decreasing losses in energy, and improve the reliability of the network. Various limitations and obstacles exist in the field of energy management. Yet, it has a bright future ahead of it, with the majority of present researches focusing on the development of advanced models and algorithms for better managing the energy on grid.

(C.Z.Elbayeh,K.Alzaareer,H.A.Gabbar,M.R.Abdussami,M.Lak,E.Aragon,A.Johnson, B.Russell,M.Avendano,B.Sun.D.Eryilmaz,R.Konidena,, 2019). In a world where the demand of energy is rising, the generation of power must also rise to meet the requirements of users and enhance their quality of life. Yet, as the number of consumers grows and the electric load's nature becomes more unpredictable, power demand might pose a challenge to system operators and electric utilities. High peak demand is likely to take place frequently and might pose a threat to the functionality of the system. The system operators and electric utility have 2 options for resolving this problem: The very 1st is (increasing the dimensions and size of network which is expensive and needs time for implementing and use energy management for reducing the potential of high peak demand throughout peak hours). The 2nd option appears more reasonable; yet, it necessitates the use of advanced methods and algorithms to manage energy. Energy management is vital for a smarter grid for various reasons: (It is automated and doesn't need direct human intervention, it provides accurate predictions and results, it allows the electric utility to better optimizing the functionality related to its generation units and reducing the costs of generation, It allows the system operator in decreasing the losses of energy on network and lines, which might significantly decrease indirect distribution electricity costs, It allows the end-users for better managing their load demand and decreasing electricity bills, It causes an increase in the load factor, where the power profile becomes less fluctuating and smoother, It causes an increase in the energy efficiency, It is conserving the resources and reducing pollution and protects the climate). Yet, conventional tariff system isn't enough for improving energy management and enhancing the electricity bill. Thus, various advanced tariff systems of electricity are suggested, like Demand Side Management and Demand Response Programs where the electricity tariff becomes variable in time (A.Ahmad, A.Khan,N.Javaid, H. M. Hussain, W.Abdul,A.Almogren,A.Alamri.I. A.Niaz, 2017) (B.M.Radhakrishnan, D.Srinivasan, R.Mehta, 2016). The energy management system monitors production and consumption, forecasts peak time and cost. The consumer is notified of this through the applications on the smart screens using the smart grid. Figure 3.1.

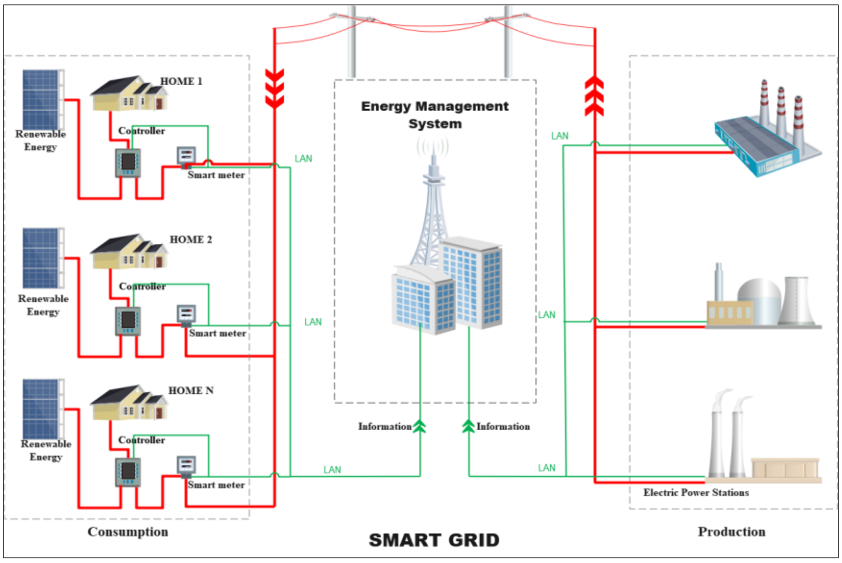

Figure 3.1: The Link Between the Consumer and the Supplier in the Smart Grid

3.2 The Peak Time-ON

Peak The maximal demand for the electrical power, which took place over a certain time period is known as Peak Time-ON on an electrical grid. The peak Time-ON, peak load or demand are terms utilized in management of energy demand for the description of a period when the electric power is expected to be provided at a considerably higher rate compared to the average supply level for an extended duration of the time. The fluctuations of the peak demand can happen on a monthly, daily, seasonal, or annual basis. The actual point related to peak demand for an electric utility company is a single 30-minute or hourly period representing highest point of electricity consumptions by the customer Figure 3.2. Peak power demand causes electrical grid fluctuations in the transmission, generation, and distribution sections of the power grid. (J.Torriti, 2016) The first solution that distribution authorities and electricity companies use to address problems with peak-time power demands is for advising consumers to turn off unnecessary appliances by emphasizing the negative consequences of excessive electricity consumption (C.Venugopal ,M.Habyarimana, 2017). Load Shedding is another significant and often used technique. The goal of load shedding is to rapidly restore the balance between consumption and production networks by voluntarily stopping the supply of at least one consumer. This is a safety feature developed to prevent voltage or frequency collapse, which could result in the loss of an entire subnet. Throughout power outage, either the load is disconnected from the source or an alternate power source is used, as described above. Throughout peak hours, such approaches were unable to meet the power demand. A system to control loads and decrease peak loads is required for the electrical power system. Figure 3.3 shows 6 load curves regarding the consumers' demands. Load curve can be characterize as the load variation with respect to the time. Also, there are 6 Demand side management (DSM) approaches where load curves have been altered between off-peak and on-peak durations (I.K.Maharjan, 2010) (C.W.Gellings,J.H.Chamberlin,, 1987) that can be summarized as:

- Peak Clipping: It has been considered as the direct load control approach focusing upon reducing demands throughout peak hours. The approach is significant in which there's an issue of investments for installing new units of generation. Figure 3.3a.

- Filling of the Valley: which is focused upon the increase in the consumption throughout off-peak hours. Demands in the off-peak hours are done through the encouragement of the end-users for the consumption of electricity by paying lower costs throughout the time. Figure 3.3b.

