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Interaction between GreenMobile Networks and Household consumers in a Smart Grid scenario

Thesis for Master's Degree

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Dedicated to:

Dear Parents, Because of all the loving efforts they have made throughout my life and have taught me how to live kindly.

Abstract

Mobile Networks are currently facing a huge increase in annual energy consumption and expenditure due to an increase in mobile traffic demand. As a result, the reduction of the overall energy consumption is one of the main targets for Mobile Network operators. Different solutions have been proposed for improving the Mobile Network energy efficiency and self-sufficiency and at the same time ensure reliability. Some of these solutions are the use of Renewable Energy sources and strategies such as WiFi offloading and Resource on Demand. Meanwhile, the transition of the power grid into a Smart Grid occurs and electricity customers are able to better manage their energy use. The interaction between the Smart Grid and their customers, such as Mobile Network operators and Household consumers, is possible and has motivated several Demand Response (DR) programs. These programs encourage consumers to reduce their consumption during peak periods providing in return incentives or discounts.

In this work we take into account a Smart Grid scenario where the Mobile Network and the Household consumers participate in a Demand Response program. The main focus is to investigate the interaction between Mobile Network and Household consumers in order to see whether it improves the response of the Mobile Network to the Smart Grid requests. This improvement is studied in terms of energy reduction and bill saving.

In this study, it was considered in which months during the year the highest consumption and in which months the lowest consumption is done and also electric vehicles were considered in the work process which are charged at certain hours and in this. The state can be used to study the process of better energy consumption. In this research, this operation has been performed and we have achieved interesting results in this field. We consider 3 scenario for EVs and we can see that scenario 3(smartly charging) is the best solution for EVs.

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Chapter 1: Introduction

1-1- Introduction

Mobile Networks are currently facing an increase in mobile traffic demand due to the higher dependency on mobile devices, such as smartphones, tablets and PCs, and to the higher number of mobile subscribers. According to Cisco Visual Networking Index [1], global mobile data traffic grew about 63% in 2016 and this growth is expected to continue with a 46% annual growth rate until 2021. This increase in traffic leads to a huge increase in energy consumption and in carbon emissions. Mobile Networks consume more than 0.5% of the global energy supply [2] and this share is expected to grow with the widespread use of mobile devices. A huge fraction of the energy supplied is due to the Radio Access Network (RAN) which accounts for almost 57 % of the consumption [3]. Furthermore, the increase in the total traffic leads also to an increase cost for mobile operators. To meet the higher traffic demand more Base Stations have to be deployed, to increase the overall network capacity. Therefore, expenditure rises, due to the greater amount of energy required from the grid to power the BSs. As a result of these ecological and economic perspectives, the reduction of the overall energy consumption is one of the main targets for Mobile Network operators. Several researches investigated how to reduce the energy consumption in all mobile network parts, especially in the RAN since it is the part which consumes the most. Among these solutions, powering the BSs with Renewable Energy (RE) sources is the most common [2, 4]. It addresses both the reduction of the energy supplied from the grid and the reduction of carbon emissions. Other solutions are, for example, WiFi offloading and Resource on Demand (RoD) strategies. WiFi offloading strategies transfer the mobile traffic to nearby WiFi Access Points [5] to reduce the BSs load and their consumption. RoD strategies dynamically switch on or off some Base Stations, depending on the traffic demand, to reduce BSs static consumption [2].

As for Mobile Network operators, also Household consumers' interest in reducing energy consumption increases. Household's energy demand constitutes a large share of the world energy demand. In 2015 they accounted for 2051 Mtoe, approximately 22% of the world energy consumption [6], where 23% is due to electricity. Therefore, the objective to reduce energy consumption with the improvement of energy efficiency solutions also involves the Household sector. However, the lack of proper information and technologies as well as different behaviours among consumers are great barriers to the fulfilment of these programs.

Meanwhile, the new concept of Smart Grid (SG) arises from the improvement of the current power grid. The Smart Grid allows a better utilization of energy and a better balancing of energy supplied and demanded. It permits a bidirectional flow of energy and information between customers and the electric utility. This permits a better integration of Renewable Energy in the grid and customers that produce their own energy, the so-called

Prosumers, are able to share it with others or with the Smart Grid [7]. Furthermore, the enabled communication between utility and customers accommodate an active participation in the management of their own consumption. This engagement of the consumers has motivated several Demand Response (DR) approaches. These strategies encourage consumers to reduce their consumption during peak periods providing in return incentives or discounts. Demand Response is suitable both for big consumers, like Mobile Network operators [8], and for smaller ones, such as Household consumers. If properly addressed they allow to reduce energy consumption and also the energy bill.

In this work we take into account Household consumers, Mobile Network operator and mobile charging in a Smart Grid scenario allowing individual participation in Demand Response programs as well as a cooperative one. The Smart Grid issues requests depending on the current price of electricity every half an hour. The Mobile Network operator implements an energy management policy which depending on the SG command adopts different strategies. It can either retrieve the energy from renewable sources and batteries, reduce consumption by applying RoD and/or WiFi offloading strategies or ask the grid for required energy. Meanwhile, Households can reduce their consumption, if the SG ask so, depending on their flexibility. Furthermore, we investigate a cooperation between Mobile Network operator and Households in cases where the SG asks to reduce the consumption and also we Energy consumption was also assessed every half hour and also throughout the month and year, and to better understand and achieve better results, we also considered the use of some devices such as mobile phones, and thus the energy consumption in the season. We looked at different times as well as different times of the month and year to get a much better management of energy and energy consumption, which is the main focus of this work. In exchange for price discounts and increased bandwidths Households can offer part of their reduction to Mobile Network if it asks so. In this way the Mobile Network can reduce its energy bill and avoid penalties. The thesis dissertation is organized as follows.

1-2- Thesis structure

In the next three chapters the main aspects of Smart Grid, Mobile Networks and Household consumption are presented. Chapter 5 describes the work and the proposed model for the overall scenario. Finally, in Chapter 6, the analysis of the results is presented before concluding.

Chapter 2: Smart Grid energy consumption

2-1- **Introduction**

This chapter describes the smart grid and explains the energy consumption process in full.

2-2- **Smart Grid**

Smart grid communication technologies have fast become a fundamental tool with which many utilities are building their smart grids.
Over recent years, administrations and national commissions overseeing electric power generation distribution and consumption have made commitments to improve efficiency, conservation, security and reliability as part of their efforts to reduce the 40% of the world's greenhouse gases produced by electric power generation [1]. Smart grid systems are a key enabling technology in this respect. Secure communications form a key component of smart grid, and underpin some of the largest and most advanced smart grid deployments in development today.
High-capacity, two-way communication networks with embedded sensing can be installed on existing electric, water, and gas distribution networks to transform them into interactive, automated, self-healing smart grids. These smart grids are monitored by a 24 × 7 network management system and analytic software platforms that enhance and modernize the efficiency, reliability, and security of electric distribution networks. Electric distribution wires touch every single critical juncture point that an electric smart grid must monitor and control and power Smart Grid devices that monitor and control electric, water, and gas distribution. Using secure, reliable, standards-based communication systems is a natural and economical extension of the existing electric distribution infrastructure, one that is sure to access every desired segment of today's grid.
Smart grid systems reduce distribution infrastructure, operating, and maintenance costs by optimizing grid operations. This optimization also reduces the amount of needed electric generation, which in turn lowers generation-related green house gas ("GHG") emissions. These particular savings emanate from efficient grid operations, including distribution automation and real-time system optimization. Smart Grid systems also enable grooming in alternative

energy sources, such as photovoltaic and wind power, and managing the large and variable loads, for example, electric transportation applications like Electric Vehicles (EVs).

2-2-1- **Smart grid features and characteristics**

The fundamental method of operating the electric distribution grid has not changed significantly in the past 100 years. Customer complaints are most often the only source inforaton about a local electrical outage. Most utilities do have reliable data reflecting local operational inefficiencies or vulnerabilities, so problems may continue for years after they develop due to inadequate or nonexistent automated monitoring and control capabilities. The digital sensing, monitoring and control technologies that are widely deployed in telecommunication networks, traffic systems and automobiles have not been similarly applied to utility distribution. Today's Smart Grid communication technologies will provide needed visibility, control, and security for the utilities of the 21st century.

A smart grid provides this information overlay and control infrastructure, creating an integrated communication and sensing network. The smart grid network provides both the utility and the customer with increased control over the use of electricity, water and gas. Furthermore, the network enables utility distribution grids to operate more efficiently than ever before. This communication capacity makes possible key benefits including:

- reduction in product "lost" during distribution;
- increases in efficiency, reducing the amount of energy actually needed to serve a given amount of demand;
- remote detection of equipment problems to extend the life of such equipment and avoid outages or repair them more quickly;
- controlling end-user consumption during peak times;
- enabling end users better to control their consumption all the time;
- integrating the wide spread use of renewable energy distributed energy resources (like roof-top solar panels and plug-in electric vehicles).

Recent United States legislation[1] characterizes smart grid as consisting of these

[1] The Energy Independence and Security Act of 2007 (Public Law 110-140).

elements:

1. increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid;
2. dynamic optimization of grid operations and resources, with full cyber-security;
3. deployment and integration of distributed resources and generation, including renewable resources;
4. development and incorporation of demand response, demand-side resources, and energy-efficiency resources;
5. deployment of “smart” technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation;
6. integration of “smart” appliances and consumer devices;
7. deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning;
8. provision to consumers of timely information and control options;
9. development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid;
10. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

The Electric Power Research Institute (EPRI)[1] defines smart grid as a power system that can incorporate millions of sensors all connected through an advanced communication and data acquisition system. Such a system will provide real-time analysis by a distributed computing system that will enable predictive rather than reactive responses to blink-of-the-eye disruptions and is designed to support both a changing generation mix in a carbon constrained world, and more effective participation by consumers in managing their use of electricity[2].

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1 **http://my.epri.com/portal/server.pt**?

2 *See* Michael W. Howard, Ph.D., P.E., Senior Vice President, R&D Group, Electric Power Research Institute, *Facilitating the Transition to a Smart Electric Grid*, Testimony Before the U.S. House of Representatives Energy and Commerce Subcommittee on Energy and Air Quality (3 May 2007).

The Modern Grid Initiative sponsored by the U.S. Department of Energy (DOE)[1] has a similar definition.

The critical nature of communications is also emphasized by EPRI in its plan to reduce U.S. carbon emissions where it identifies "Deployment of smart distribution grids and communications infrastructures to enable widespread end-use efficiency technology deployment, distributed generation, and plug-in hybrid electric vehicles" as one of four strategic technology challenges to be met to enable its overall plan[2].

The European Commission ***Strategic Research Agenda*** recognizes that the communications system is a key element of active grids and the management of dispersed generation[3], and identifies the following characteristics of smart grid:

1. flexible: fulfilling customers' needs whilst responding to the changes and challenges ahead;
2. accessible: granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions;
3. reliable: assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties;
4. economic: providing best value through innovation, efficient energy management and "level playing field" competition and regulation[4].

It further describes how the system can "efficiently link power sources with consumer demands, allowing both to decide how best to operate in real time. The level of control required to achieve this is much greater than in current distribution systems. It includes power flow assessment, voltage control and protection require cost-competitive technologies as well as new communication systems with more sensors and actuators than presently in the distribution system"[5].

The May 2007 **European Strategic Energy Technology Plan** (SET-PLAN)

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1 The DOE Sponsored Modern Grid Initiative identifies a Modern or Smart Grid as having five components, Integrated Communications, Sensing and Measurement, Advanced Components, Advanced Control Methods and Improved Interfaces and Decision Support. It states "[o]f these five key technology areas, the implementation of integrated communications is a foundational need, required by the other key technologies and essential to the modern power grid." and that "[h]igh-speed, fully integrated, two-way communications technologies will allow much-needed real-time information and power exchange." A Systems View of the Modern Grid at B1-2 and B-1.

2 The Power to Reduce CO2 Emissions, The Full Portfolio at 3-1 August 2007, EPRI.

3 EUR 22580 – Strategic Research Agenda for Europe's Electricity Networks of the Future (EC Strategic Research Agenda) at 62, European Commission, 2007.

4 EC Strategic Research Agenda at 15.

5 EC Smart Grid Vision Report at 27.

also identifies System control and data exchange via ICT systems as one of the main technologies for the deployment of the smart grid[1]:

- "improving the ability to monitor and control areas of our networks not considered before will lead to improved deployment of RES [renewable energy sources] and real-time optimisation and operation of our networks in a more secure and safer way … Integration of large amounts of intermittent renewables will require increased data exchange (for instance intercompany data exchange among the generation to supply value chain to comply with deregulation requirements) and intelligent control systems in order to deliver the desired reliability with dedicated "platforms" managing the transmission of information among the different electricity system players (e.g. according to the UK model). This in turn will deliver the ability to react in real-time for trading, fault prevention, asset management, residential and industrial generation control, demand side participation (e.g. frequency control from white goods appliances, integration of carbon credit schemes, etc), demand response management, energy data management, automated metering infrastructure where smart meters will offer tailored tariffs, flexible contract and value added services. The application of intelligent, highly distributed control strategies will enhance reliability and quality of service and provide self-healing capabilities at the distribution level including local black-start capabilities".

As these policy pronouncements all make clear, smart grid is far more than advanced meters in homes and the remote monitoring and transmission of energy usage data via an advanced meter infrastructure (AMI). It is a network of sensors and devices providing real time analysis and control of the use of electricity throughout the distribution area, including on the grid itself[2].

1 European Strategic Energy Technology Plan (SET-PLAN) Annex 1 at 6 May 2007. The other technologies are wind and intermittent renewables, storage and demand side management and smart metering. Each of these technologies also requires a communications component.

2 The New York Public Service Commission recently stated that "it is essential that deployment of communication facilities for [advanced metering infrastructure] does not result in stranded facilities that are not capable of being expanded for broader smart grid applications. Therefore, AMI systems must be designed to meet future requirements of the smart grid, and particular must contain communications systems that are scalable and expandable to accommodate sensors in multiple locations throughout the grid." Order adopting minimum functional requirements for advanced metering infrastructure systems and initiating an inquiry into benefit-cost methodologies at 18, New York Public Service Commission (13 Feb. 2009).

2-3- **What is automated meter reading (AMR)?**

Automated meter reading (AMR) refers to the technology used for automating collection of water and energy (electricity or gas) consumption data for the purposes of real-time billing and consumption analysis. At a specified time, the AMR system gathers real-time data and transfers the information gathered to the central databases, through networking technology, for billing, troubleshooting and analysing.
The primary benefit of AMR is that it provides more accurate and precise measurement of water, electricity or gas consumption, saves utility providers the expense of periodic trips to each physical location to read a meter, and provides readings free of human errors in transcription.
AMR technologies include handheld, mobile and network technologies based on telephony platforms (wired and wireless), radio frequency (RF) or powerline transmission.

2-3-1- **How does automated meter reading (AMR) work?**

AMR operations are simple on the surface but rather complex underneath. Initially, the meter must be read by the meter interface. Then the same interface translates the data into digital information to facilitate transmission. A code is then added to the meter data reading so that the data can be attributed to the correct subscriber. Once the data is encoded, the data is then read by a data collection unit, either a mobile handheld unit or a wireless gateway, operated by the utility personnel. During this time, a digital transfer from the meter interface to a device that the meter reader controls takes the data, whereby, the data collected is downloaded in the office. Data can also be automatically transmitted to the database through automatic data transmission protocols.

2-3-2- **Difference between automated meter reading (AMR) and advanced metering infrastructure (AMI)**

The advent of AMR came about in the early 1990s as an automated way to collect basic meter-reading data. Whereas, the term and technology behind advanced metering infrastructure (AMI) began showing itself around 2005, evolving from the foundations of AMR. The two terms, AMR and AMI, are used interchangeably even though the actual meaning or definition is slightly different. All AMI systems contain AMR functionality, although it is not the core of its purpose, but all AMR systems are not AMI systems.

AMR likely includes all one-way systems, drive-by and walk-by systems, phone-based dial-up systems, handheld reading entry devices and touch-based systems. These systems tend to be collection only, without means for broadcasting command or control messages. In addition, data from AMR systems is typically gathered only monthly or, at most, daily. AMI is typically more automated and allows real-time, on-demand interrogations with metering endpoints. The meters in an AMI system are often referred to as smart meters, since they often can use collected data based on programmed logic.

2-3-3- **Typical configuration**

AMR

The configuration of an AMR system generally begins at the meter and includes a meter reading interface device, a data collection device, and the mobile application software, which calculates the billing information to the client. For an AMR system, the meter reading interface device is a radio device which reads the data off of the meter. It is in close proximity to the meter and is generally mounted on a wall near the meter. The information that is read with the meter interface unit is transmitted over to a data collection point. Some data collection devices use radio frequencies in close proximity, such as walk-by or drive-by devices, which are mobile data collection devices that can read the data off the meter interface unit at short distances. Other data collection devices come in the form of a wireless gateway. Once the data is collected, the mobile application software analyses the data and the information is stored and information for billing is also processed for the consumer.

AMI

The configuration of an AMI system includes the aspects of AMR within its infrastructure, but also implements automated two-way communication for real-time, on-demand data access at the metering endpoints. There is two-way communication between the meter interface unit and the base application software. This communication may be transported using one or more of several available media. In this case, the information collected from the meter is analysed and consumption of the utility is assessed. For AMI, there are two major ways in which the control portion of the system operates. Firstly, the radio signal from the meter to the device can be controlled, similar to that of a thermostat, where the utility consumption level would be assessed at a certain threshold. Secondly, there would be communication back from the meter to the utility and then to the device to be controlled via the internet.

Currently, there are a wide variety of standard technologies being used in AMI applications, which include cellular modems, dial-up modems, power-line telecommunications, as well as the more common radio technologies, for example, WiFi and RF mesh technologies.

2-4- Smart metering as a required component for a metering infrastructure in Europe

On 12 March 2009 the European Commission set out a standardization mandate M/441 to the European Standards Organization CEN, CENELEC and ETSI to develop one standard[1].

The description of the mandated work is:

"CEN, CENELEC and ETSI are requested to develop:

1. A European Standard comprising a software and hardware open architecture for utility meters that support secure bidirectional communication upstream and downstream through standardised interfaces and data exchange formats and allows advanced information and management and control systems for consumers and service suppliers. The architecture must be scalable to support from the simplest to the most complex applications. Furthermore, the architecture must consider current relevant communication media and be adaptable for future communication media. The communication standard of the open architecture must allow the secure interfacing for data exchanges with the

[1] The text can be obtained at http://ec.europa.eu/enterprise/standards_policy/mandates/database/ by typing the mandate number into "other search" folder.

protected metrological block.

2. European standards containing harmonised solutions for additional functionalities within an interoperable framework using where needed the above-mentioned open architecture for communication protocols. These solutions must be standardised to achieve full interoperability. Solutions meant to be installed in living quarters should be silent, non-intrusive and safe.
3. The standards to be developed must be performance-based and permit innovation in the protocols that enable remote reading of utility and advanced information and management services for consumers and suppliers. In particular, the standards shall permit fully integrated instruments, modular and multi-part solutions. Standards developed under this mandate and M/374 should not conflict with each other and other standards and any overlaps should be indicated.

CEN, CENELEC and ETSI should take into account international, European and national standard that have already been developed or are under development."

As one goal the customer should have an indication of his current and thus adjust his consumption (intelligent metering).

The ESO are requested to provide a progress report by the end of October 2010.

CENELEC (Comité Européen de Normalisation Electrotechnique) is the European Committee for Electrotechnical Standardization and is responsible for European Standardization in the area of electrical engineering. ETSI (European Telecommunications Standards Institute) is responsible for European Standardization in the area of telecommunications whereas CEN (Comité Européen de Normalisation) the European Committee for Standardization tasks are in the other technical areas.

Additionally CEN, CENELEC and ETSI will invite ANEC (European Association for the Coordination of Consumer Representation in Standardisation, www.anec.org), ECOS (European Environmental Citizens Organisation for Standardisation, www.ecostandard.org), NORMAPME (European Office of Crafts, Trades and Small and Medium sized Enterprises for Standardisation, **www.normapme.com/**) and the Open Meter Project (European Consortium, **www.openmeter.com/**) to take part in the standardization work.

The ESOs are guided through a high level steering and coordination forum SM-

CG (smart metering coordination group). Two ad hoc groups, one which deals with ‘communication’ (architecture of standardization parts) and the other one dealing with ‘additional functionalities’ (catalogue of additional features in the sectors of gas, electricity, water and heating), were established. The Council of European Energy Regulators (CEER) is represented by currently five members from Austria, France, Germany, Italy and the United Kingdom.
ETSI signed a memorandum of Understanding with the Smart Metering Industry Group and CENELEC cooperates with ESMIG[1].

2-5- Smart grid communication network technologies

Various types of communication networks may be used in smart grid implementation. Such communication networks, however, need to provide sufficient capacity for basic and advanced smart grid applications that exist today as well as those that will be available in the near future.
Assessing communications needs of various smart grid applications requires an understanding of 1) the “control loop” timeline of the application[2], 2) the amount of data that needs to be transferred at any particular time, 3) the number and location of devices with which communications must be maintained, and 4) the overall communication capacity of the proposed communication system. An application’s timeline and tolerance for latency in transferring and analysing data or control signals is critical to determining appropriate communications capability.
For example, the gathering of metering data for daily meter collection can tolerate a latency period of many hours (and even a period of several days in the case of monthly billing). But real-time, control-oriented applications such as voltage control, integration of distributed generation resources, and distribution switching require latency periods of no more than two seconds[3].

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1 **http://www.esmig.eu/newsstor/esmig** or **http://www.etsi.org/website/newsandevents/200905_esmig.asp**.

2 The control loop timeline refers to the overall length of time to make a decision and initiate action relevant to a particular control application. For instance, a control decision that needs to be made with real-time information every 30 seconds cannot utilize a communications link that takes 60 seconds to transfer the related data.

3 For example, distributed protection systems use multiple isolating switches and relays that disconnect power from a section of the electric distribution system in the event of a failure or short circuit. Such disconnection helps reduce the size and impact of any resulting outage, prevent widespread damage to the system, and minimize public safety hazards. In order to make control decisions, these systems rely on widely dispersed devices that access information about real-time conditions at other devices connected to the distribution grid.

Contemporaneous consideration must also be given to the consistency or predictability of a particular application's activity. For example, a utility generally can schedule the collection of metering data and gradually perform such collection throughout the day or night in order to smooth out any data peaks. Many of the applications with the most stringent latency needs (e.g. outage alerts, system control applications), however, occur randomly and their activity therefore cannot be scheduled. A utility's full analysis of its communication needs will therefore address all such application timelines, latency tolerances, and application predictability, including consideration of simultaneous activity from multiple applications.

The fundamental characteristic of a smart grid is its integrated communication and sensing network, which allows proactive management of the energy input sources as well as consumer demand. This communication capacity can and often will, be enabled by various technologies; however they all present different challenges and limitations.

One solution uses communication **via power lines**. This solution requires only the addition of communication/sensing devices overlaid on the existing electric distribution infrastructure.

Testing has shown PLC based 'Smart Meter' solutions to be sufficient for monthly readings or non-critical daily device communications[1]

An attractive alternative are the various wireless Smart Grid solutions being developed worldwide and applied in Europe. Ranging from point-to-multipoint solutions (e.g. cellular radio or satellite) through RF mesh solutions, and including hybrid deployments of both architectures[2].

In Europe, ETSI TC M2M (Technical Committee Machine to Machine)[3] is developing the response on European Mandate M/441. Smart meters as a device within smart grids are understood a part of broader machinery telecommunications. The deliverables contain a functional architecture on M2M[4], use cases for smart metering[5] and the technical report on ETSI M2M

Distributed protection systems respond to events of only several milliseconds in duration and must communicate information just as quickly in order to perform their functions effectively.

1 ESB Networks, Smart Meter Project, 11 November 2010 – http://www.cer.ie

2 ibid

3 http://portal.etsi.org/portal/server.pt/community/M2M.

4 Draft ETSI TS 102 690 V<0.1.2> (2010-01) Work item Number DTS/M2M-00002.

5 Draft ETSI TR 102 691V0.4.1 (2010-02) Work item Number DTS/M2M-00003.

plans and deliverables for the EU Smart Meter Mandate M/441[1].

The functional architecture decompose the architecture into M2M core, M2M access network and in the customers properties (e.g. houses, flats, etc.) installed M2M devices. The M2M devices got access to the access network directly or via an M2M area network and an M2M gateway.

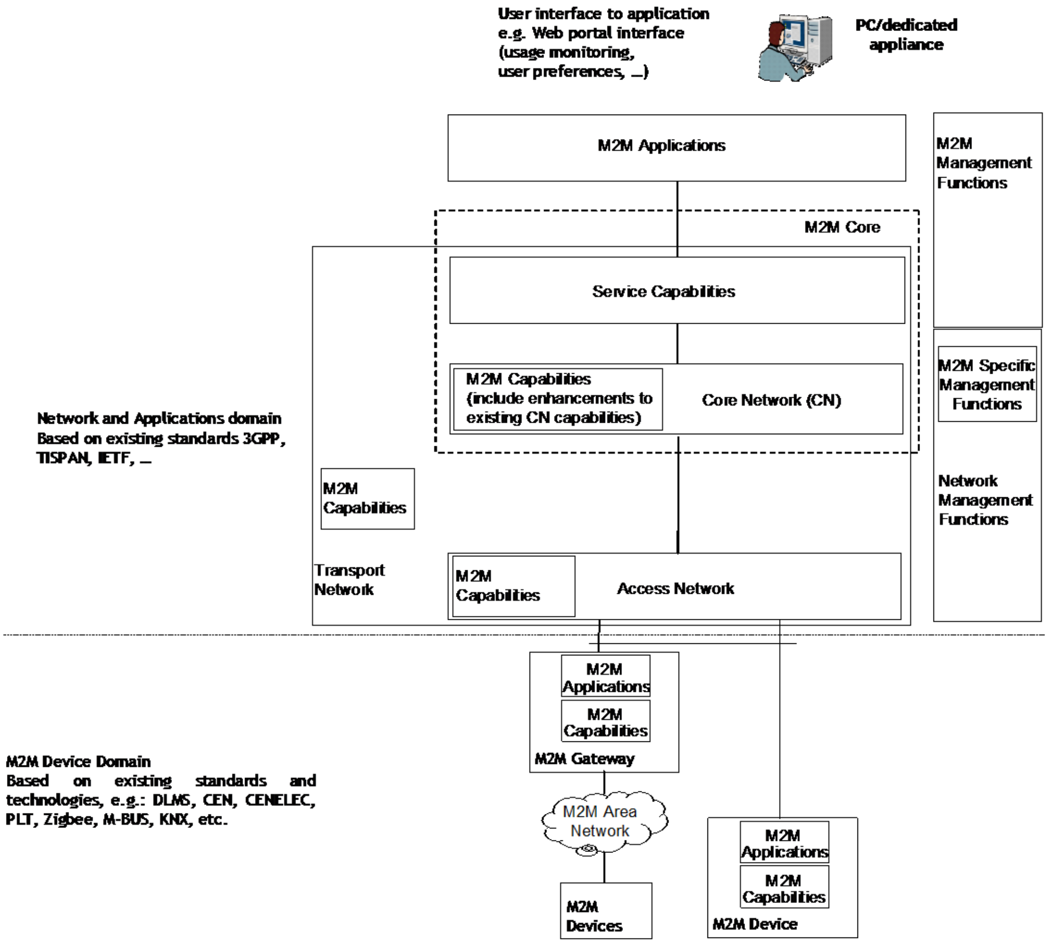

Figure (2-1) - Draft ETSI TR 102 691V0.4.1 (2010-02)

The M2M area network may use technologies such as IEEE 802.15 (e.g. Zigbee), Bluetooth, etc. or local networks such as PLC, M-BUS, Wireless M-BUS and KNX[2]. The M2M access network is based on existing access networks. Examples of access networks may include: xDSL, HFC, PLC, satellite, GERAN, UTRAN, eUTRAN, W-LAN and WiMAX. DSL technologies may include sharing an Internet access from the telecommunication premises of a subscriber.

1 ETSI TR 102 xxx V<0.0.1> (<2010-03>) Work item Number DTR/M2M-00009.

2 KNX is an open standard ISO/IEC 14543 (also known as EN 50090). M-Bus (or Meter-Bus) is the European standard EN 13757 series for remote reading meters.

Access to the smart meter with mobile networks (e.g. GSM/GRPS) may be assumed as one of the first deployed solutions. Those technologies are well introduced in the markets and the network operators can use their experiences in traditional markets.
PLC or the various wireless alternatives to cellular can offer economic efficiencies when their deployment is practical.
[Others: To be developed]
While all the different types of smart grid telecommunication technologies listed above can be used in specific circumstances, in some cases, especially where population densities and grid architecture dictate, Non-GPRS based smart grids may enable utilities to achieve the performance and cost profiles that allow for mass deployment and the full exploitation of the smart grid concept

2-6- **Smart grid benefits**

2-6-1- **Reducing overall electricity demand through system optimization**

Existing local electric distribution systems are designed to deliver energy and send it in one direction, but lack the intelligence to optimize the delivery. As a result, energy utilities must build enough generating capacity to meet peak energy demand, even though such peaks occur only on a few days per year and the average demand is much lower. Practically, this means that during days when demand is expected to be higher than average, the utility companies will restart occasionally used, less-efficient and more expensive generators.
In addition, utilities have limited information about the actual conditions on the distribution grid. The use of highly distributed sensors and two-way communications made possible with smart grid enables utility companies effectively to manage those peak loads and optimize their systems: studies show that by more tightly controlling voltage, utilities can reduce overall energy usage by 2 to 3%[1]. Additional savings can be realized by taking action to reduce line losses and reducing unnecessarily high voltage levels that serve only to inflate the amount of generation (and customer bills) needed to support a given

[1] California Energy Commission on the Value of Distribution Automation, California Energy Commission Public Interest Energy Research Final Project Report at 89 (Apr. 2007) (CEC Report).

level of demand. The EU, the U.S. Congress[1], the International Energy Administration[2] and many researchers and utilities believe that smart grid is an essential technology to improve the reliability and reduce the environmental impact of electric consumption. The EPRI has estimated that smart grid-enabled electrical distribution could reduce electrical energy consumption by 5% to 10% and carbon dioxide emissions by 13% to 25%[3].

2-6-2- **Integrating renewable and distributed energy resources**

Rising energy costs and ever-greater environmental sensitivity mean that more and more individuals and companies are taking it upon themselves to generate their own electricity from renewable energy sources, such as wind or solar. Government incentives are often used to subsidize the deployment of these technologies, whether at a micro-generation level (i.e. an individual household) or as part of a larger commercial development. Unfortunately, the existing energy distribution network, which was never designed to accept ***input*** from the edge of the network, but merely to send power ***out*** to the edges, has difficulty in accommodating distributed generation patterns.

As a result it is often difficult, expensive, or even impossible to connect distributed renewable energy sources to the grid. Furthermore, even where renewable energy is fed back into the grid, the present distribution grids around the world have no way of anticipating or reacting to this backflow of electricity. Because these systems must be kept in balance and electricity is not easily stored, and because distribution systems and equipment are designed with the assumption that only the utility will determine when and where to send electricity, renewable and distributed resources put strain on the grid[4].

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1 For example, recent U.S. federal legislation, the Energy Independence and Security Act of 2007 (Public Law 110-140), sets out as the policy of the United States the implementation of smart grid systems to modernize the electric grid, and requires both the federal and state governments and regulators to take specific actions to support the implementation of a smart grid.

2 International Energy Agency, Energy Technology Prospectives, 2008 at 179.

3 See Electricity Sector Framework for the Future: Achieving the 21st Century Transformation at 42, Electric Power Research Institute, (Aug. 2003) ("EPRI Report"), available at: http://www.globalregulatorynetwork.org/PDFs/ESFF_volume1.pdf.

4 See, e.g., Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids, Part 1: Technical Analysis, at p.14 (May, 2007), available at: **http://www.ferc.gov/about/com-mem/wellinghoff/5-24-07-technical-analy-wellinghoff.pdf** ("System components such as transformers may impose additional constraints on the delivery limit because they may not be designed to sustain a constant high loading [from electric vehicles] without a period of lower

Smart grid changes that. By communicating back to the control centre how much energy is required and how much is being input from the edges, the main generating capacity can be balanced to meet demand. Because smart grid enables this to happen in real time, utility companies can avoid the question of how unpredictable renewable energy sources are. They can compensate for fluctuations in renewable supply by system optimization, demand response and the integration of distributed electric storage such as plug-in hybrid vehicles, making the wide-scale use of distributed generation from micro and large-scale renewable sources a practical possibility. The recent report for the California Energy Commission on the Value of Distribution Automation, prepared by Energy and Environmental Economics, Inc. (E3), and EPRI Solutions, Inc., stated that the value of such distributed electric storage capable of being managed in real time (such as a battery or plug-in vehicles) would be increased by nearly 90% over a similar asset that is not connected by a smart grid[1].

2-6-3- **Providing a resilient network**

PLT technology uses the electric distribution lines to sense events on the grid, allowing network operators to gather real-time intelligence on the status of their network. This enables providers of critical national infrastructure both to prevent outages before they occur and quickly pinpoint the site of an incident when one does occur. Smart grid does this by a series of software tools that gather and analyse data from sensors distributed throughout the electric distribution network to indicate where performance is suffering. Distribution companies can maximize their maintenance programmes to prevent breakages, and quickly dispatch engineers to the scene of an incident, independent of consumer feedback. In recent years, highly publicized blackouts in North American and European networks have made electricity network security a political question, and with an aging network the number of outages, and associated disruptions to end users, are only going to increase. Smart grid will provide a real tool in this constant battle for control. For example, PLT has been successfully used in Texas and Colorado to identify grid issues, eliminate

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load conditions during which the equipment can cool down.")

1 California Energy Commission on the Value of Distribution Automation, California Energy Commission Public Interest Energy Research Final Project Report at 95 (Apr. 2007) (CEC Report).

outages, reduce outage times, and eliminate customer-impacting events and associated customer complaints[1].

2-7- **Smart grid in North America**

In the United States, government agencies have recognized the real-time, high-capacity capabilities of a smart grid will enable utilities and end users to access the full economic and environmental benefits from renewable, especially distributed renewable, resources[2]. Similarly, these capabilities are expected to unleash the potential benefits of dynamic rate structures and demand response applications that require the ability to interact with many thousands of devices in real time[3].