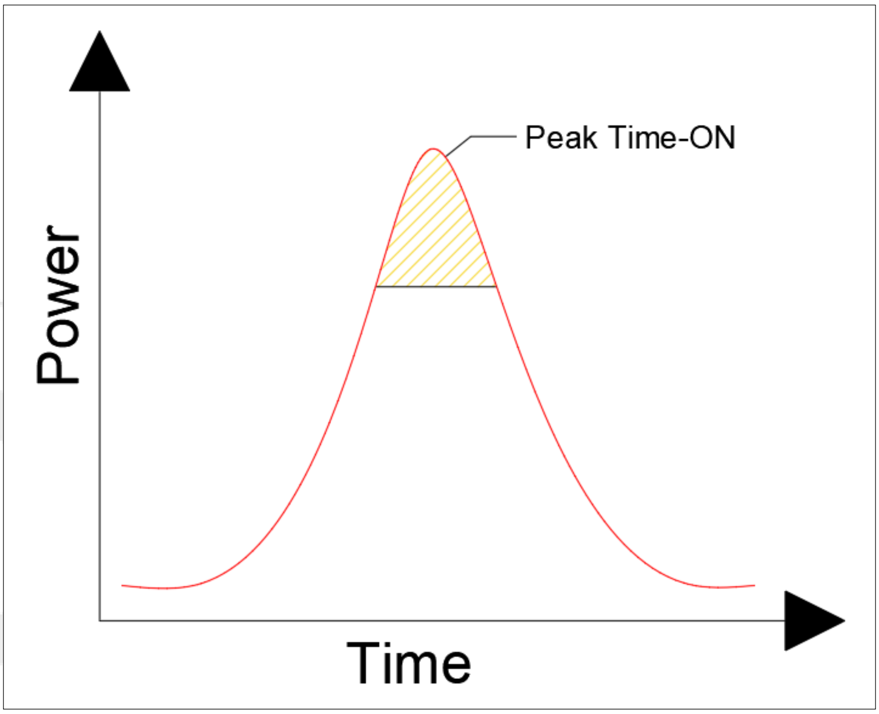

Figure 3.2: Peak Time

- Shifting of the Load: It is one of the majorly applied and most effective (DSM) methods. It’s done via load shifting from values of Peak Time-ON to Time-OFF hours. The customers are encouraged by paying less prices throughout the Peak Time-OFF hours. This approach has been defined as the optimal solution from a viewpoint of the utility Figure 3.3c.
- Reduction of Load: This method has been referred to as the strategic energy conservation as well. As can be seen fromFigure 3.3d, area under new characteristic has been smaller compared to the previous area. Which is why, peak may be decreased. The decrease of the load is accomplished with the use of more sufficient appliances, significant as well at global levels.
- Growth of the Load: This method has been referred to as the load building as well. It results in increasing power consumption of the users with specific

limits. It’s accomplished through the encouragement of the users in spending electricity for the maintenance of capacities of power system and for power system’s smooth operations Figure 3.3e.

- Flexible Load Shape: In which, there’s a load redistribution to a variety of the time slots. Where the, customers that have flexible load levels have been characterized who are ready for controlling their consumption in return for a variety of the motivations. Figure 3.3f.

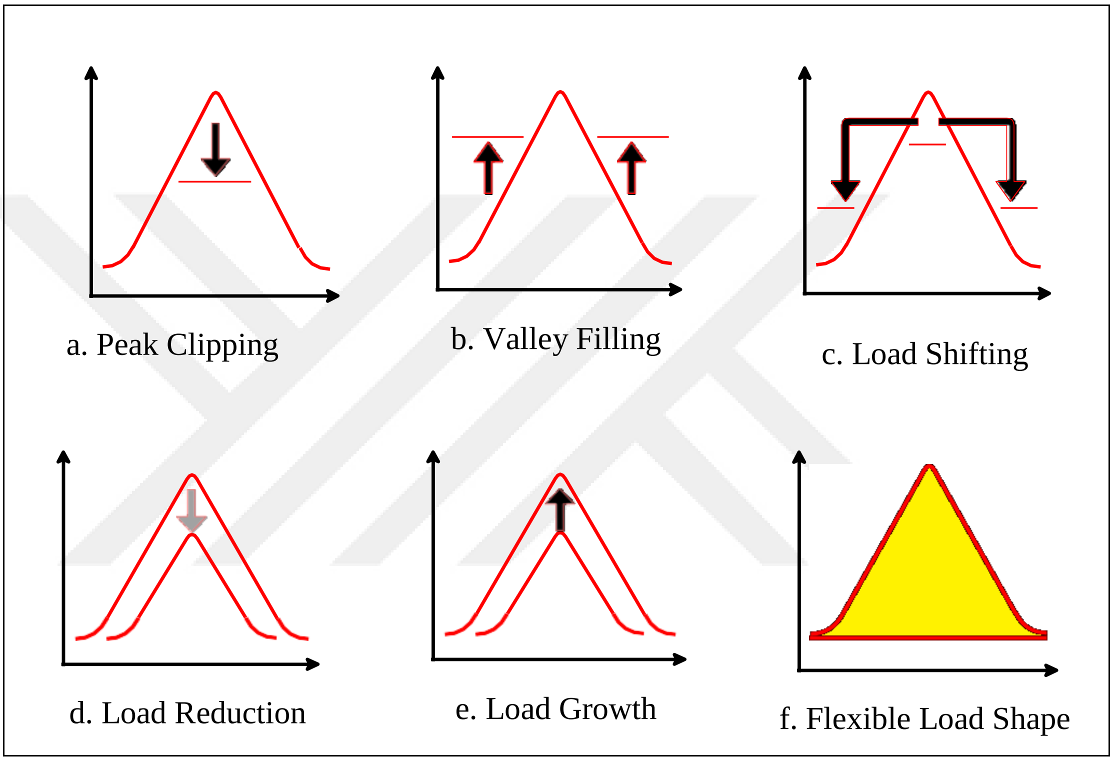

Figure 3.3: Demand Side Management Techniques

Source: (I.K.Maharjan, 2010) (C.W.Gellings,J.H.Chamberlin,, 1987).

3.3 Proposed of Energy Management

Aggregating companies assist consumers in formulating demand responses in various nations. More red tape and third-party costs are caused as a result of this. Furthermore, in the case when there are many customers, this is practically impossible. Decentralized demand response, which allows all customers enabled via their smart meters to autonomously participate, might be a promising method in light of the impending liberalization regarding the whole energy markets in various nations. It is the answer to the problem of electrical energy management.