U.S. authorities already acknowledge a fully integrated communication network as an integral part of a smart grid. For instance, the U.S. Department of Energy-sponsored modern grid initiative identified that "the implementation of integrated communications is a foundational need [of a smart grid], required by the other key technologies and essential to the modern power grid …"[4]

The Department goes on to say that "high-speed, fully integrated, two-way communications technologies will allow much-needed real-time information

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1 See Xcel Energy SmartGridCity™ Update: Project Status and Early Benefits, at 11-15, 7 July 2009, Commissioners' Information Meeting, available at **http://www.dora.state.co.us/puc/presentations/InformationMeetings/09M-247ALL-CIMs.htm**. Similarly, "through the broadband-over-power-line network, [Oncor Electric Delivery] is able to monitor its electric delivery system, obtaining a steady stream of data that can be analysed for potential problems. Once a problem is pinpointed, Oncor dispatches operations personnel to investigate the irregularity before it can become an outage or other service issue. Issues are often resolved before consumers even realize that there was a problem." See "Oncor Reaches National Milestone," (Sept 19, 2007), available at **http://oncor.com/news/newsrel/detail.aspx?prid=1094**.

2 In late 2008, the California Air Resources Board (CARB) stated that "a 'smart' and interactive grid and communication infrastructure would allow the two-way flow of energy and data needed for widespread deployment of distributed renewable generation resources, plug-in hybrids or electric vehicles, and end-use efficiency devices. Smart grids can accommodate increasing amounts of distributed generation resources located near points of consumption, which reduce overall electricity system losses and corresponding GHG emissions. Such a system would allow distributed generation to become mainstream, … would support the use of plug-in electric vehicles as an energy storage device … [and] would in turn allow grid operators more flexibility in responding to fluctuations on the generation side, which can help alleviate the current difficulties with integrating intermittent resources such as wind." California Air Resources Board Scoping Plan, Appendix Vol. I at C-96, 97, CARB (Dec. 2008).

3 See e.g. Enabling Tomorrow's Electricity System – Report of the Ontario Smart Grid Forum, Ontario Smart Grid Forum (February, 2009) which cautions "initiatives on conservation, renewable generation and smart meters begin the move towards a new electricity system, but their full promise will not be realized without the advanced technologies that make the smart grid possible."

4 *See* A Systems View of the Modern Grid at B1-2 and B1-11, Integrated Communications, conducted by the National Energy Technology Laboratory for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability (Feb. 2007). Such integrated communications will "[connect] components to open architecture for real-time information and control, allowing every part of the grid to both "talk" and "listen". The smart grid: An Introduction at 29, U.S. Department of Energy (2008).

and power exchange"[1].

Similar emphasis on advanced communications functionality has been put forth by state authorities[2] and other industry stakeholders. For example, the Ontario Smart Grid Forum recently stated that "communications technology is at the core of the smart grid. [Such technology] brings the data generated by meters, sensors, voltage controllers, mobile work units and a host of other devices on the grid to the computer systems and other equipment necessary to turn this data into actionable information"[3].

2-8- **Smart grid in Europe**

Extensive European expertise and resources have been devoted to understanding and promoting smart grids as a solution to the challenges that Europe faces in terms of climate change and energy efficiency, including all of the following initiatives:

- **January 2008, Fiona Hall MEP Report "Action plan for energy efficiency: realizing the potential"**[4] Report recognizes the importance of information and communication technologies to help generate additional productivity gains beyond the EU's 20% target and considers that "*certain technologies such as smart grid technology … should … be the subject of effective policy recommendations*".
- June 2008, European Parliament (first reading) on the Directive on common rules for the internal market in electricity[5] advocates that

[1] *Id.*

[2] "Modernizing the electric grid with additional two-way communications, sensors and control technologies, key components of a smart grid, can lead to substantial benefits for consumers." California PUC Decision Establishing Commission Processes for Review of Projects and Investments by Investor-Owned Utilities Seeking Recovery Act Funding at 3 (10 Sept. 2009), available at: **http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/106992.pdf**. *See also,* California Energy Commission on the Value of Distribution Automation, California Energy Commission Public Interest Energy Research Final Project Report at 51 (Apr. 2007), available at: http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CTF.PDF. "[C]ommunications is a foundation for virtually all the applications and consists of high speed two-way communications throughout the distribution system and to individual customers.")

[3] *See* Enabling Tomorrow's Electricity System – Report of the Ontario Smart Grid Forum at 34, Ontario Smart Grid Forum (Feb. 2009). The Report also states that "the communication systems that the utilities are developing for smart meters will not be adequate to support full smart grid development. The communications needs associated with the collection of meter data are different from those of grid operations. Additional bandwidth and redundant service will be needed for grid operations because of the quantity of operational data, the speed required to use it and its criticality." *Id.* at 35.

[4] **http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A6-2008-0003+0+DOC+PDF+V0//EN&language=EN**.

[5]

"pricing formulas, combined with the introduction of smart metres and grids, shall promote energy efficiency behaviour and the lowest possible costs for household customers, in particular households suffering energy poverty."

- The **Smart Grid European Technology Platform**[1] works to "formulate and promote a vision for the development of European electricity networks looking towards 2020", and in particular looks at how advanced ICT can help electricity networks become flexible, accessible, reliable and economic in line with changing European needs.
- The **Address project**[2] (Active distribution networks with full integration of demand and distributed energy resources) is an EU-funded project which aims to deliver a comprehensive commercial and technical framework for the development of "active demand" in the smart grids of the future. ADDRESS combines 25 partners from 11 European countries spanning the entire electricity supply chain. PLT is a significant component of the projects underway pursuant to Address[3].

2-9- European activities in some Member States[4]

2-9-1- The European Industrial Initiative on electricity grids

The European Industrial Initiative on electricity grids[1] is launched by the

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http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P6-TA-2008-0294.

1 http://www.smartgrids.eu/.

2 http://cordis.europa.eu/fetch?CALLER=ENERGY_NEWS&ACTION=D&DOC=1&CAT=NEWS&QUERY=011bae3744bf:2435:2d5957f8&RCN=29756.

3 See "Iberdrola, EDP Announce Big Smart Grid Expansions at EUTC Event," Smart Grid Today, 9 November 2009 ("Iberdrola is using PLC to connect its smart meters while EDP is using a mix of PLC and wireless").

4 Source for whole paragraph: European Regulators' Group for Electricity and Gas Position Paper on Smart Grids - Ref: E09-EQS-30-04, Annex III http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_CONSULT/CLOSED PUBLIC CONSULTATIONS/ELECTRICITY/Smart Grids/CD http://www.energy-regulators.eu/portal/page/portal/EER_HOME/ EER_CONSULT/CLOSED%20PUBLIC %20CONSULTATIONS/ELECTRICITY/Smart%20Grids/CD.

European Commission within the European Strategic Energy Technology (SET) Plan.

The SET-Plan was proposed by the European Commission's General Directorates for Energy and for Research on 22 November 2007 with the aim to accelerate the availability of new energy technologies and to create a long term EU framework for energy technology development. The SET-Plan brings together the coordination of the European Commission, the research capacities of the major European institutes and universities, the engagement of European industry and the commitment of the Member States. One of two challenges addressed by the SET-Plan is mobilizing additional financial resources, for research and related infrastructures, industrial-scale demonstration and market replication projects. In the SET-Plan communication, the Commission informed about the increased budgets of the Seventh Framework Programme of the European Communities (2007-2013), as well as the Intelligent Energy Europe Programme.

The average annual budget dedicated to energy research (EC and Euratom) will be €886 million, compared to €574 million in the previous programmes[2]. The average annual budget dedicated to the Intelligent Energy Europe Programme will be €100 million, doubling previous values.

To engage the European industry, the European Commission proposed to launch in spring 2009 six European Industrial Initiatives (EII) in the areas of wind; solar; bio-energy; CO_2 capture, transport and storage; electricity grids and nuclear fission. EIIs are devoted to strengthen energy research and innovation, to accelerate deployment of technologies and to progress beyond business-as-usual approach. EIIs bring together appropriate resources and actors in industrial sectors, in which sharing of risks, public-private partnerships and financing at European level gives additional value.

The EII on electricity grids is expected to focus on the development of the smart electricity system, including storage, and on the creation of a European Centre

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[1] References: European Commission, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions "A European strategic energy technology plan (SET-Plan) - Towards a low carbon future", COM(2007) 723 final, 22 November 2007 European Commission, "Energy for the Future of Europe: The Strategic Energy Technology (SET) Plan", MEMO/08/657, 28 October 2008.

[2] European Commission, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions "A European strategic energy technology plan (SET-Plan) - Towards a low carbon future", COM(2007) 723 final, 22 November 2007.

to implement a research programme for the European transmission network[1], with the final objective to enable a single, smart European electricity grid able to accommodate the massive integration of renewable and decentralized energy sources[2]. As for other European Industrial Initiatives, EII on electricity grids shall have measurable objectives in terms of cost reduction or improved performance.

2-9-2- **National technology platform – smart grids Germany**

"E-Energy: ICT-based Energy System of the Future[3]" is a new support and funding priority and part of the technology policy of the Federal Government. Just like the terms "E-Commerce" or "E-Government", the abbreviation "E-Energy" stands for the comprehensive digital interconnection and computer-based control and monitoring of the entire energy supply system.

It was decided that the electricity sector would be the first area addressed by the project, as the challenges with regard to real-time interaction and computer intelligence are particularly high due to electricity's limited ability to be stored. The primary goal of E-Energy is to create E-Energy model regions that demonstrate how the tremendous potential for optimization presented by information and communication technologies (ICT) can best be tapped to achieve greater efficiency, supply security and environmental compatibility (cornerstones of energy and climate policy) in power supply, and how, in turn, new jobs and markets can be developed. What is particularly innovative about this project is that integrative ICT system concepts, which optimize the efficiency, supply security and environmental compatibility of the entire electricity supply system all along the chain - from generation and transport to distribution and consumption - are developed and tested in real-time in regional E-Energy model projects.

To force the pace on the innovative development needed and to broaden the impact of the results, the E-Energy programme focused on the following three

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1 The proposal to constitute a European Centre for Electricity Networks came from the 6FP RELIANCE project, in which eight European transmission system operators participated.

2 European Commission, "Energy for the Future of Europe: The Strategic Energy. Technology (SET) Plan", MEMO/08/657, 28 October 2008.

3 **http://www.e-energy.de/en/**.

aspects:

1. creation of an E-Energy marketplace that facilitates electric legal transactions and business dealings between all market participants;
2. digital interconnection and computerization of the technical systems and components, and the process control and maintenance activities based on these systems and components, such that the largely independent monitoring, analysis, control and regulation of the overall technical system is ensured;
3. online linking of the electric energy marketplace and overall technical system so that real-time digital interaction of business and technology operations is guaranteed.

An E-Energy technology competition was held and six model projects were declared the winners. They each pursue an integral system approach, covering all energy-relevant economic activities both at market and technical operating levels.

The programme will run for a 4-year term and mobilizes, together with the equity capital of the participating companies, some €140 million for the development of six E-Energy model regions:

- eTelligence, model region of Cuxhaven
  Subject: Intelligence for energy, markets and power grids
- E-DeMa, Ruhr area model region
  Subject: Decentralized integrated energy systems on the way towards the E-Energy marketplace of the future
- MeRegio
  Subject: Minimum Emission Region
- Mannheim model city
  Subject: Model city of Mannheim in the model region of Rhein-Neckar
- RegModHarz
  Subject: Regenerative model region of Harz
- Smart Watts, model region Aachen
  Subject: Greater efficiency and consumer benefit with the Internet of Energy

Besides the project coordinators, others like vendors of electrical equipment, system integrators, service providers, research institutes and universities are involved.

By 2012, the selected model regions are to develop their promising proposals up to the stage at which they are ready for market launching and to test their marketability in everyday application.

2-10- **Data rates, bandwidths, frequency bands and spectrum requirements needed to support the needs of power grid management systems**

2-10-1- **AMI/AMR frequencies**

The following is a list of bands used for AMR/AMI.

Table (2-1) - AMR/AMI frequencies

Frequency (MHz)
220-222
450-470
869
902-928
1 427-1 432
2 400-2 483.5
3 600-3 650
5 150-5 250
5 725-5 850

2-10-2- **Middle mile**

Where there are numerous collector points, it may be more efficient to use point-to-multipoint architecture to link them to the backhaul network. This can be referred to as the middle mile. Some characteristics of middle mile are as shown in Table (2-2) .

Table (2-2) - Middle mile

Frequency band (MHz)	**1 800-1 830**
Architecture	Point-to-point/point-to-multipoint
Modulation	QPSK/16-QAM/64 QAM[1]
Channel spacing (MHz)	3.5 MHz/5 MHz
Maximum Rx antenna gain (dBi)	Base: 11 dBi
Feeder/multiplexer loss (minimum) (dB)	1 dB
Antenna type (Tx and Rx)	Base: Omni/sectoral Terminal: flat panel
Maximum Tx output power (dBW)	2 Watts in any 1 MHz
e.i.r.p. (maximum) (dBW)	+55 dBW per RF channel
Receiver noise figure (dB)	3

2-10-3- **Backhaul**

Wireless backhaul can make use of any fixed point-to-point frequency band.

2-11- **The ITU-T Focus Group on Smart Grid**

ITU-T Focus Group on Smart Grid (FG Smart) was established further to ITU-T TSAG agreement at its meeting in Geneva, 8-11 February 2010 followed by ITU-T study groups and membership consultation.

The Focus Group was formed to, from the standardization view points and within the competences of ITU-T:

- identify potential impacts on standards development;
- investigate future ITU-T study items and related actions;
- familiarize ITU-T and standardization communities with emerging attributes of smart grid;
- encourage collaboration between ITU-T and smart grid communities.
- The Focus Group collaborates with worldwide smart grid communities (e.g. research institutes, forums, academia) including other SDOs and consortia.
- These are the findings of the Focus Group.

2-12- **Conclusion**

High-capacity, two-way communication networks employing PLT or other telecommunications technologies that couple sensors and smart meters can transform existing electric distribution networks into smart grids. These interactive networks can be monitored and controlled to enhance the efficiency, reliability, and security of electric distribution networks.

Chapter 3: Mobile Energy Consumption

3-1- Introduction

3-2- Overview of smarter electricity networks

In general terms, the electric network is divided into several parts. Power plants and the high voltage transmission lines that send the power into the grid comprise the generation and transmission systems. The distribution network delivers power to homes and businesses. Home area networks allow customers to control their energy usage and communicate with the utility.

The distribution system is characterized mainly by a radial configuration where there is an identifiable single path to a source of power for every load, though new grid configurations are beginning to change this model. This radial configuration simplified the engineering to account for one-way power flow in the monitoring, protection and control of the power grid.

Figure (3-1) below schematically illustrates the legacy electricity network configuration.

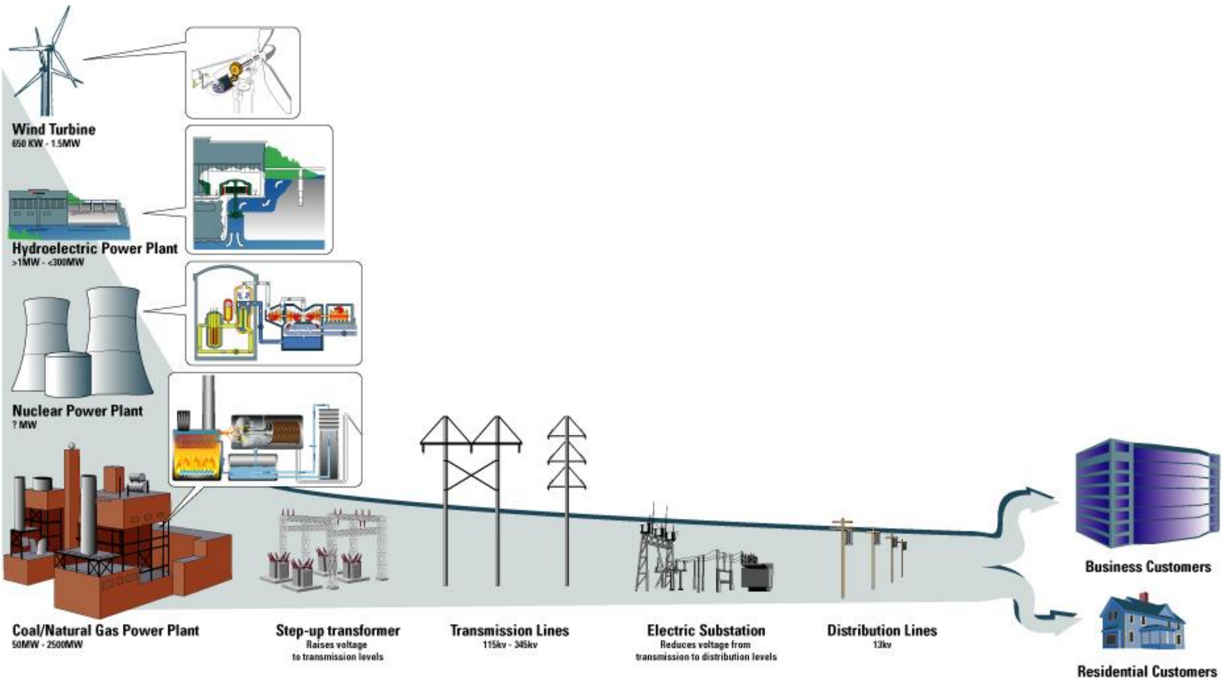


Figure (3-1) - Electricity network infrastructure

Today's paradigm is vastly different, with the expectation that generation, storage, and mobile vehicle load, among other newer applications, create two-way power flows on those same lines, and that the end customer is extremely participative in the overall stability and functioning of that network.

Figure (3-2) below illustrates the major changes taking place in the energy sector as companies are required to develop smarter networks in order to accommodate very large numbers of renewable and low carbon energy sources. The traditional generation plants, very large power stations using fossil fuels are being replaced with much higher number of smaller units using wind, solar and natural gas. These smaller power stations are distributed over a large geographical area.

In addition, individual companies and individual homes can also generate power from wind and solar and this energy is fed into the energy grid. This has the effect of creating millions of small energy sources which utilities need to manage and control.

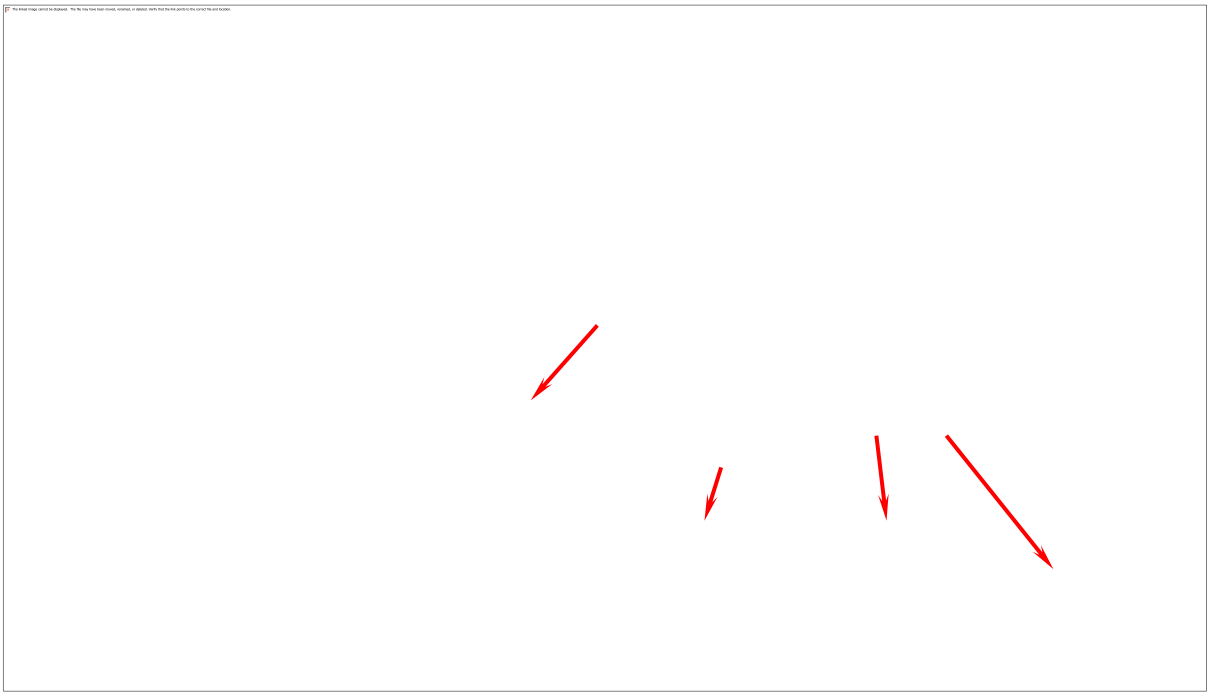


Figure (3-2) - Smarter electricity network

The need to create smart distribution grids is universal across the world. Smart distribution energy networks will be integrated with smart homes, buildings, transport and cities. The key issue for the energy sector is connectivity to the many thousands of assets and energy sources in distribution networks. The information and communications technologies (ICT) needed to manage and control complex smart energy networks demands very high availability and reliability and needs to provide communications connectivity when the energy supply fails. The communications capacity and coverage required in the distribution network is not in place today and energy companies are planning new communications networks and services to meet the needs of smart grids. Many technologies will be used but the grid assets are spread over a large geographical area and in remote locations and therefore wireless communications will play a key role.

Specifically, utilities are deploying real-time, two-way communications networks that extend beyond the distribution substations all the way to the customer premises. These networks must be highly reliable and provide low latency communications. Moreover, the networks must support higher capacity to enable smart grid data traffic from a proliferation of devices that reside on the grid and in the home. Finally, the networks must provide high security to protect against cyber security and other external vulnerabilities.

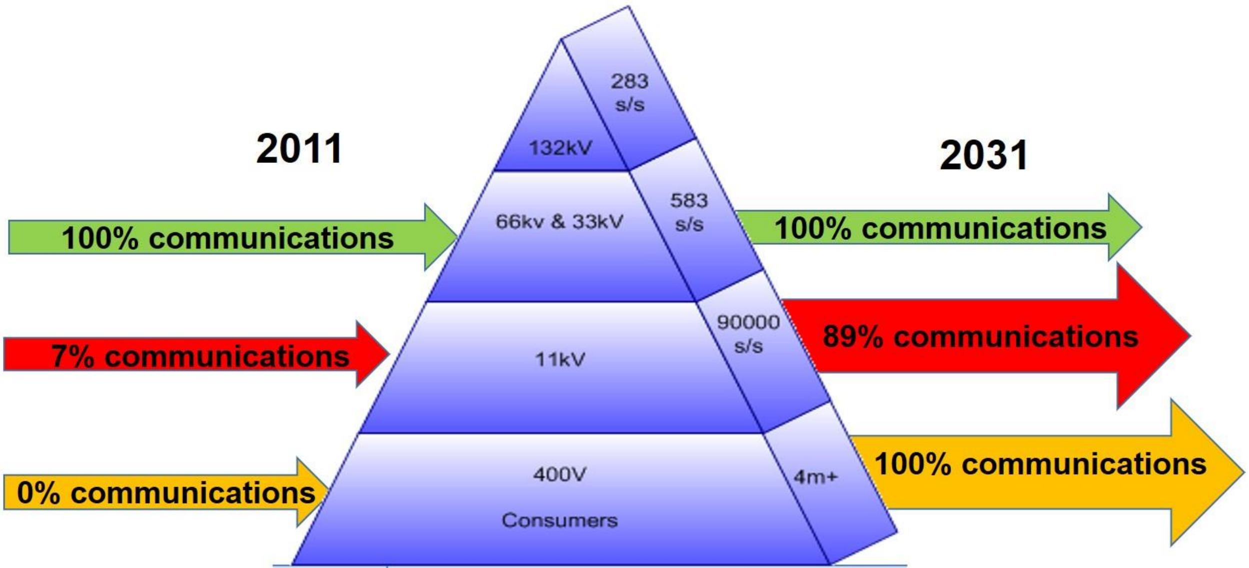
3-3- **Distribution network assets [1]**

A study by consultants in the UK devised the following representation of utility asset management for a typical distribution company with 4 million customers serving an area of 29 000 km^2 through a network of 80 000 km of underground cables and 48 000 km of overhead lines; see Figure (3-3) below. Compared to 2011, the increase in connected end points was forecast to grow by 775% by 2021 and 1199% by 2031.

Although the degree of communications connectivity required at the 11 kilovolt (kV) level (or alternative equivalent Medium Voltage (MV) level) is still uncertain, most utility commentators consider it will have to be between 50% and 100% of all end points, plus monitoring in real-time of many distributed assets to deliver the capacity increases required by low-carbon energy solutions.

Since this model is typical of most electricity distribution networks across Europe, it can provide a first level approximation of the increase in connections that will be required. European data indicates approximately 200 million households across Europe, and although this does not precisely mirror the data above, it can be scaled to suggest 4.5 million assets at Medium Voltage level across the EU, indicating:

- 2011: connectivity of 315 000 units
- 2021: connectivity of 2.4 million devices
- 2031: connectivity of 4 million devices



	Quantity of sites requiring comms (% increase over 2011)	
	2021	2031
Total	775%	1199%

Source: Telent study for ENA Aug 2011

Figure (3-3) - Distribution network assets

3-4- **Smart Network Applications & Services**

Smart Electric Network applications are briefly described below. We have included traditional power grid applications such as SCADA because the traffic for these traditional applications also has to be carried over the communications networks [4].

3-4-1- **Supervisory Control and Data Acquisition (SCADA)**

In this report, SCADA refers to communication between Remote Terminal Units (RTU) or Intelligent Electric Devices (IED) deployed in a substation (or a generation plant) with the SCADA Master (Control) in the utility DCC. An RTU in the substation collects measurement and status information from some or all measurement devices, relays, and other elements in the substation. In response to periodic polls received from the Master, the RTU sends measurement + status messages to the SCADA Master. In addition, events generated at the relays and other instrumentation are transmitted to the SCADA Master as they occur (asynchronously). The RTU also receives controls from the SCADA Master that are delivered to the relays, bay controller, or other devices for necessary action.
For substation automation based on IEC 61850 standards, IEDs deployed at the substation replace traditional relays, bay controllers, other measurement devices, and switchgear. In this case, each IED is capable of direct communication with the SCADA Master Control: direct communication is used for periodic polls from the SCADA Master, measurement + status responses, event reports, and control signals.

3-4-2- **Advanced Metering Infrastructure (AMI)**

Utilities are deploying smart meters at consumer locations. Smart meters report electrical measurements (energy, voltage, power, etc.) at frequent intervals (e.g., once every 15 minutes). In addition to billing, these frequent meter measurements are used by many new and emerging applications including Automated Demand Response (ADR), energy management, rate management, power quality, and asset management systems.

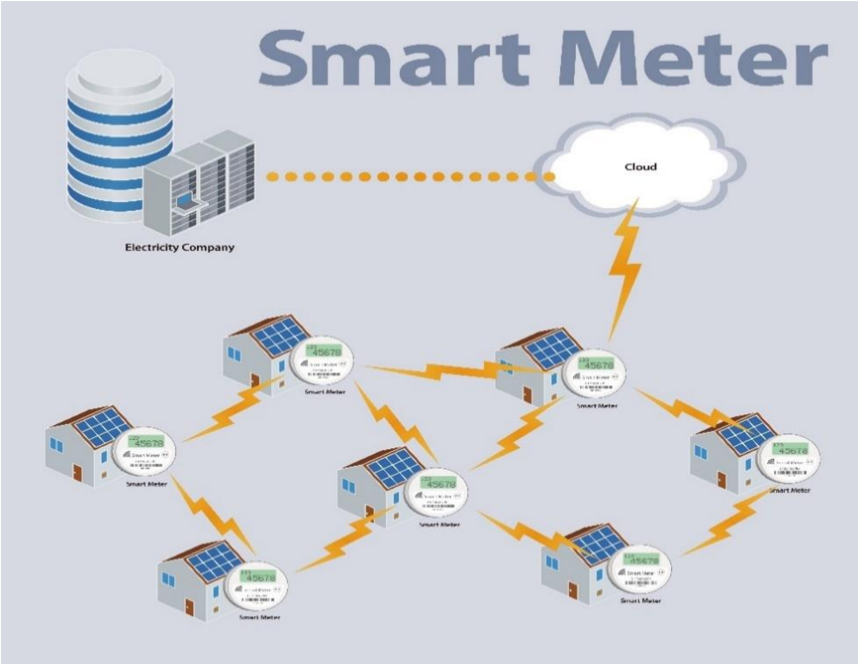


Figure (3-4) - Smart meter network configuration

In an AMI solution, meters communicate with the utility Meter Data Management System (MDMS) located at the utility DCC. Meters send periodic measurement + status information to the MDMS, often in response to periodic polling from the MDMS. Asynchronous events such as voltage alarms are also sent to the MDMS. The MDMS may also send control signals to the meters (e.g., disconnecting the meter). Currently, there are three different prevalent AMI solution architectures. A utility may deploy one or more AMI solutions in its service area (illustrated in Figure (3-5)).

- **Direct Meter Connection (Figure (3-5) -A):**

In this approach, communication between each individual meter and the MDMS is carried directly over a communications network to the FAN (such as a 3G/4G wireless broadband connection, utility-owned wireless connections over licensed or unlicensed spectrum, and/or Gigabit Passive Optical Network — GPON— connection).

Power Line Communication (PLC) Neighborhood Area Network (NAN) (Figure (3-5) -B): In this AMI architecture, meters at consumer locations connected to a distribution transformer communicate with a meter data concentrator located near the distribution transformer. The data concentrator aggregates traffic from the individual meters connected to it and connects to the AMI solution´s head end over a FAN connection. On the other hand, the MDMS sends control signals to the head end to be forwarded to the meters.

Radio Frequency (RF) Mesh NAN (Figure (3-5) -C): An AMI solution over RF mesh uses wireless communication between the meters and a meter data concentrator over licensed or unlicensed spectrum. The meter concentrator is usually deployed at a substation. However, it is not necessary that the data concentrator support only the meters at the customer locations connected to that substation. Communication between a meter and the data concentrator goes over zero or more intermediate meters with each intermediate meter forwarding data received from its neighbouring meter(s) to another meter or to the data concentrator.

To extend the range of an AMI solution (and thus increasing the number of meters in the RF mesh), data forwarder elements may also be deployed on rooftops or poles, for example, as intermediate mesh nodes. Like the PLC AMI solution, the meter concentrator connects to the head end through the substation router or over its own FAN connection. A data concentrator in these solutions can support a large number of meters (up to 10 000 or more).

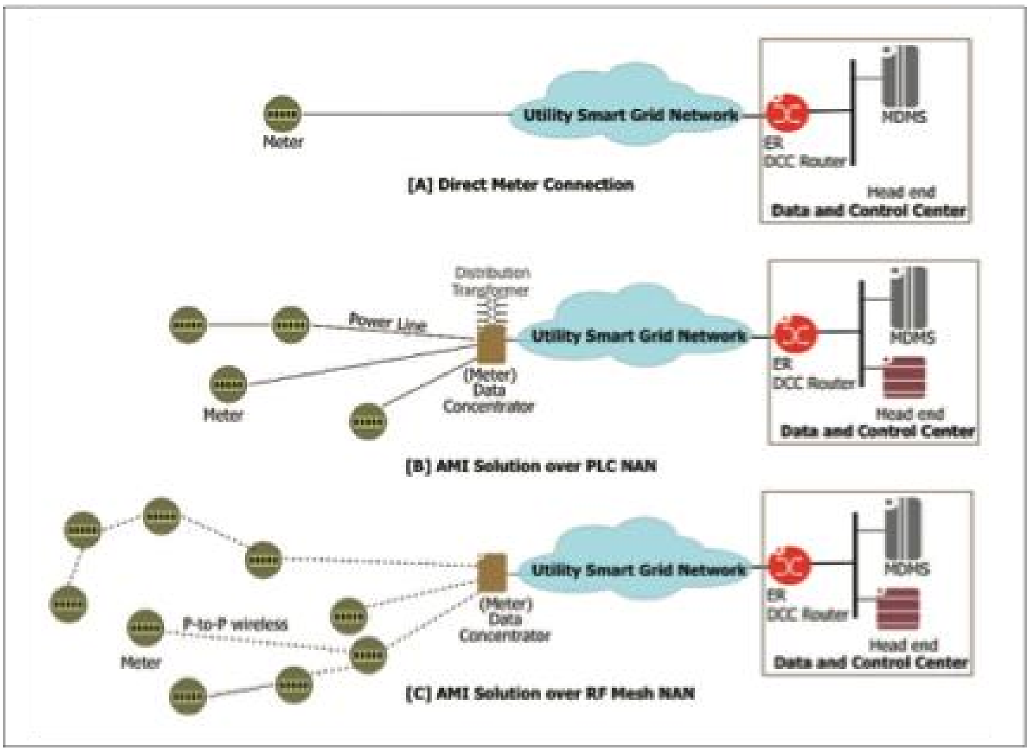


Figure (3-5) - AMI solution architecture

3-4-3- **Demand Response (DR)**

Demand Response refers to actions taken by a utility to adapt to changes in demand. Some DR methods, such as ADR, occur over the timescale of seconds. New Demand Response solutions require the deployment of new wireless infrastructure to facilitate the increase in generation, transmission, and/or distribution capacity.

Currently, ADR is most prevalently used for commercial and industrial (C&I) consumers. It is expected that use of ADR will be extended more prevalently to residential and small business consumers in the near future. In general, third-party data communication services or the Internet is used for ADR communication today. In the future, DR traffic will likely be carried over the Smart Grid communications network, possibly using the same links supporting communication between the utility's AMI solution the meter.

3-4-4- **Distribution Automation (DA)**

DA refers to monitoring and control of IEDs deployed in the utility distribution system outside of the distribution substation. These IEDs may be deployed at reclosers, switches, and capacitor banks installed along feeders (distribution lines) and possibly, in the future, at distribution transformers. The DA IEDs are assumed to use DNP3 to communicate with the DA control system in the DCC. We will refer to this control system as the DA Master. DA IED functions are similar to those of substation IEDs, possibly with larger interval between sending of the successive measurement+status message.

Each DA IED can connect directly to the DA Master over its individual FAN connection. An RF or a medium voltage PLC NAN can be used to connect the DA IEDs in a neighbourhood to a DA Data Concentrator, typically located at the distribution substation connecting the respective feeders. The DA concentrator, in turn, connects to the DA Master through the substation router or over its individual FAN connection.