3.3.1 Proposed model

The management of electrical energy is one of the most important factors in maintaining the sustainability and stability of electrical energy, and it is one of the most important reasons for electrical energy in Iraq, as the central production does not cover the real consumption of energy, and this is what generated a difference between supply and demand for energy, and one of these solutions is electrical energy management in Peak times, Hata! Başvuru kaynağı bulunamadı. shows the mount of energy required and supplied for nearly 50 years (Iraqi Ministry of Electricity, 2019). In this research, a model will be taken, which is the city of Karkh located in Baghdad, the capital of Iraq, which represents half the area of the capital, where the rate of energy supply in the capital is 2459 MW / hour. The required load is 5397-megawatt hours, and the city represents 56% of the capital's load, supplying electrical energy estimated at 1,380-megawatt hours according to the annual statistical report of the Iraqi Ministry of Electricity for the years 2018 and 2021. The peak load rate for the city was calculated as 1400 megawatt-hours (Central Statistics Department, 2018,2021). The actual readings of the city loads were taken from the Electric Power Control Center in the Iraqi Ministry of Electricity on the first day of February of the year 2021, and the peak times for electrical loads were determined in and Figure 3.5 and Table 3.1.

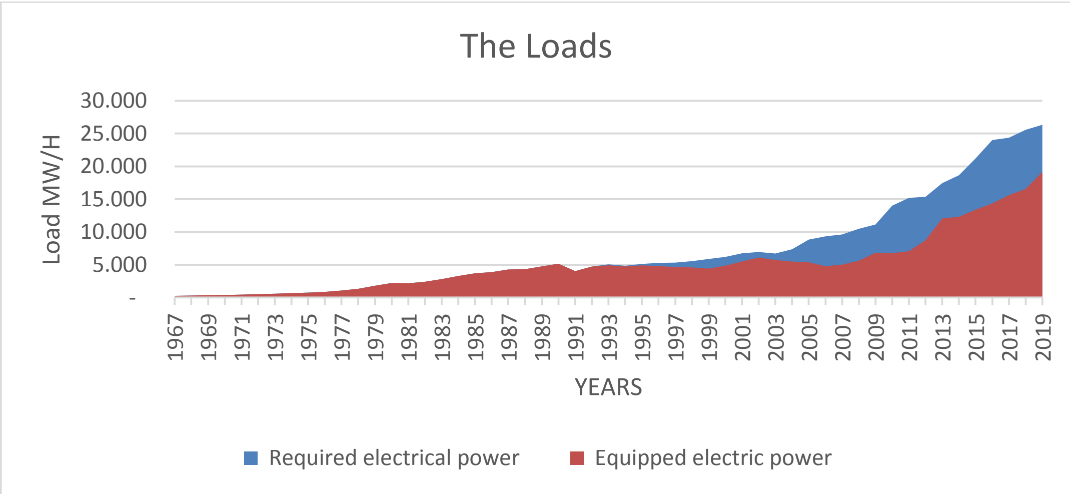

Figure 3.4: Comparison of the Required and Supplied Power

Source: (Iraqi Ministry of Electricity, 2019).

These loads will be analyzed manually using Microsoft Excel as a tool to help us understand these loads and how to reduce them at peak times and reduce their cost as well and compare the results between the loads and their costs before and after peak times, in an attempt to understand the problem of energy management in this city, which is an example for several other cities.

Table 3.1: The Loads

No.	Time	Loads at Peak Time-OFF MW/H	Loads at Peak Time-ON MW/H
1	1:00 AM	1336.6	
2	2:00 AM	1356	
3	3:00 AM	1178.5	
4	4:00 AM	1338.2	
5	5:00 AM	1358.5	
6	6:00 AM	1350	
7	7:00 AM	1297.3	
8	8:00 AM	1193	
9	9:00 AM	1242.1	
10	10:00 AM	1168.8	
11	11:00 AM	1322.7	
12	12:00 PM	1329.2	
13	1:00 PM		1417.4
14	2:00 PM	1231.8	
15	3:00 PM	1241.1	
16	4:00 PM		1409.6
17	5:00 PM	1141.3	
18	6:00 PM	1280.7	
19	7:00 PM		1401.5
20	8:00 PM		1472.4
21	9:00 PM	1194.4	
22	10:00 PM		1470.8
23	11:00 PM	1391.3	
24	12:00 PM		1458.3

Peak Time-ON ≥ 1400MW/H, Peak Time-OFF <1399MW/H. (Central Statistics Department, 2018,2021)

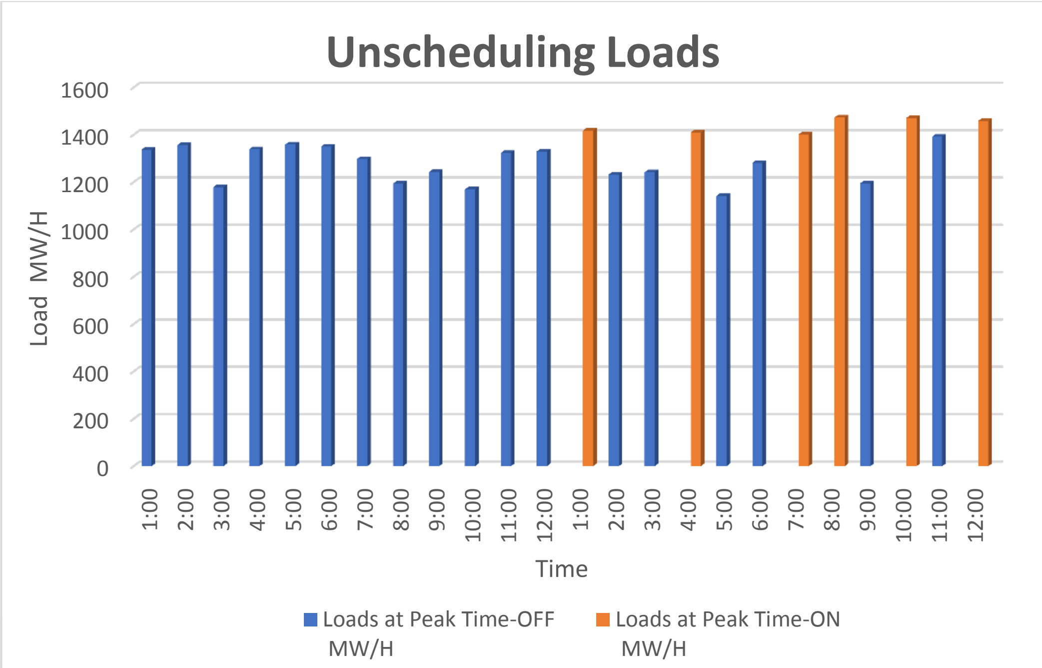

Figure 3.5: The Loads

3.3.2 Flexible load average

The average household unit energy consumption will be used depending on the time and duration of operation of the electrical appliances, as shown in Table 3.2 .The percentage of flexible loads is about 26.5% as in Figure 3.6, which is the ratio at which the operating time may be changed from Peak Time-ON to Time-OFF or change to renewable energy source. It is a percentage that has been calculated for the consumer, which has a very high impact on a large city that is our research model

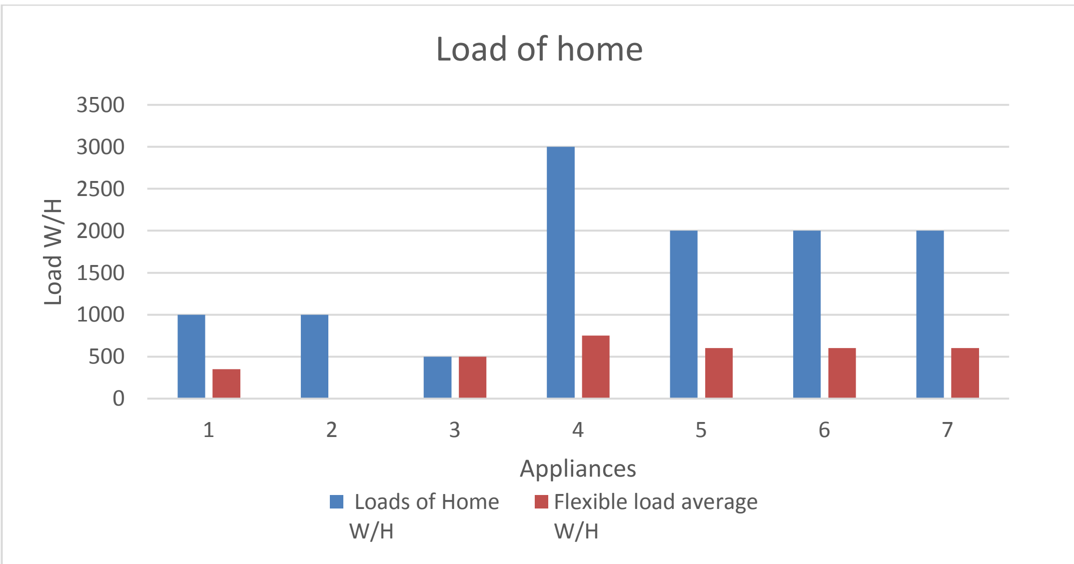

Figure 3.6: Flexible Load Average

Table 3.2: Home Loads

APPLIANCES	Nu.	Loads W/H	Time ON						Schedule the Expected Load	
			From	To	From	To	From	To	Load W/H	Rate%
Lights	1	1000	6:00 PM	6:00 AM					350	35%
Refrigerator	1	1000	12:00 AM	12:00 PM						
Washing machine	1	500	10:00 AM	1:00 PM	6:00 PM	9:00 PM			500	100%
Water heater	1	3000	7:00 AM	9:00 AM	3:00 PM	5:00 PM	8:00 PM	12:00 PM	750	25%
Air Condition (bedroom 1)	1	2000	2:00 PM	5:00 PM	8:00 PM	4:00 PM			600	30%
Air Condition (bedroom 2)	1	2000	2:00 PM	5:00 PM	8:00 PM	4:00 PM			600	30%
Air Condition (living room)	1	2000	7:00 PM	12:00 PM					600	30%
Power Total (W/H)		11500							3050	26.5%

3.3.3 Model specifications

The customers optimize their patterns of consumption in an independent manner from each other as a response to the market prices at the same time. Every one of the loads has an on-duration, a preferred starting-time, and maximum and minimum time-frame where power consumption of the load must be dispatched. Customers have pre-set all of such parameters. In the Peak time, prices are set in the market on the basis of aggregated supply and demand.

3.3.4 Formulation of load shifting

3.3.4.1 Electricity cost (ECs)

The ECs represent costs that are paid by the consumers to utilities and it's calculated as the power that is consumed by the appliances, it is weighted with the price that has been announced by an appliance at that hour. The cost factor is the main factor for the consumer, by which the electric power can be managed. The formulas for calculating the electricity cost over a certain hour and an entire day can be represented by Equation**3.1** and Equation**3.2** (Amit.S , Anil.M, Nitesh.F, Neeraj. D., 2020). the value of the EC for 1h is calculated as:

$$EC = \sum_{i=1}^{n} P(Ai) \times L_{Ai} \times B \qquad \mathbf{(3.1)}$$

Electricity cost for a complete day:24 h

$$EC\ over\ a\ day\ =\sum_{i=1}^{24}\sum_{i=1}^{n}P(Ai)\times L_{Ai}\ \times B_h \qquad \mathbf{(3.2)}$$

where, *Ai* represents specific appliance. *P(Ai)* represents power ratings of every one of the appliances. In this case, n appliances have been considered. *Bh* represents the price of the electricity tariff, which is generated by a utility for the hour *h,* and *LAi* represents the operational time length of every one of the appliances.

h = 1, 2, _ _ _, 24.

Using equation **(3.2)** it is possible to calculate the cost of the registered loads for the city and calculate the bill for electric energy and according to the prices installed in the Table 3.3, Costs can be known at peak times. As shown in Table 3.5, where the cost at the time of Peak Time-ON is high, while when converting to the time of non-peak or when changing the source of energy to the source of renewable energy, the cost is lower. This shows us the need to manage energy effectively by using modern technologies and applications to reduce cost and maintain stability energy. As in Figure 3.7**.** depending on the electric energy bill price, Table 3.4. The average price for the electric power unit kilowatt-hour was taken from the real price of the national electricity, and the prices were proposed for the power unit to control the cost and the peak load. Figure 3.7&Figure 3.8. Comparing costs at peak times and times when using a renewable energy source. Table 3.5 and Figure 3.9.. The invoice price will be reduced for flexible loads when using the renewable energy source. Equation **(3.3).**