3-4-5- **Distributed Generation (DG)**

Large-scale distributed generation (solar, wind, fuel cells, biomass and biogas, etc.) are an integral part of Smart Grid evolution. DG deployments that require monitoring and control by the utility generate network traffic. These DG sources will be equipped with IEDs. DG IEDs are assumed to use DNP3 to communicate with the systems in the DCC. The DG IED functions are similar to those of substation IEDs, possibly with larger intervals between successive measurement status.

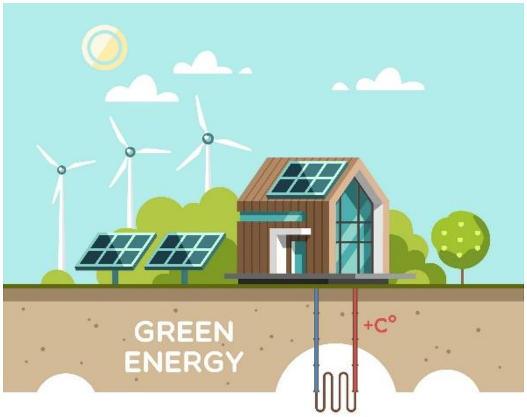


Figure (3-6) - Solar and wind generation

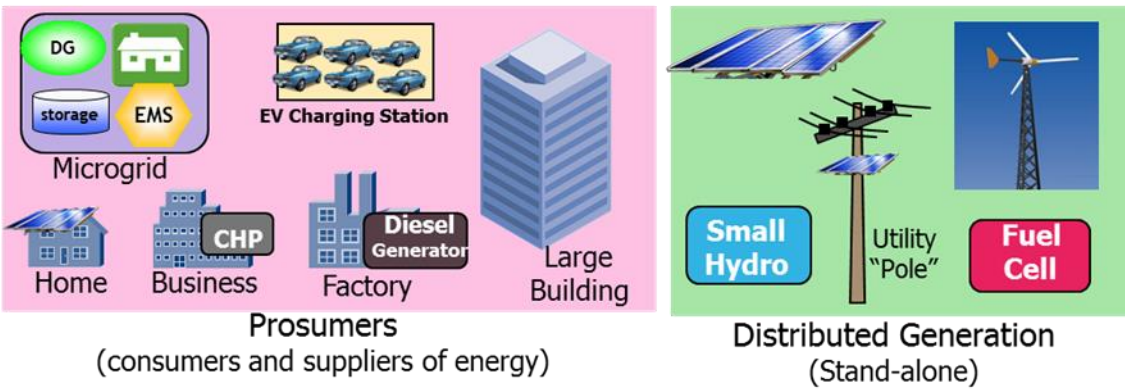


Figure (3-7) - Large scale distribution generation

3-4-6- **Distributed Storage (DS)**

In addition to electric energy storage necessary at many DG deployments to mitigate voltage transients, the utility may deploy stand-alone storage facilities such as large batteries, flywheels, super capacitors, and pumped hydro systems. For the purpose of traffic estimation, the DS IED characteristics will be assumed to be the same as those for the DG IEDs.

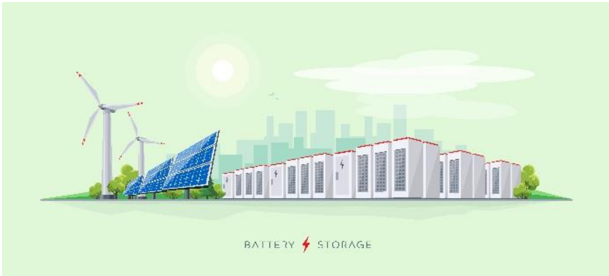


Figure (3-8) - Storage

3-4-7- **Electric Vehicle Charging Stations (EVCS)**

Electric Vehicle Charging Stations that allow EVs parked at the station to discharge energy from vehicle batteries into the grid (in addition to charging EV batteries) can be considered standalone DS deployments. For the purpose of traffic estimation, EVCS IED characteristics will be assumed to be the same as those for DG IEDs. Note that in addition to the periodic measurement+status traffic, there may be (asynchronous) traffic related to authentication (and billing-related) traffic between the EVCS and utility DCC for the vehicles parked at EVCS for battery charging and/or discharging.

Figure (3-9) - Charging station

3-4-8- **Synchrophasors**

Synchrophasors are Phasor Measurement Units (PMU) that measure electrical properties (voltages and currents) of their respective phasor components as well as other quantities (such as line frequency deviation). PMUs are special purpose, state-of-the art IEDs that report measurement+status at very short intervals (e.g. 60 or 50 times a second).
These reporting intervals are significantly shorter than the several second long intervals used by SCADA IEDs. PMUs are deployed at transmission substations (TSS). PMU measurements from transmission substations are collected and analysed to support wide area situational awareness and control of the regional power system. Each measurement+status message from each PMU carries a Global Positioning System (GPS)-derived timestamp. The North American Synchrophasor Initiative Network (NASPInet) is the first network deployed for Wide Area Situational Awareness in regions of North America. While Synchrophasor deployment is currently limited to transmission substations, their deployment at distribution substations (DSS) for management and control of distribution systems (including power quality control) is also possible in the future.

3-4-9- **Dynamic Line Rating (DLR)**

Increasingly, DLR systems are being deployed to monitor environmental conditions at transmission lines using IEDs deployed at or close to transmission towers. DLR IEDs measure ambient temperature, wind, solar radiation, ice accumulation, sag, and other parameters. By closely monitoring transmission lines, DLR helps utilities optimize power delivery and enhance operational safety. DLR IEDs are assumed to use DNP3 to communicate with systems in the DCC. DLR IED functions are similar to those of SCADA IEDs, possibly with a larger interval between sending of the successive measurement+status messages.

3-4-10- **Utility Engineering and Operations**

In addition to the periodic traffic and asynchronous control traffic between the sensors (IEDs, PMUs, or meters) and their respective operations and control systems at the DCC, other types of data transfer are required for operations and engineering needs. Examples of such data transfer include the retrieval of sensor data for analysis, software/firmware upgrades, remote programming, and configuration of sensors, and, in the case of meters, re-registration of meters after blackouts.

3-4-11- **Closed Circuit Television (CCTV)**

Utilities are increasingly deploying CCTV cameras at substations, DCCs, and other locations to support physical and operational security. Video feeds from cameras are typically stored in local Digital Video Recorders (DVR). At any time, several feeds are also streamed, as necessary, to the (security operations center within the) DCC. When required (such as during an incident at a substation), one or more live video feeds may also be uploaded to the DCC.

3-4-12- **Mobile Workforce (MWF)**

Utility mobile workforce requires ubiquitous voice and data communications. Conversational (person-to-person) voice communication between MWF personnel, as well as between MWF personnel and anyone outside the MWF is assumed to have the mission critical communication characteristics. Similarly, the “data” needs (including video) of MWF will be assumed to have the same characteristics. MWF frequently uses Mapping and Geographical Information System applications. Finally, MWF personnel may need to stream live video (from an MWF camera) during an incident.

3-4-13- **Teleprotection**

Protection relays in two transmission substations connected over a transmission line communicate with each other to detect faults. When a fault is detected, a control signal is sent to trip a circuit breaker. While a fault may be detected and circuit breaker tripped locally at a substation, in many cases, the tripping of a circuit breaker will be triggered by a remote substation. Teleprotection is a very critical application requiring very short communication delays (about 10 ms). Further, for high reliability, two independent connections are used to support communication between the relays. Teleprotection is also used between a DG, DS, and EVCS location and the connecting distribution substation. Protection relays at such locations communicate over a FAN. Teleprotection is typically only used at high capacity DG, DS, EVCS locations.

3-4-14- **Utility Business Voice**

The Smarter Electricity Network architecture of Figure (3-2) supports voice traffic for utility personnel located in business offices, field offices, and other sites as well as for MWF personnel. Support of voice communication over the smart grid requires the use of IP-based interfaces.

3-4-15- **Utility Business Data**

The Smarter Electricity Network architecture of Figure (3-2) supports business data traffic for utility personnel located in business offices, field offices and other sites as well as for MWF personnel. Business video traffic (including videos over the Internet or corporate intranet and video conferencing from user data devices) are considered as a part of the business data needs.

3-5- **Utilities Integrated Communications Network Architecture** [6]

Currently, communication network needs for most utilities are supported by disparate networks, each supporting a utility application such as SCADA, physical security (CCTV), or mobile workforce communication. With smarter electricity network evolution as well as the expected growth with a large number of new applications supporting a large number of endpoints, creation of a purpose-built network for each application cannot be sustained. It is extremely important that the utility ICT needs including that of connectivity to distributed generation are supported by an integrated network.

A practical, flexible, and scalable target communication network architecture supporting all smarter electricity network applications is illustrated in Figure (3-10) .

IP is assumed to be the underlying network protocol for the integrated network with support for connecting legacy endpoints and protocols (such as TDM) using tunnels, circuit emulation, and/or gateways.

Given the expanse of the utility service territory, the number of endpoints that need to be connected into the network, and since communications for most applications are predominantly between sensors and/or remote endpoints and the central application control or processing servers, an edge-core network architecture is preferred as illustrated in Figure (3-10) . Another important aspect of this architecture is traffic aggregation at intermediate points in the network rather than direct communication between the endpoints, thus facilitating ease of traffic routing, reliability, QoS implementation, and reduced costs.

To avoid complexity in the figure, not every possible application or network connectivity option is included in Figure (3-10) . In any case, the actual physical connections will be dictated by network design.

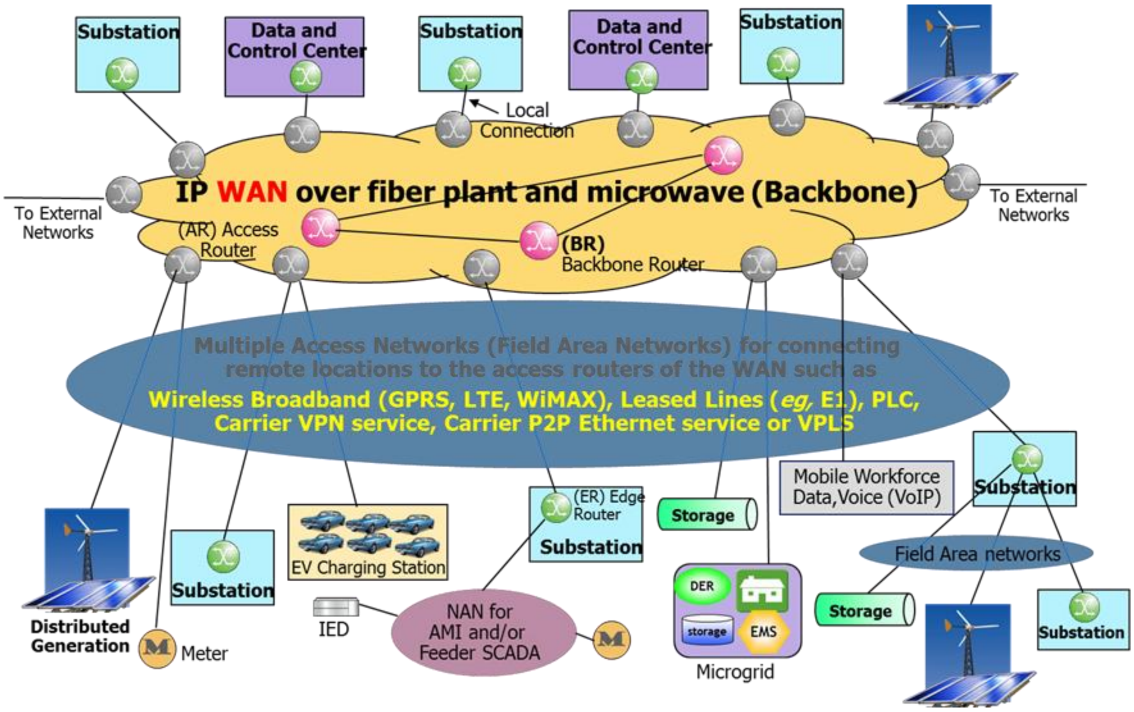


Figure (3-10) - Architecture for Integrated Communications Network for the Smart Grid

While the enterprise voice and data applications or utility enterprise offices are not included in Figure (3-10) , they can be easily supported by the architecture based on a utility's preference about integrating the OpTel and business applications on the same network.

3-5-2- **Traffic Aggregation at Network Endpoints**

An Edge Router (ER) at an endpoint location aggregates traffic from multiple sources and applications at that location. For a location with a single endpoint or only a few endpoints, there may not be an ER at that location that aggregates their traffic and these endpoints may be connected directly into the network. Depending on network design, an ER may also be used to aggregate traffic from other locations in the vicinity. For example, an ER at a (large) substation may aggregate traffic from other (smaller) substations as well as traffic from other locations in the vicinity, in addition to the traffic generated at that substation itself.

3-5-3- **Core Network (WAN)**

Depending on the network expanse and end points, the core network (sometimes called WAN – Wide Area Network) may vary from a single router up to a mesh of (redundant) interconnection of backbone routers (BR) and access routers (AR). ERs not connected to other ERs and endpoints not connected to an ER connect to the ARs for network connectivity. Based on the reliability requirement, an endpoint (such as the data and control center or a "important" substations may connect to two different access routers. An AR aggregates traffic to/from the endpoints that connect to the ARs, possibly through the ERs. The WAN must be a reliable network with very high reliability (eg, there must be at least two physical paths between every pair of ARs). For that purpose additional routers BRs may be deployed in the core network based on the network design.

Often, the core network will be close to the utility data and control centres as well as to the substations in metro areas. Thus some of the ARs may be collocated with these utility sites. For such a collocated site, its endpoints may connect to the corresponding AR over the LAN in that site. If required for redundancy, ER at this site may additionally connect to an AR at another location over a FAN.

Based on security policies and security designs, firewalls and IDS/IPS systems are deployed at ARs and BRs.

In many cases the WAN will be owned and operated by the utility but that may not always be the case. Even the utility-owned WAN may lease or share basic physical resources such as fiber plants and spectrum.

Optical fibre is used extensively in the majority of Europe's transmission system operator (TSO) companies. However due to the fact that they link the main electricity generators with the consumers centres, their capacity to contribute to distributed generation in medium voltage networks is limited.

Only a small number of distribution system operators (DSOs), mainly in Western Europe, have any substantial amount of optical fibre. Nevertheless most of them think they will need to install in the future as smart grids deploy, mainly in medium voltage networks. This will contribute to the deployment of highly reliable, cost efficient and secure networks.

3-5-4- **Access Networks (FANs)**

Access networks (often called Field Area Networks – FANs) provide connections between utility locations and the ARs. After presenting a brief overview of the wireline and wireless FANs, we present a few more details on the Power Line Communication (PLC) technology which is being increasingly used in smart metering access and being explored for deployment in FANs including connectivity to DG.

The utility may use multiple wireline and wireless technologies for FANs. The FANs may be owned and operated by the utility (self-provided) or service provider networks may be used as FANs. Wireline technologies may include PLC, private lines, Layer 2 technologies as Ethernet and Frame Relay, and MPLS VPN service. The wireless broadband technologies may include GPRS and HSPA with a migration path to LTE and WiMAX.

The mix of utility-owned and service provider network FANs depends on the service level agreements (SLA) provided by the service provider networks consistent with utility requirements, networking technology availability in an area, costs and other considerations. The choice of FAN technologies and ownership mix can evolve over time depending on the emergence of new technologies, utility access to spectrum, and network expansion with new applications and endpoin

While strictly not FANs, and based on AMI communication technology, local Neighborhood Area Networks (NAN) such as over 2.4 GHz or 900 MHz RF mesh over unlicensed spectrum or over PLC may be used for concentrating smart meter traffic at substations or near distribution transformers. The NANs may also be used for concentrating the SCADA traffic from the IED deployed over feeders to RTU/IED in the substation. Note that meters and feeder IEDs may also directly connect to the ARs, depending on the vendor product communication technologies.

3-5-5- **Power Line Communication**

Power Line Communication over the power lines themselves as communication medium has been in use since early 20th century, initially for voice communication. In the last fifty years or so, PLC was also used for low data rate communication over HV and MV lines for applications such as teleprotection and SCADA. PLC was not considered a useful technology by many for data communication because of its low range, susceptibility for interference with other communication applications, costly solutions to overcome the problem of communication through transformers (requiring coupling equipment to bypass transformers), and very low data rates.

However lately, PLC technology has taken its roots in smart grid evolution as one of two Neighborhood Area Networking (NAN) technologies for AMI. In the last several years, many countries (particularly in Europe) are looking to deploy PLC FANs connecting to DG, meter concentrators, and other smart grid endpoints. Many standards bodies and industry forums have developed and are developing standards for supporting PLC communication.

3-5-6- **Evolution of Substation LAN Architecture**

Currently communication within most substations is limited to SCADA. IEDs and RTUs in the substation use point-to-point communication between them, often through a “data concentrator”. Most protocols are proprietary. The SCADA communication link between the substation and the SCADA control center are often point to point TDM connections. If there are other applications located at the substations (such as teleprotection, synchrophasors, and CCTV), they each have a separate communication links to their respective counterparts.