Cost Scheduled < Cost Unscheduled. **(3.3)**

Table 3.3: Prices and Costs of Electrical Loads

TIME	Unscheduling Loads MW/H	Scheduling Loads MW/H	Price at Peak Time-OFFMW/H	Cost at Peak Time-OFF	Price at Peak Time-ON	Cost at Peak Time-ON	Price at change to Peak Time-OFF	Cost at change to Peak Time-OFF	Price at change to renewable energy	Cost at use Renewable Energy
1:00 AM	1336.6		$30	$40,098						
2:00 AM	1356		$ 30	$40,680						
3:00 AM	1178.5		$30	$35,355						
4:00 AM	1338.2		$30	$40,146						
5:00 AM	1358.5		$30	$40,755						
6:00 AM	1350		$ 30	$40,500						
7:00 AM	1297.3		$ 30	$38,919						
8:00 AM	1193		$ 30	$35,790						
9:00 AM	1242.1		$ 30	$37,263						
10:00 AM	1168.8		$30	$35,064						
11:00 AM	1322.7		$ 30	$39,681						
12:00 PM	1329.2		$30	$39,876						
1:00 PM	1417.4	375.92			$50	$18,796	$30	11,278	$25	$9,398
2:00 PM	1231.8		$30	$36,954						
3:00 PM	1241.1		$30	$37,233						
4:00 PM	1409.6	373.85			$50	$18,693	$30	11,216	$25	$9,346
5:00 PM	1141.3		$30	$34,239						
6:00 PM	1280.7		$30	$38,421						
7:00 PM	1401.5	371.70			$50	$18,585	$30	11,151	$25	$9,293
8:00 PM	1472.4	390.51			$50	$19,525	$30	11,715	$25	$9,763
9:00 PM	1194.4		$30	$35,832						
10:00 PM	1470.8	390.08			$50	$19,504	$30	11,702	$25	$9,752
11:00 PM	1391.3		$30	$41,739						
12:00 PM	1458.3	386.77			$50	$19,338	$30	11,603	$25	$9,669

Table 3.4: The Prices

Details	Price $, KW/H
Price average	0.03
Price at Peak Time-ON	0.05
Price at Peak Time-OFF	0.03
Price at change to Renewable Energy Source	0.025

Table 3.5: Comparison of Load Costs

Scheduling Loads MW/H	Cost at Peak Time-ON	Cost at Peak Time-OFF	Cost at use Renewable Energy
375.92	$18,796	11,278	$9,398
373.85	$18,693	11,216	$9,346
371.70	$18,585	11,151	$9,293
390.51	$19,525	11,715	$9,763
390.08	$19,504	11,702	$9,752
386.77	$19,338	11,603	$9,669
Total	$114,441	68,665	$57,221

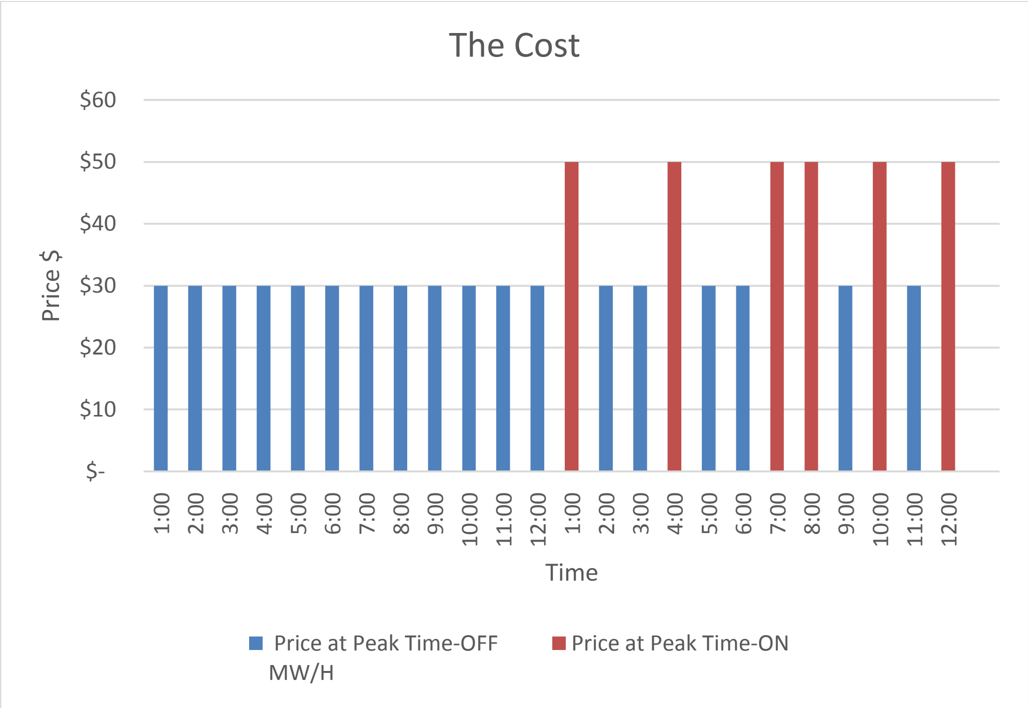

Figure 3.7: The Prices

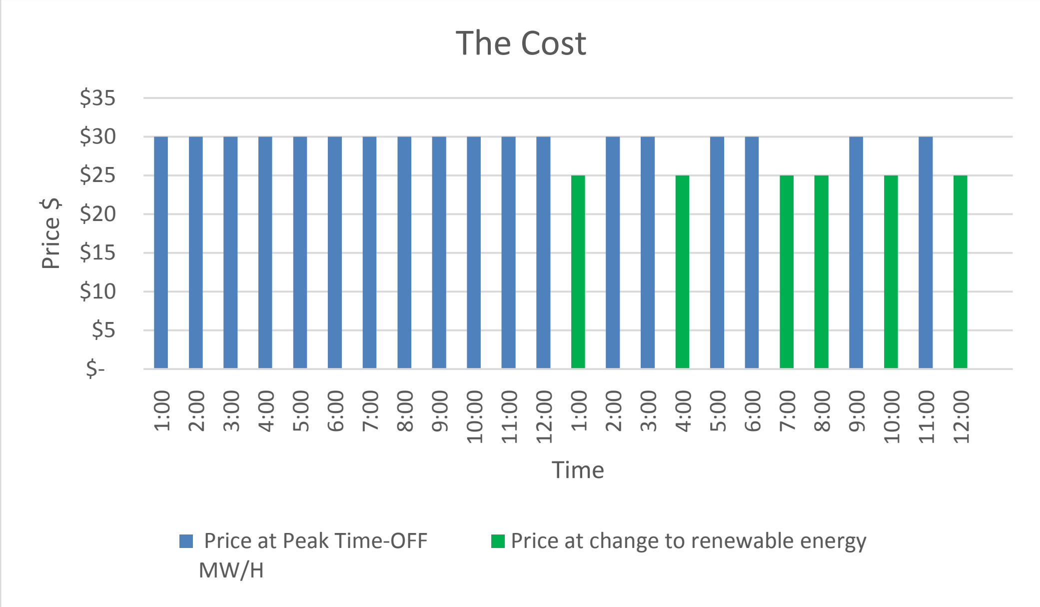

Figure 3.8: Reducing the Price When Using Renewable Energy

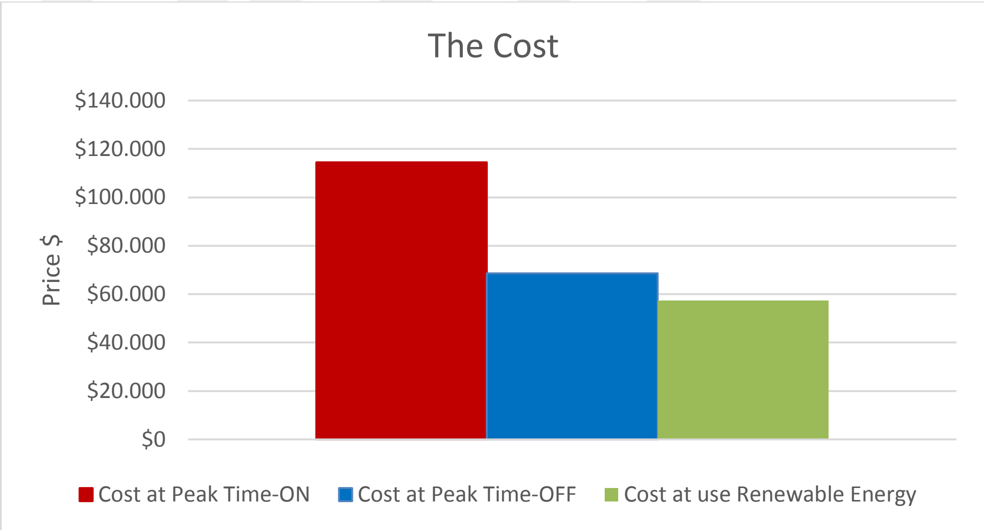

Figure 3.9: The Costs

3.3.4.2 Electrical loads

The loads that have been recorded for the city for a period of 24 hours, showing the electrical loads at peak times, and the consumer or the end-user will have a major role in reducing these loads by shifting the overload or flexible load from Peak Time-ON to Time-OFF. This is the first option. As for the second option, at Peak Time-ON, the change from a central energy source to a renewable energy source. Using equation **(3.4)** (Amit.S , Anil.M, Nitesh.F, Neeraj. D., 2020), Table 3.6 and Figure 3.11 shows the loads at the Peak Time-ON and Peak Time-OFF. Table 3.5 shows the loads at the Peak Time-ON to the amount of flexible loads. It shows that approximately 300-400 MW/hour is the amount shifting of the load.

Assuming that the *Loadh* represents the value of the load that is consumed in 1 h. It can be estimated with the use of Equation **(3.4)**:

$$load_h = \sum_{i=1}^{n} P(Ai) \quad \textbf{(3.4)}$$

where, *P(Ai)* represents the rating of the power of all of the appliances that function throughout this hour.

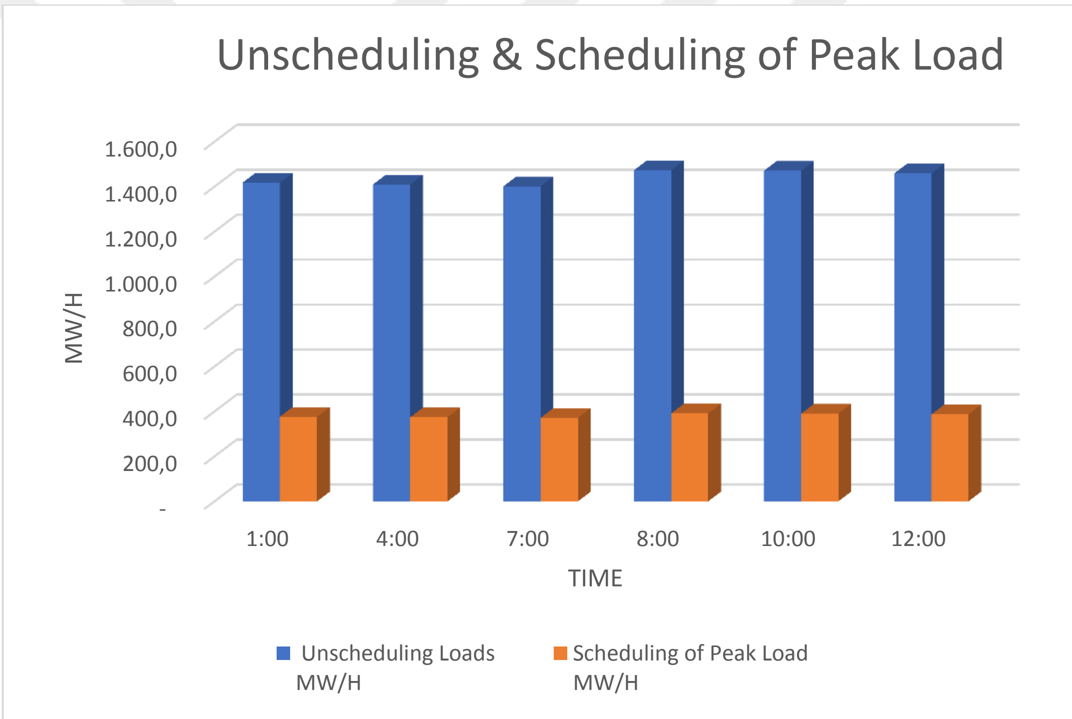

Figure 3.10: Scheduled Load Rate

Table 3.6: Comparison of Loads After Scheduling

	The consumer has two options					First option	Second option
	TIME	**Unscheduling Loads MW/H**	**Flexible loads Rate%**	**Scheduling Loads MW/H**	**Loads after Scheduling MW/H**	**Scheduling of Peak Load MW/H**	**The Change to Renewable Energy (HOME)**
1	1:00 AM	1,336.6					
2	2:00 AM	1,356.0					
3	3:00 AM	1,178.5					
4	4:00 AM	1,338.2					
5	5:00 AM	1,358.5					
6	6:00 AM	1,350.0					
7	7:00 AM	1,297.3					
8	8:00 AM	1,193.0					
9	9:00 AM	1,242.1					
10	10:00 AM	1,168.8					
11	11:00 AM	1,322.7					
12	12:00 PM	1,329.2					
13	1:00 PM	1,417.4	0.265	375.92	1,041.48	375.92	375.92
14	2:00 PM	1,231.8					
15	3:00 PM	1,241.1					
16	4:00 PM	1,409.6	0.265	373.85	1,035.75	373.85	373.85
17	5:00 PM	1,141.3					
18	6:00 PM	1,280.7					
19	7:00 PM	1,401.5	0.265	371.70	1,029.80	371.70	371.70
20	8:00 PM	1,472.4	0.265	390.51	1,081.89	390.51	390.51
21	9:00 PM	1,194.4					
22	10:00 PM	1,470.8	0.265	390.08	1,080.72	390.08	390.08
23	11:00 PM	1,391.3					
24	12:00 PM	1,458.3	0.265	386.77	1,071.53	386.77	386.77