The substation LAN evolution will be on two different levels. At one level, the substation architecture of the utility operations applications such as SCADA and teleprotection will evolve to the architecture specified in IEC 61850 standard. On another level, traffic generated by many new smart grid and other applications that will be resident at the substation such as the meter concentrators and CCTV will be aggregated at the substation router along with the SCADA and other operations traffic. The substation router is an ER in our integrated architecture of Figure (3-11) . The router at a (large) substation may additionally aggregate traffic generated in the vicinity of the substation.

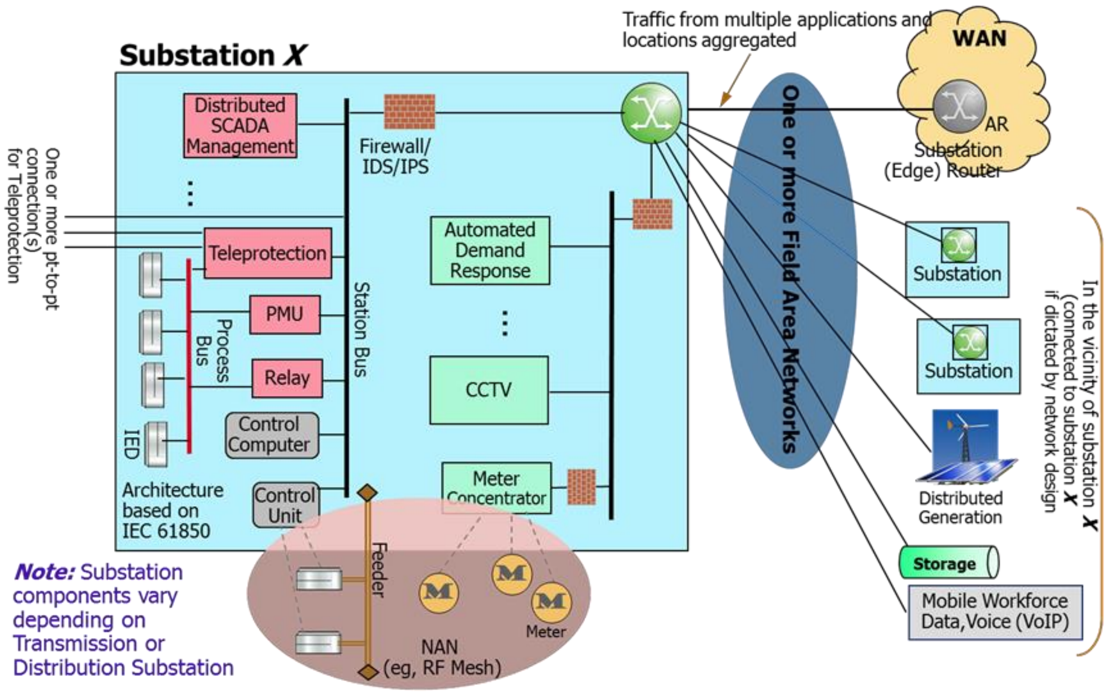


Figure (3-11) - Evolution of substation architecture based on IEC 61850 standards

IEC 61850 defines a *process bus* that is an Ethernet bus. All SCADA IEDs and optionally the teleprotection IEDs and PMUs connect to the process bus. For legacy equipment gateways may be used to connect into the process bus. There may be more than one process bus.

The *station bus* is used to connect the process busses as well as other operation systems such as the distribution automation traffic concentration from the feeder IEDs (if thus designed).

Access to all these operation elements is protected by protecting the station bus behind firewall and/or Intrusion detection and protection (IDS/IPS) systems.

The substation may use another Ethernet network for connecting other smart grid and utility systems such as the CCTV, meter concentrators, and demand response systems; access to these systems is protected by another firewall and/or IDS/IPS system.

Finally, the substation router aggregates all traffic generated at the substation and possibly traffic generated at (smaller) substations in the vicinity as well as traffic from other endpoints in the vicinity – examples of which are shown in Figure (3-11) .

Note that the utility may continue to use its existing TDM networks and/or possibly Ethernet connections for the teleprotection traffic. The teleprotection

traffic may not be carried over the IP network for a period of time.
Connectivity to home area networks (HAN) is an important aspect of smart electricity network evolution in actively incorporating the consumer in energy management. Depending on the utility policies, the home networks *may* be allowed to be a part of the utility's integrated communication networks either with the connection through the smart meter or through a "home gateway".
Utilities are implementing new systems to automate operations and enhance their monitoring and control capabilities. These systems support a variety of applications, including advanced metering, demand response, distribution automation, and wide area measurement, protection and control (WAMPC). Overall, these systems will improve operational efficiency, safety and reliability by extending communications further into the distribution network and improving their performance.
The network architectures for these systems are varied. Some utilities deploy networks using centralized network architecture, such as point-to-multipoint networks; while others rely on decentralized network architecture, such as mesh networks. There are also hybrid networks that include combinations of network architectures, as well. The FAN is expected to bridge the backhaul network to the field devices.
The Figure (3-12) below shows a combination of networks in a suburban configuration. A utility must manage the spectrum needs of its applications across the entire geographic footprint and account for the different device densities, geography, zoning regulations, and other technical and non-technical limitations [2].

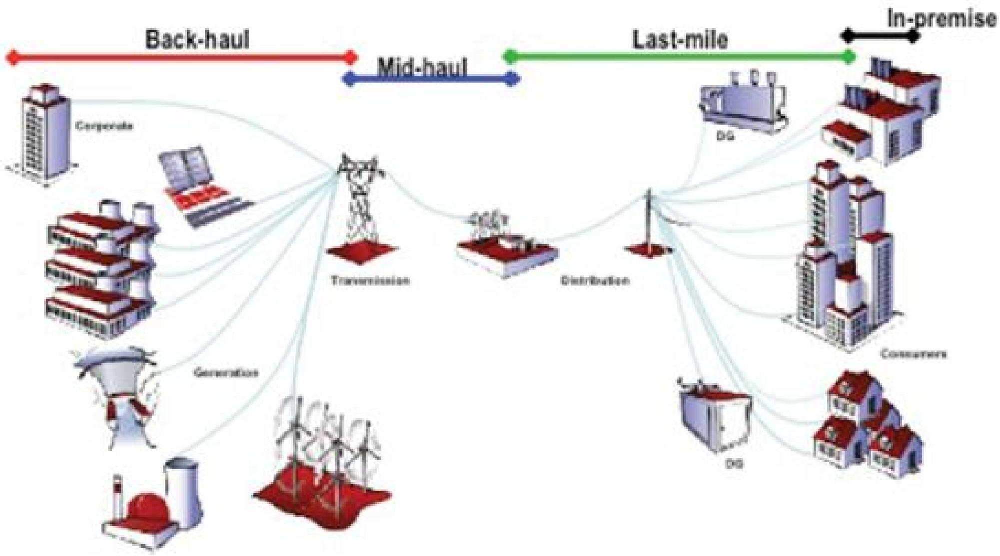


Figure (3-12) - Networks in a suburban configuration

In Figure (3-13) below, we have mapped how the smart network applications and communications technologies can be layered onto the different elements of the energy network physical infrastructure. The communication requirements applicable to generation, transmission, distribution and customer premises have some differences and these are explained in greater detail in the following section.

Figure (3-13) also illustrates how the communications layer elements, the wide area network, neighborhood and field area network and the home networks overlap the different power systems elements which make up the energy system.

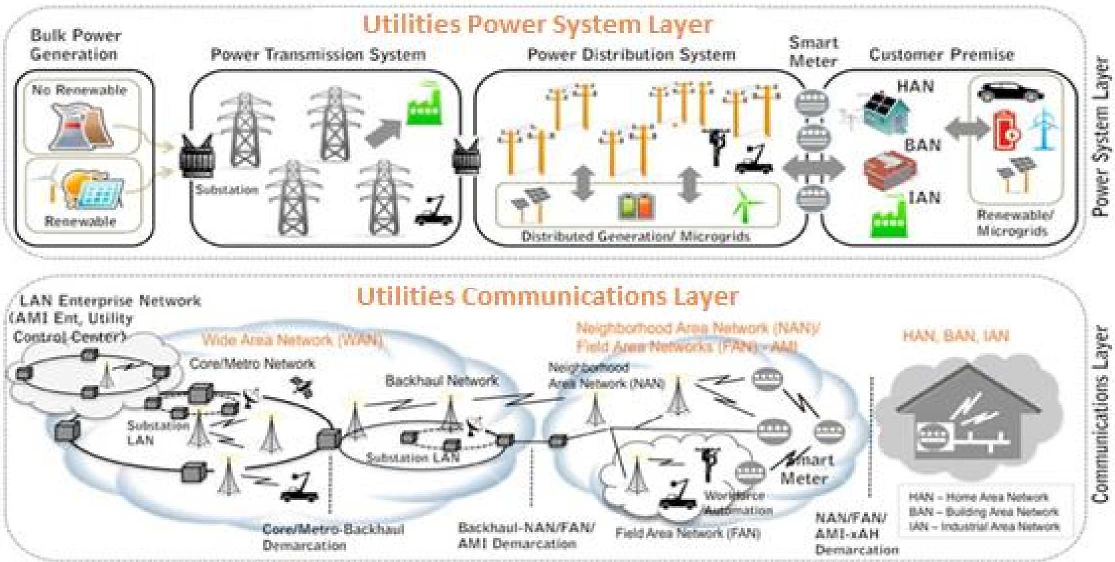


Figure (3-13) - Utilities communications physical architecture

There will be numerous applications, including several that require significantly greater bandwidth. While utilities may not implement all of these applications, they will need to design the FAN so that all of the applications that they do implement can be supported both now and, in the future, as demands increase. In addition, the network needs to be designed so that it is reliable and provides coverage and low latency to meet their functional requirements effectively. Flowing from the applications and their functional requirements, utilities may choose the network architecture that best supports their needs —and there are advantages and disadvantages to each.

3-6- **General technical and operational considerations of utility applications in the Land Mobile Service**

Utility systems are characterized by high reliability, high availability and low latency. Utilities typically operate their own operational communications networks in order to ensure communications reliability during extended power outages or other situations when public commercial communications networks may become affected. They also communicate in areas that commercial communications networks do not cover but where utilities may have critical assets, such as remote areas where generation or transmission infrastructure is located.

Finally, radiocommunication systems supporting utilities may need to support communication with very low latency, depending on the type of utility application. This is necessary in order to isolate a fault before it causes a widespread outage. Hence, radiocommunication systems used for utility communications can be characterized as highly reliable, available, and operate at low latency.

As utilities implement grid modernization more densely and deeper into their infrastructure, their communications networks are expected need additional capacity and coverage as they shift towards two-way, real-time communications systems that would provide increased control, for example, to turn on/off systems remotely, automatically and dynamically without the need to send out a truck to manually reclose circuits, or when breakers have tripped for example. Moreover, those communication networks will be used to automatically detect a power outage and restore power instantly where, for example, a tree has fallen across a power line or a power transformer has failed. This kind of automation would benefit from additional capacity and coverage functions that would be provided by certain types of radiocommunication systems.

3-7- **Utility Communications Requirements**

Utility systems are characterized by high reliability, high availability and low latency. Utilities typically operate their own operational communications networks in order to ensure communications reliability during extended power outages or other situations when public commercial communications networks may become adversely affected. This includes extended back-up power and diverse and redundant routing of backhaul communications networks at every wireless site. They also communicate in areas that commercial communications networks do not cover but where utilities may have critical assets, such as remote areas where generation or transmission infrastructure is located.

Utilities communicate with very low latency, depending on the type of utility application as low as 20 milliseconds or less. Some applications, as teleprotection and synchrophasors, needs extremely low latency services to prevent faults on the grid from cascading and causing widespread outages and/or safety issues. Hence, utility communications networks can be characterized as highly reliable, available, and operate at low latency, as shown in the Figure (3-1) below.

As utilities implement grid modernization more densely and deeper into their infrastructure, they are expected to need additional capacity and coverage as they shift towards two-way, real-time communications systems to provide increased control to turn systems on and turn off remotely, automatically and dynamically without the need to send out a truck and manually reclose circuits when breakers have tripped. Moreover, they will be able to automatically detect a power outage and restore power instantly by rerouting it, instead of having to attempt to triangulate a power outage based upon customer calls that a power outage has occurred and then sending a truck into the area to determine the exact location where a tree has fallen across a line or a transformer has failed. All of this automation would benefit from additional capacity and coverage. Ensuring that these systems are secure and can be delivered in a cost-effective way is a high priority within the industry.

Table (3-1) - Smart network communications parameter

Smart network communications parameter matrix				
Smart network sub-system	Coverage	Reliability	Latency Time	Security
Meter reading - AMI	Medium	Medium	High	High
Field area network	High	High	Medium	High
Phase measurement	Medium	High	Low	Medium
Teleprotection	Medium	High	Low	Medium

Finally, some of smart grids is that the key characteristics the operational communications components of utility networks are highly ruggedized for extreme conditions within the substation environment and have traditionally used extended depreciation cycles; so that the equipment must last for an extended period of time. These key characteristics to maintain utility networks and their functions are detailed in Table (3-2) below.

3-7-2- **Communications Requirements of Smart Grid Communications Technologies**

Table (3-2) - Network requirements

Application	Bandwidth	Latency	Reliability	Security	Backup Power
AMI	10-100 kbps/node, 500 kbps for backhaul	2-15 sec	99-99.99%	High	Not necessary
Demand Response	14 kbps- 100 kbps per node/device	500 ms-several minutes	99-99.99%	High	Not necessary
Wide Area Situational Awareness	600-1 500 kbps	20 ms-200 ms	99.999-99.9999%	High	24 hour supply
Distribution Energy Resources and Storage	9.6-56 kbps	20 ms-15 sec	99-99.99%	High	1 hour
Electric Transportation	9.6-56 kbps, 100 kbps is a	2 sec-5 min	99-99.99%	Relatively high	Not necessary

	good target				
Distribution Grid Management	9.6-100 kbps	100 ms-2 sec	99-99.999%	High	24-72 hours

Getting the data from field devices to the electric utility's back office system, or getting commands to devices from back office systems, relies upon a secure, reliable network covering a geographical footprint that can vary from dense urban areas to remote locations with virtually no population. This data is often critical in managing the power system. Simultaneously being able to respond to events via central commands adds to the complexity needed to manage the communications network. Thus, the network needs to be able to support the increased bandwidth requirements, as well as ongoing wide-area coverage and low-latency communications requirements necessary to effectively monitor and control operations.

3-7-3- **Operational Requirements for Modern Utilities**

Utilities around the world use communications networks in their operations to support the safe, secure and reliable delivery of essential electric, gas and water services to the public at large. Such operational communications networks facilitate utility networks and are desired to be resilient with low latency to enable the use of certain utility applications.

Utilities use wireless technologies, for voice, control and data communications to support the operation of their critical systems. However, as described more in details below, a wireless solution would need to support the ever-growing demand for the utilities services and certain performance characteristics associated with utility's system availability, operation and management, (e.g. performance requirements for smart grids).

Non-wireless telecommunications alternatives may be impractical for many applications that would need wide service area coverage and low-cost implementation. For example, it is usually difficult to enable fibre and wired technologies for millions of smart grid devices, many of which may be located in remote and otherwise inaccessible areas across the wide service area of a utility.

Suitable communications technologies can enable more efficient management and control to flow of energy onto the distribution infrastructure. Some utilities are also implementing newer distribution automation technologies thereby enabling utilities to maintain power resilience and restore power more quickly after an outage and protect the utilities' critical assets against physical and cyber-attacks. These are just some of the utility applications that are creating additional demand for new wireless communications capacity and coverage.

3-7-4- **Utility Operational Standards and Functional Requirements**

Utilities utilize highly reliable and resilient communications in order to ensure operational safety, reliability and security of the underlying electric, gas and water services that they support.

This includes extended back-up power and diverse and redundant routing of backhaul communications networks at every wireless site. In addition, energy networks utilize extremely low latency services in order to ensure that utility tele-protection systems and synchrophasors operate to prevent faults on the grid from cascading and causing widespread outages and/or safety issues. Ensuring that these systems are secure and can be delivered in a cost-effective way is becoming a high priority within the utilities industry. Finally, some of the key characteristics the operational communications components of utility networks are highly ruggedized for extreme conditions within the substation environment and have traditionally used extended depreciation cycles; so that the communications network devices must last for an extended period of time. These are the key characteristics to maintain utility networks and their functions.

3-7-5- **Utility Radiocommunication Systems**

These systems support voice applications, such as routine dispatch and emergency restoration, and for data applications, such as supervisory control and data acquisition (SCADA), distribution automation (DA) and advanced metering infrastructure (AMI). Collectively, these systems comprise the [field] area network, and they are characterized by wide area coverage, high reliability and availability, and redundancy/resiliency. Details of communication systems supporting those applications are described in Report **ITU-R M.2014** Digital land mobile systems for dispatch traffic and Report **ITU-R SM.2351**.

While utilities also use fixed wireless access systems that provide point-to-multipoint communications with high capacity backhaul that operate across different platforms, access to higher capacity licensed in the mobile service could be better suited to offer wide area coverage, not just on a point-to-point or point-to-multipoint basis.

Many of the applications considered in the proposed draft new report would be accommodated under fixed service, but there are other applications that could also be accommodated under mobile service, as well.

Utility grid modernization represents a fundamental change in the way that utility networks currently operate; for example, dynamically responding to an isolated fault and rerouting power before it leads to a widespread and extended outage or anticipating the fault before it occurs and changing out a transformer before it fails. In addition to fixed operations for intelligent electric devices on the grid, grid modernization also envisions mobile data applications to trucks and personnel so that they can access files with information about utility infrastructure as they are restoring power and then communicate back remotely to the utility when the work is completed, and power has been restored. Such developments could dramatically reduce the time it takes to restore power and improve the safety and efficiency of operations overall.

Grid modernization depends on the underlying communications systems that would support the operational requirements for this modernized grid.

3-8- **Spectrum Related Aspects**

The key ingredient to maintaining these Smarter Utilities Networks is radio frequency spectrum. Energy and water providers use spectrum in various bands to operate mission-critical functions like Supervisory Control and Data Acquisition (SCADA) systems that are used to manage industrial control systems such as electric grids, protective relaying and smart grid applications. Additionally, utility workers use mobile radio devices to communicate when repairing lines or restoring service after an outage. The inability of utility personnel to communicate in the field could have catastrophic consequences for utility employees and public safety. The regulatory agencies are responsible for allocating commercial spectrum. Energy and water providers understand that spectrum is a finite resource, and the regulatory bodies have the task of allocating and expanding access to spectrum in ways that promote wireless deployment, but do not harm incumbent existing spectrum license holders. Given the criticality of energy and water providers to the nations wellbeing, spectrum policies implemented by governments should reflect this reality.

[In order to provide additional capacity and cost-effectiveness, utilities would benefit from access to wideband spectrum with channel sizes of 200 kHz or more in a frequency range below 2 GHz to provide favourable propagation and to avoid line of site issues, such as trees and buildings that can degrade or block services in higher frequency bands. Finally, to maintain low latency, high reliability communications would benefit from access to existing spectrum bands that are not subject to interference to avoid complex and costly operational communications networks.

While some applications are non-mission critical and can be supported using unlicensed spectrum, many of the applications must meet higher standards for reliability and latency due to their impact on operational safety and security – and will demand access to licensed spectrum, which is generally less susceptible to interference, operates at higher power and provides greater overall reliability. However, certain applications require greater bandwidth than can be supported using available licensed spectrum. For these applications, access to licensed spectrum with greater bandwidth is necessary to support increasing communications requirements.

3-8-1- **Utility bands and applications**

Utilities operate fixed and mobile systems in various land mobile bands, and they use these systems to support various voice and data applications. Specifically, some utilities operate systems within portions of the 137-512 MHz frequency range, as well as 800/900 MHz land mobile bands. These systems support voice applications, such as routine dispatch and emergency restoration, and for data applications, such as supervisory control and data acquisition (SCADA), distribution automation (DA) and advanced metering infrastructure (AMI). Collectively, these systems comprise the field area network, and they are characterized by wide area coverage, high reliability and availability, and redundancy/resiliency.

Utilities also use license-exempt spectrum to provide additional capacity. While utilities also use microwave for point-to-point and point-to-multipoint communications that provide high capacity backhaul, access to higher capacity licensed land mobile spectrum could be better suited to offer wide area coverage, not just on a point-to-point or point-to-multipoint basis. It should be noted that licensed-exempt and fixed microwave spectrum bands are already well-understood and used by utilities and which have inherent limitations in terms of coverage and reliability.

Many of the utility applications considered in this document are fixed, but some utility applications also are mobile. The fixed applications include remote terminal units and other devices that operate across utility transmission and distribution networks; and unlike older one-way relatively slow speed devices that utilities have used in the past, these devices enable two-way, real-time communications that would provide utilities with much better visibility and control over their entire critical infrastructure delivery networks.

Utility grid modernization represents a fundamental change in the way that utility networks currently operate; for example, dynamically responding to an isolated fault and rerouting power before it leads to a widespread and extended outage or anticipating the fault before it occurs and changing out a transformer before it fails.

In addition to fixed operations for intelligent electronic devices on the grid, grid modernization also envisions mobile data applications to trucks and personnel so that they can access files with information about utility infrastructure as they are restoring power and then communicate back remotely to the utility when the work is completed, and power has been restored. Such developments could dramatically reduce the time it takes to restore power and improve the safety and efficiency of operations overall.

Grid modernization depends on the underlying communications systems, which in turn are dependent upon access to sufficient and suitable spectrum, particularly for field area networks.

3-8-2- **Shared use of existing bands**

The intent here is to make more effective use of existing land mobile service spectrum bands without disrupting incumbent operations (e.g. neither by interference nor relocation). Instead, by sharing existing bands the spectrum could facilitate more timely access to spectrum.

In addition, sharing the existing bands could open up the potential for the development of shared systems that could allow existing passive network infrastructure, such as sites and active components such as fiber connectivity to be exploited thus reducing overall costs relative to operating separate networks.

Research of current uses for international electricity, gas and water utility communication systems has identified a typical common set of spectrum characteristics as shown below:

- VHF spectrum – for resilient voice communications and distributed automation for rural and remote areas.
- UHF spectrum for tele-protection, control, automation and metering.
- Lightly regulated or deregulated shared spectrum for smart meters.
- L-Band for more data intensive smart grid, security and point-to-multipoint applications.
- Public microwave and satellite bands for access to the core fiber networks of utilities or strategic backhaul.
- Although utilities make extensive use of copper and fiber based communications systems – and in the case of electricity, communicating down the electrical supply cables in some instances, radio also plays an essential role. Radio is valuable in this role because:
- the communications network can be independent of the assets being managed;
- radio is flexible and can be deployed more quickly than fixed assets;
- if radio services are interrupted, they can usually be restored more quickly than wired systems; and
- radio is more cost effective in many applications.

Radio systems need spectrum in which to operate. Some services may be able to operate in license-exempt bands designed for short range devices (SRDs), but no protection is available for services in unlicensed bands if they suffer interference. For greater certainty of communication and protection from interference, licensed spectrum must be obtained.

Systems that could allow existing passive network infrastructure, such as sites and active components such as fibre connectivity to be exploited thus reducing overall costs relative to operating separate networks or deploying new systems.

- **Suitable radio spectrum**

Radio spectrum is undeniably important to running a Smarter Electricity Network. Smarter Electricity Networks will require communications as much as computerization to successfully monitor and control the electricity network and provide communications for personnel working on the grid.

Smarter Electricity Network communications are necessary for the day-to-day functionality and the administrative savings to be made, UTC citing regular functions in the Critical Infrastructure Industries (CII) as ‘voice and data, mobile applications, monitoring and control of remote facilities, the extension of circuits to areas unserved by commercial carriers, security, video surveillance and emergency response. Furthermore, the communications are highly valuable during a crisis.

In Europe, the European Utility Telecom Council (EUTC) is proposing a portfolio of spectrum to address utility requirements, including a total of 16 MHz of licensed spectrum in the vital 400 MHz to 3 GHz space. Canadian utilities have been granted access to 30 MHz of spectrum in the band 1 800-1 830 MHz for intelligent electricity networks.

It has been estimated that the functionality of the Smarter Electricity Network could be facilitated within 20 MHz of spectrum, utilizing 4G technology. It has also been suggested from industry that this could be allocated to ‘Utility Radio Operations’. Similar to radio astronomy, maritime and aeronautical, this would be a designated range of spectrum reserved for the use of utilities companies. The benefit of such an allocation would be that utility companies could build interoperable communications to industry standards and not have concerns about 3rd party management. This provides a guarantee that will allow companies to make efficient investment decisions in appropriate technologies by removing the uncertainty in current spectrum-based planning.

Current policies in the US have moved to expand the amount of spectrum made available to digital data, following the launch of 4G public communications networks and plans for high speed internet. In recent developments policy makers have proposed to auction a significant amount of spectrum, around 500

MHz, for use by the digital data community. Whilst considerations have been made for first responders in the 700 MHz band, no such plan has been made for utilities.

- **The Case for Sharing Spectrum**

An alternative to using dedicated spectrum for private networks would be for utilities to share spectrum with other network users. A solution such as this would alleviate the issues around finding spectrum n and the difficulty for utilities to compete for access to spectrum at auction. However, sharing spectrum involves some trade-offs, because utilities would no longer solely control the network, and that may limit functionality and degrade the quality of service.

- **Commercial Network Providers**

Another alternative would be for utilities to approach a commercial carrier to manage their utility telecommunication networks. Commercial providers would aim to reduce the cost of building and maintaining the network. While reducing the cost would be a benefit, key issues face commercial providers about the quality of service they would be able to provide.

Firstly, the utility networks need to provide full coverage of their asset base with 99.999% availability, something that has proven to be commercially unviable for public mobile. Current utility networks are built to cover the entire geographic area with overlap redundancy, power redundancy, strict maintenance schedules and emergency group talk functions. Despite the poor financial case, a commercial provider would have to provide a network that fulfilled all of these criteria. As such, a commercial provider is unlikely to be able to provide the same quality of service at a reduced cost.

Another issue is interoperability during adverse conditions. Maintaining and re-establishing communications during crises has always been fundamental in recovery plans for utility providers. The recent emergence of a report by the FCC on the impact of the June 2012 Derecho casts a certain amount of doubt as to whether commercial operators would provide sufficient resilience.

While commercial operators may be able to reduce the costs associated with building a network, the evidence suggests that this is at the expense of the quality of service. While sufficient for commercial operators, it is unlikely to be acceptable to support utilities.

3-8-3- **Socio-economic benefits [5]**

In 2011 UTC/European UTC and JRC UK carried out a study to assess the socio-economic benefits of utilities use of radio spectrum to support the complex smart networks of the future. The Executive Summary of the report is included here for information [5].

- When commercial entities are faced with decisions on whether or not invest in assets, their decisions are based purely on an economic assessment of the value of such assets to the entity. Where those assets also have a social value, it is for society, through the proxy of government, to assess any additional societal benefits and attribute a financial value to them.
- Public safety organizations and elements of the critical national infrastructure have traditionally used radio communications to underpin their operations. The allocation of this spectrum has historically been made by governments who have implicitly taken into account the socio-economic value in making allocations of spectrum to these sectors.
- With the modern tend towards the application of market mechanisms for the award of spectrum to all entities, including the public sector, utilities will assess the economic value of radio spectrum to them in judging the amount of money to commit to spectrum access in any competitive award process, and the associated business risks. Any societal value will thus be ignored.
- The purpose of this study was to investigate whether there might be an element of socio-economic value attributable to radio spectrum deployed by utilities in the conduct of their business; and if this is the case, to place an indication of the amount of socio-economic value which might thus be overlooked if an award is made purely on the basis of the economic value of the radio spectrum to the utilities concerned.
- There are limitations due to the sources of data used in the report. The data is mainly based around research in the UK and USA and relates to power interruptions to electricity networks stretching back several decades in some cases.
- More study is required on the socio-economic value of radio spectrum used to support utility operations in Europe. This new study should look

forward to valuations based on Smart Grid Deployment to facilitate renewable energy generation, greenhouse gas reduction and enhance security of supply.

- On the basis of the available data, the report concludes that the societal benefit of spectrum used by the electricity industry to ensure reliable operation of the electricity supply network may have a societal benefit 50 to 150 times the economic value of the electricity itself.
- Within the resources available for the study, it has not been possible to produce equivalent figures for the gas and water utilities, although it is probable that a similar situation pervades these industries. The impact of disruption to these industries is most probably at the lower end of the multiplier ratio due to much less economic impact from disruption to gas and water supplies, although the social impact of loss of gas and water may be greater under certain climatic conditions.
- On the basis of the analysis of this report and work in the USA, radio regulatory authorities should review their spectrum allocation mechanisms to ensure that this socio-economic value of spectrum is not overlooked when formulating spectrum policy. This becomes especially important as utilities face challenging energy policy objectives and apply innovative ICT solutions to the networks to benefit European citizens, commerce and industry.

3-9- **Conclusions**

In conclusion, it is critical for policymakers and utilities to understand the enormous amount of data that Utility Communications Networks will need to carry in order to enable the vision of the next generation utility network. There will be numerous applications, including several that require significantly greater bandwidth. While utilities may not implement all of these applications, they should design theirs network so that all of the applications that they do implement can be supported both now and in the future as demand increase. In addition, the network needs to be designed so that it is reliable and provides coverage and low latency to meet their functional requirements effectively. Flowing from the applications and their functional requirements, utilities may choose the network architecture that best supports theirs needs – and there are advantages and disadvantages to each. Thus, different utilities have deployed different network architectures and have gained lessons learned along the way. Key issues going forward include the need for radio spectrum to support these various network architecture and standardization/interoperability of utility networks – which must be addressed in order to ensure operational safety, reliability and efficiency.

To recap, the utilities services network, including the field area network (FAN), bridges the gap between energy consumers and energy providers by connecting monitoring and control technologies with robust command, control, and information processing enterprise applications. There is no single reference design for a FAN: the technologies cover a wide range of radio spectrum and designs philosophies, from mesh to star to hybrid. The choice between licensed or unlicensed technology is made based on traceable requirements, as is the one between private or public network infrastructures. There is little doubt that the multitude of new smart electricity applications will require greater use of radio spectrum, whether in existing frequency bands or in new allocations of different frequency bands.

Interoperable systems and their benefits to society can be seen in many of today´s technologies, including the IEEE 802.11 family of Wi-Fi products and the IEEE 802.15 family of Bluetooth products. The utility industry and the smart electricity networks have not reached this level of interoperability, though frameworks and standards are being refined daily. Before a utility assumes a vendor´s claim of interoperability for smart electricity products, the vendor should demonstrate test results that confirm any claims. Many vendors will not be able to meet this requirement at this time, as smart electricity device testing for interoperability is in its infancy. In some instances, the utility´s one choice is creating its own test facilities.

Utilities that were early adopters of smart electricity applications and FAN connectivity are providing valuable insight from their experiences that should be leveraged by subsequent adopters. The industry learned that smart grid applications have a wide range of system requirements in the amount of data to be transmitted and the speed at which the data received and acted upon. Network designers must be familiar with detailed use case information in order to plan traffic load. The use cases must include normal, start up and emergency

modes. RF modelling prior to final design and purchase decisions, often complex and tedious, is key to understanding the day-to-day operation of these systems. While no single network design will meet all requirements for the industry, let alone a single utility, the technologies are maturing and real world experiences is being added into current standards activities.
Smart electricity applications are presented in a number of categories and the requirements of each of the categories are discussed. The backhaul FAN is critical in overall smart grid performance and this document includes a discussion of backhaul, the use of commercial or private back haul options and some guidelines for making these choices. Standards continue to play a role on FAN designs and a discussion of standards, a few examples of standard families are provided. Finally, a wireless FAN relies on radio spectrum, so a summary of spectrum options is also included.
There are different architectures, each with advantages and limitations. The design of the FAN communications network to support day-to-day grid operations must be completed with the same amount of care and diligence as the grid itself. The utility creates its vision of the smart electricity networks by selecting which applications to deploy. These applications have use cases that must be clearly understood. Use cases lead to FAN architecture options and ultimately data throughput needs. Data throughput will determine spectrum requirements and the choice between licensed and unlicensed spectrum. The bandwidth requirements are going to be different for each technology, depending on the applications and the functional requirements for those applications.
Finally, given the critical nature of electric utility services, providers must make complex and sophisticated choices regarding the communications networks over which the various applications can run. Without flexibility to choose the nature of the technology and the structure of the networks, the continued stability of the power grid will be compromised. These choices are also influenced by the size of utilities and their consumers. Some smaller distribution utilities, for example, may consider reliance on commercial networks a necessity, due to their size, staffing requirements and trade-off between reliability and cost.
Table (3-3) and Table (3-4) on the next pages illustrate the types of applications that can and cannot be supported using commercial networks based on their latency and relative priority requirements. For example, teleprotection

applications, such as breaker reclosers and PMUs, which have extremely low latency and relatively high priority requirements, cannot generally be reliably supported using commercial wireless broadband networks. However, advanced metering and some monitoring applications, such as AMI periodic measurements and fault recordings, could potentially be supported over existing commercial networks [2] [6].

Table (3-3) - Application latency requirements

Application	Minimum Delay Allowance (ms)	Priority: 0 = Max to 100 = Min	
Delay ≤ 10 ms			Extreme reliability and delay requirements that Broadband Wireless will not support for awhile
(High Speed) Protection Information	8, 10	2	
Load Shedding for Under Frequency	10	20	
10ms < Delay ≤ 20 ms			
Breaker Reclosures	16	15	
Lockout Functions	16	12	
Many Transformer Protection & Ctrl Apps	16	12	
System Protection (PMU)	20	12	
20 ms < Delay ≤ 100 ms			Applications that can be supported over a Private Broadband Wireless Network
Synchrophasor Measurements (Class A)	60	10	
SCADA Data Poll Response	100	25	
PTT Signaling (critical)	100	30	
PMU Clock Synchronization	100	20	
100 ms < Delay ≤ 250 ms			
VoIP Bearer (inc. PTT)	175	50	
VoIP Signaling (inc. PTT – normal)	200	60	
Dynamic Line Rating (DLR)	200	40	
Real-time Video (mobile WF)	200	55	
On Demand CCTV video	200	55	
Other SCADA Operation	200	45	
Enterprise Data – Preferred	250	70	
Most Distribution and SCADA Apps.	250	65	
AMI – Critical	250	60	

Traffic for these applications is only between two substations connected with transmission line. This traffic must be designed to be only single hop. Thus, the corresponding delay requirements must be considered only single hop. All other delay requirements may have to be satisfied over multiple network hops.