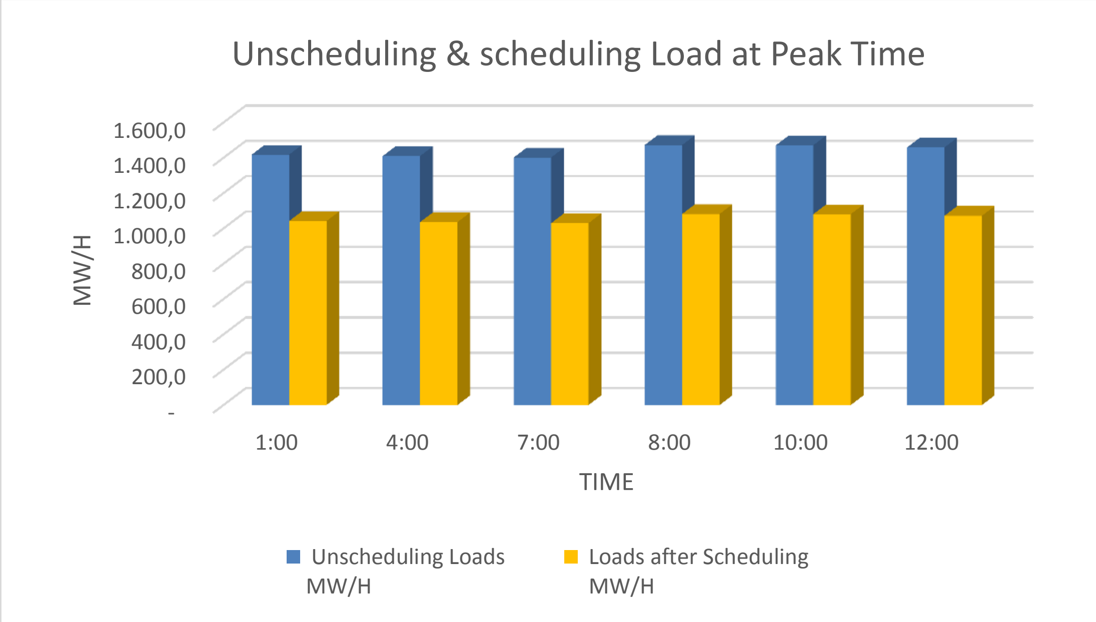

Figure 3.11: Comparison of Loads After Scheduling

3.3.4.3 Peak to average ratio (PAR)

PAR has been reduced, which helps to balance the demand and supply of electricity. Fixed appliances have been misplaced because they play a secondary role; Thus, Interruptible devices were given higher priority to reducing PAR (Amit.S , Anil.M, Nitesh.F, Neeraj. D., 2020).

PAR is calculated based on:

$$PAR = \frac{Max\ load}{Average\ load} \qquad \mathbf{(3.5)}$$

Max load is maximum load consumed for a certain hour and mean demand represents the load that is consumed throughout a day. Similarly, loadavg represents average load for a whole day, calculated with the use of Equation **3.6**:

$$load_{avg} = \frac{\sum_{h=1}^{24} \sum_{i=1}^{n} p(Ai)}{24} \qquad \mathbf{(3.6)}$$

The Equation **(3.5)** , **(3.6)** for PAR can be symbolized as below:

$$PAR = \frac{max(Load_h)}{load_{avg}} \qquad \mathbf{(3.7)}$$

3.3.4.4 User comfort (UC)

This parameter is measured with regard to the waiting time (WT). The lower the value of the WT, means that the level of user satisfaction is higher. As a result, in order to enhance the UC, The time it takes for devices to start up should be reduced. The appliance's execution pattern is depicted in Figure 3.12. OT stands for operational time for the appliance, which is defined as the maximum amount of time that the user can schedule the appliance. The length of operational time, or LOT, refers to how long the appliance has been running. We've taken one appliance as an example of how long it takes to wait. The ending time and the starting time of the appliance that is to be scheduled are indicated by OT2 and OT1. The actual starting time in the case where appliance is turned on is LOT1, and the ending time when the appliance is turned off is LOT2. As a result, Appliance LOT = LOT2 - LOT1, in which Appliance LOT represents the appliance's operational time (S.Khan, A. Khan, N.Mushtaq,, 2018).

The value of the waiting time ranges from 0 to 1. The value of the waiting time for a certain appliance is calculated with the use of Equation (**3.8**).

$$Waiting\ time = \frac{LOT1 - OT1}{OT2 - OT1 - \ Appliance\ LOT} = \begin{cases} 0 & UC\ is\ high \\ 1 & Otherwise \end{cases} \quad (\mathbf{3.8})$$

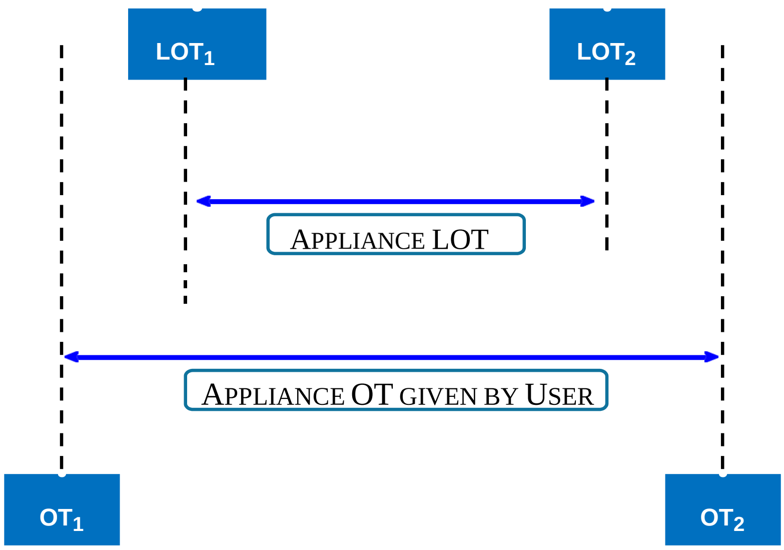

Figure 3.12: Execution Pattern For An Appliance With Timing Illustrations

Source: (S.Khan, A. Khan, N.Mushtaq,, 2018)

3.3.5 Renewable energy sources

The renewable energy source will be a secondary source to reduce the load during Peak Time-ON. Solar energy can also be harnessed during the day without the need for energy storage batteries approximately from 07:00AM in morning to 07:00PM, Which means 2 hours of Peak Time-ON can be covered, which are 1:00 PM and 4:00 PM, Table 3.7, which is another factor affecting the load and the cost. In addition, making the average consumer a contributor to the production of electric energy. it is an environmentally friendly energy source that is generated from natural sources and has many advantages, the most important of which is the dispensation of fossil fuels and the reduction of environmental pollution. Some consumers use it to reduce the cost of the electric energy bill, which is a major motive for using renewable energy sources instead of traditional sources. Governmental organizations must also encourage the consumer to rely on renewable energy sources by reducing the cost of equipping the tools of these sources. In this model, renewable energy was used as an alternative to the concentrated energy source, as its source was used to reduce the load at peak times, which will reduce the cost of the electricity Time ON

Table 3.7: Time ON

Power source	TIME ON	Price $KW/H
Use of renewable energy only at Peak Time-ON	1:00 PM	0.025
	4:00 PM	0.025
Use of renewable energy only at Peak Time-OFF	8:00 AM	0.025
	10:00 AM	0.025
	2:00 PM	0.025
	3:00 PM	0.025
	5:00 PM	0.025
Use of central electric power source	3:00 AM	0.03
	8:00 AM	0.03
	10:00 AM	0.03
	2:00 PM	0.03
	3:00 PM	0.03
	5:00 PM	0.03
	9:00 PM	0.03

4. THE RESULTS

The results that have been reached through the readings of the demand for electrical energy for 24 hours in the winter season and due to the low temperatures, the population tries to operate the air-conditioning devices whose consumption value is approximately 20% of the energy consumption, so the demand for energy increases as shown in Table 3.1 and Figure 3.5 It is possible to observe the electrical loads for all hours in a unit of megawatt-hour, and also to note peak times whose load capacity exceeds 1400 megawatt-hours, and the number of peak hours is 6 hours out of 24 hours (1:00 pm, 4:00 pm, 7 00:00 pm, 8:00 pm, 10:00 pm, and finally 12 pm). And Table 3.7 shows us the prices and hours to which the electrical loads will be shifting at the peak time. It is also inferred from Table 3.6 that the peak demand loads before scheduling according to their times, respectively It is (1458.3,1470.8,1472.4,1401.5,1409.6,1417.4) and Table 3.2 shows us the role of the elastic load factor, which is valued at 26.5% of the value of the domestic load. It plays a role in reducing the peak loads. Table 3.6 shows the value of the flexible loads, which are respectively (386.77). ,390.08,390.51,371.70,373.85,375.95). It also shows the value of the loads after scheduling, which is respectively (1071.53,1080.72,1081.89,1029.80,1.035.75,1041.48). Figures 3.10 and 3.11 show these values and ratios in the flow chart. As for the PAR factor, it is much higher at unscheduled loads because it is related to the load and represents equation (3.5), and it is compared after scheduling these loads, where the value of this parameter decreases.

As for the electrical cost factor, the figure shows us the prices and cost of electrical energy, as it shows that the cost of the loads before scheduling for peak times is, respectively, (19.338,19.504,19.525,18.55,18.693.18.796) US dollars. At a price of 50$ per megawatt, as Table 3.4 indicates. As for the cost of these loads after scheduling, they are respectively (11.603,11.702,11715,11,151,11.216,11.278) US dollars at a price of 30$, as shown in Figure 3.5. Also, when using renewable energy (ie relying on solar photovoltaic, home energy), there will be a reduction in the price for the same consumed value of energy, as shown in Figure 3.4. Table 3.5 shows the difference in costs before scheduling and after scheduling, where the total before scheduling is 114,441 US dollars and after scheduling 68.665 US dollars. And when using renewable energy, the cost is 57,221 US dollars for the same value of the consumed load to encourage dependence on renewable energy sources (solar energy), and participation with a portion of the energy production, the consumer can also sell the surplus electrical energy from renewable energy sources to the grid using the smart grid, figure 3.9 also shows the difference between the costs of electrical energy. Figures 3.7, and 3.8 show a comparison between prices before scheduling and after scheduling for each hour within 24 hours. As for the user convenience factor, it is the second factor after the cost factor . Figure 3.12 shows us the waiting time to operate the devices, meaning the less waiting time, the higher the user's satisfaction, meaning turning on the devices as soon as possible before or after peak times.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, the cost is used in managing electrical energy using a smart grid. The results in the fourth chapter proved that the use of the cost factor in peak load management reduced electric energy bills and stimulated the consumer to rationalize energy use. The cost and loads decreased through the comparison between scheduled and unscheduled loads. Reducing the peak-to-average ratio and reducing the waiting time for scheduled operation of devices for the user comfort. In addition, consumers are encouraged to use home solar energy sources to reduce peak loads and environmental pollution. It has motivated some consumers to be part of the electric energy producers by using renewable energy such as solar energy at some times and exporting energy to the grid at other times. This study confirmed in this thesis that energy management using the smart grid with all its technologies and applications is the optimal solution in the field of electric power.

5.2 Recommendations

- Preparing the physical and organizational infrastructures to support the use of the smart grid.
- Increasing investments in equipping energy transmission and distribution equipment such as smart meters, smart devices and smart sensors...etc.
- Increasing investments in supplying renewable energy equipment.
- Establishing open markets that allow diverse participation to ensure the sustainability of renewable energy sources since their participation in energy production will be using the smart grid.
- Taxes and customs duties on smart grid technology equipment and renewable energy sources should be reduced.
- Take advantage of a variety of smart grids, big data, smart buildings, and IoT applications to accurately forecast the peak demands.

- Preparing a national roadmap for reaching the application of smart grid in the electric power system.
- A prelude to the establishment of a competitive electricity market, so that the sector will be transformed from a sector that relies heavily on government support to a sector that operates on a commercial basis.
- Governmental organizations should support cooperation between the public and private sectors in implementing the smart grid because it is the main factor in energy management.
- Develop national data security standards in the electric power sector, to ensure the security and reliability of the electrical network.
- Integration of the smart grid with telecommunication networks to transfer data with high reliability.
- Providing financial support for renewable energy technology for home units by government organizations to educate consumers to use it and reduce peak loads.
- Regulating the electricity, telecommunications and information technology sector and relevant authorities to develop a plan that contributes to moving forward in smart grid projects.
- Encouraging educational and training bodies to adopt specialized curricula that support new skills required in the labour market, such as renewable energy, smart meters, data security, and the smart grid.

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RESUME

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