Table (3-4) - Application latency requirements (cont.)

Application		**Minimum Delay Allowance (ms)**	**Priority: 0=Max to 100=Min**	
	250 ms < Delay ≤ 1s			
AMI – Priority		300	70	Applications that can be reasonably supported over current carrier networks (leased capacity)
CCTV Stream – Normal		400	75	
PMU (Class C)		500	80	
Some Transformer Protection & Ctrl Apps		500	80	
Enterprise Data - Other		500	80	
	1 s ≤ Delay			
Image Files		1 000	90	
Fault Recorders		1 000	90	
(Medium Speed) Monitoring and Ctrl Info		1 000	90	
(Low Speed) O&M Info		1 000	90	
Fault Isolation and Service Restoration		1 000	90	
Distribution Applications		1 000	90	
AMI Periodic Measurements		1 000	85	
Text Strings		1 000	90	
Audio and Video Data Streams		1 000	78	
Fault Recorders		1 000	90	
Best Effort, Default		2 000	100	

Traffic for these applications is only between two substations connected with transmission line. This traffic must be designed to be only single hop. Thus, the corresponding delay requirements must be considered only single hop. All other delay requirements may have to be satisfied over multiple network hops.

Chapter 4: Household Consumption

4-1- **Introduction**

This chapter examines the household consumption and energy consumption used in this study.

4-2- **Household Consumption**

World energy consumption is experiencing an increasing trend in recent years. This growth in consumption concerns all economic sectors from Industry, to Commercial as well as Residential one. Focusing on the Household sector, between 1990 and 2004, total final energy use rose by 14% in the 15 IEA countries[7]. As we can see the increase in the population is slower than the one of final energy use, which highlights the growth in energy use per capita (4%). Furthermore, CO_2 emissions also increased by almost 14% during the same period. This growth is certainly influenced by the increasing dependency of households on electric appliances such as TVs, personal computers, communication devices and air conditioners. Indeed, the electricity use for appliances in the residential sector of the IEA15 grew 48% from 1990 to 2004 [7]. However, there are other factors that influence this growth such as weather conditions, population age and density. Furthermore, another important reason is the ineffective use of appliances: for example, keeping devices in standby-mode, instead of switching them off, or putting hot or warm food into the fridge, which causes a lot of wastefulness and unnecessary electricity consumption. These results highlight the need for improvement in energy efficiency solutions to better utilize the energy in the household sector and reduce overall energy consumption.

4-2-1- **Household consumption in a Smart Grid**

Today the electric utility mostly uses Flat Pricing methods that adopt a fixed price for electricity consumption and do not take into account the actual electricity price. In this way customers are unaware of their total energy use and are not stimulated to reduce their consumption. With the evolution of the power grid into a Smart Grid and with the deployment of new technologies such as AMI equipment, the consumer is more involved, and their active participation is possible. With the purpose to reduce the overall electricity consumption and the resulting carbon emissions, the electric utility developed Demand Response programs. Demand Response provides electricity prices and other information to consumers, in order to encourage them to reduce their electric consumption if the situation so requires.

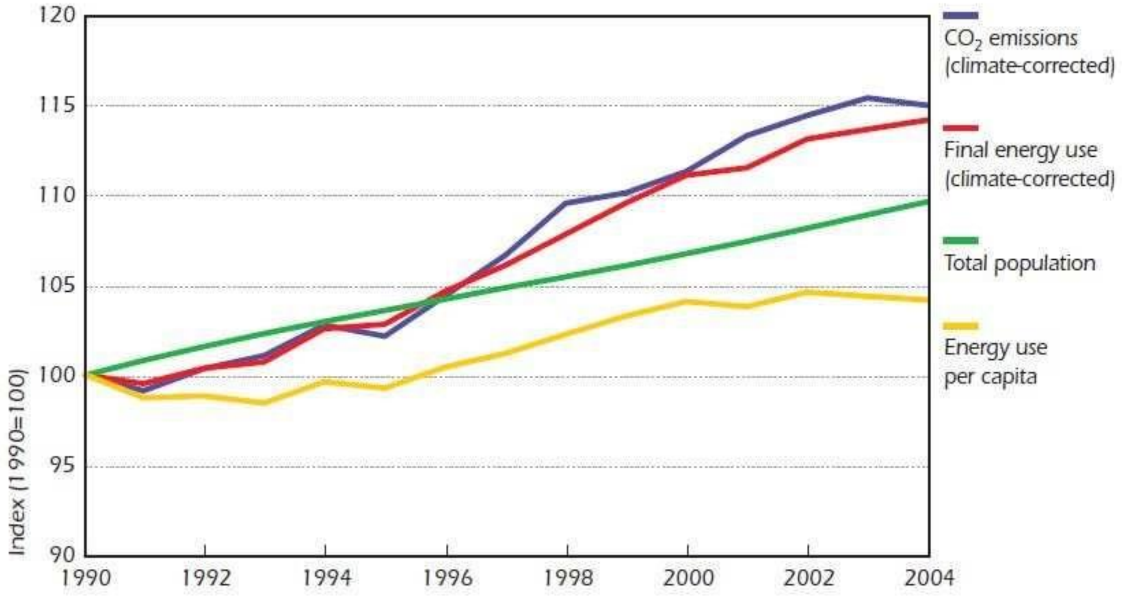


Figure (4-1) - Key trends in the Household sector [7]

- **Challenges of Demand Response in the Household sector**

Unfortunately, even if several Demand Response strategies have been implemented, a lot of barriers prevent their fulfilment. In [8] we can find a classification of the main challenges of DR. The classification includes three groups of barriers: the structural ones, those related to consumer and those related to producer. We briefly review those consumer's challenges most related to the residential case which is the main focus of this work:

4-2-2- **Household consumption in a Smart Grid scenario**

1. Consumer knowledge. Many people have very limited knowledge about

their usage patterns and about the electricity market. This lack of awareness made difficult to implement DR programs.

2. Availability of technology. DR programs needed to monitor the consumer's electricity consumption to measure the amount of reduction to properly reward or penalize them. Enabling technologies such as smart meters are indispensable for this purpose.
3. Information feeds. Not only the utility needs suitable technologies to monitor consumer's consumption, the consumers need in-home displays, or other devices, to easily retrieve price and consumption information.
4. Response fatigue. To correctly participate in DR programs, consumers have to properly program their appliances during peak periods to run during off-peak periods. As the requests to reduce consumption increase, consumers have to respond more frequently. This induces a phenomenon called response fatigue which results in gradual disengagement.
5. Technology cost and financing. All DR enabling technologies require an initial investment to be deployed. What is not clear is who should finance them.
6. Potential savings. To encourage customers to reduce their consumption, incentives or sales could not be enough if electricity cost is only a small fraction of their overall expenditure [8].

These challenges must be appropriately addressed during the development of DR programs, otherwise they lead to failure. Of these problems the most difficult to address are the ones related to consumers' behaviours and preferences (4 and 6). If consumers are not effectively involved in DR programs, no benefits can be achieved.

4-3- **Conclusion**

This chapter examines household consumption and emphasizes its importance in energy consumption.

Chapter 5: Electric Vehicles

5-1- **Introduction**

This chapter explains electric vehicles of types of that because we use it in simulator so we introduce it in this chapter.

5-2- **Electric Vehicles**

Just as there are a variety of technologies available in conventional vehicles, plug-in electric vehicles (also known as electric cars or EVs) have different capabilities that can accommodate different drivers' needs. A major feature of EVs is that drivers can plug them in to charge from an off-board electric power source. This distinguishes them from hybrid electric vehicles, which supplement an internal combustion engine with battery power but cannot be plugged in.
There are two basic types of EVs: all-electric vehicles (AEVs) and plug-in hybrid electric vehicles (PHEVs). AEVs include Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). In addition to charging from the electrical grid, both types are charged in part by regenerative braking, which generates electricity from some of the energy normally lost when braking. Which type of vehicle will fit your lifestyle depends on your needs and driving habits. Find out which BEVs and PHEVs are available to suit your needs.

All-electric vehicles (AEVs) run only on electricity. Most have all-electric ranges of 80 to 100 miles, while a few luxury models have ranges up to 250 miles. When the battery is depleted, it can take from 30 minutes (with fast charging) up to nearly a full day (with Level 1 charging) to recharge it, depending on the type of charger and battery .

If this range is not sufficient, a plug-in electric vehicle (PHEV) may be a better choice. PHEVs run on electricity for shorter ranges (6 to 40 miles), then switch over to an internal combustion engine running on gasoline when the battery is depleted. The flexibility of PHEVs allows drivers to use electricity as often as possible while also being able to fuel up with gasoline if needed. Powering the vehicle with electricity from the grid reduces fuel costs, cuts petroleum consumption, and reduces tailpipe emissions compared with conventional vehicles. When driving distances are longer than the all-electric range, PHEVs act like hybrid electric vehicles, consuming less fuel and producing fewer emissions than similar conventional vehicles. Depending on the model, the internal combustion engine may also power the vehicle at other times, such as during rapid acceleration or when using heating or air conditioning. PHEVs could also use hydrogen in a fuel cell, biofuels, or other alternative fuels as a back-up instead of gasoline.

Following some best practices can help you maximize your all-electric range and vehicle efficiency whether you have an AEV or PHEV.

5-2-1- **Types of EVs**

- EVs (also known as plug-in electric vehicles) derive all or part of their power from electricity supplied by the electric grid. They include AEVs and PHEVs.
- AEVs (all-electric vehicles) are powered by one or more electric motors. They receive electricity by plugging into the grid and store it in batteries. They consume no petroleum-based fuel and produce no tailpipe emissions. AEVs include Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs).
- PHEVs (plug-in hybrid electric vehicles) use batteries to power an electric motor, plug into the electric grid to charge, and use a petroleum-based or alternative fuel to power the internal combustion engine. Some types of PHEVs are also called extended-range electric vehicles (EREVs).

Electric transportation offers ideal opportunities for the broader introduction of renewables to the transport sector. As energy-consuming technologies, electric vehicles (EV) create new demand for electricity that can be supplied by renewables. In addition to the benefits of this shift, such as reducing CO2 emissions and air pollution, electric mobility also creates significant efficiency gains and could emerge as an important source of storage for variable sources of renewable electricity.

IRENA analysis shows that EVs have significant growth potential:

- There is the potential to increase the number of electric passenger cars from just over 2 million in 2016 to 200 million in 2030.
- Electric two- and three-wheeled vehicles could outnumber four-wheeled vehicles, with as many as 900 million on the roads by 2030.
- Electric buses and light-duty vehicles could number well over 10 million by 2030.

Electric vehicles provide opportunities to link the renewable power and low-carbon transport sectors.

- Linked power, heating and transport sectors will increasingly play a role.
- Storage and the ability to introduce higher shares of variable renewable power into the grid will be key drivers.
- EVs offer multiple solutions for growing urban environments and cities, including in terms oftheir energy needs

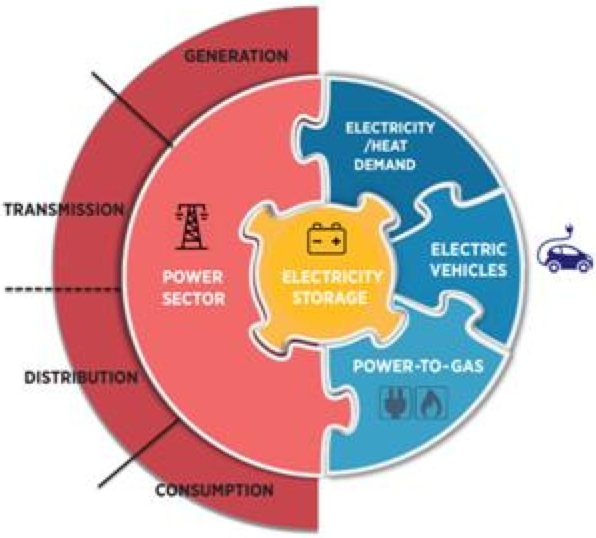


Figure (5-1) - Different types of Electic Vehicles

Challenges to overcome in achieving the potential increase in use include:

- Increasing average annual sales of EVs from under 1 million in 2017 to 10 million by the early 2020s.
- Vehicle cost is key, and the price of battery packs remains high.
- Investing in charging infrastructure is also necessary to accelerate sales.

5-3- **Conclusion**

We introduced electric vehicles and types of that in real world. We need to know evs because we use it a lot in out thesis.

Chapter 6: System Model

6-1- **Introduction**

In this work, we consider a scenario composed by a LTE Mobile Radio Access Network, Household consumers who live within its coverage and a Smart Grid which supply energy to both, as shown in Figure (6-1) . The Mobile Network is composed of one Macro BS, able to provide coverage over a wide area and six Micro BSs which provide additional capacity over the same area. In addition, the Macro BS is equipped with a set of PV Panels. The locally produced Renewable Energy can be used as source of energy for the whole cluster, instead of the Smart Grid. Unfortunately, RE generation is typically intermittent since it depends on weather conditions. Hence, the Macro BS is also equipped with storage devices to save RE when produced in excess, or provide it as needed. The presence of RE generators and storage devices allows the Mobile Networks to answer to Smart Grid requests in a more suitable way.

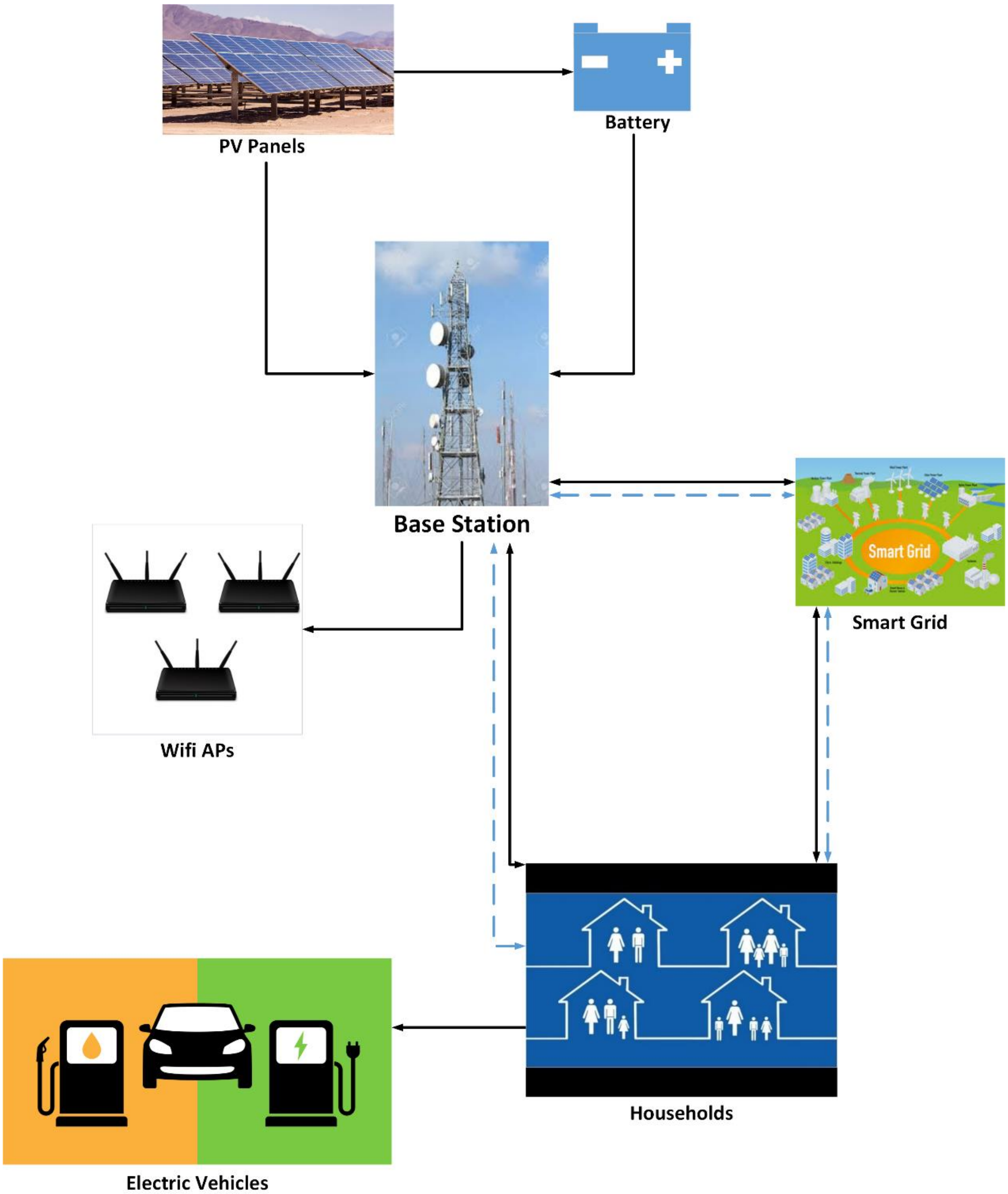


Figure (6-1) - Scenario

Household consumers live within the area covered by the cluster of BSs. They are supplied energy from the grid to support everyday activities, such as cooking, watching TVs or washing their clothes. Some of them participate in the Smart Grid Demand Response program reducing their consumption as needed. we also consider electric vehicles as EVs wich consume energy to be charge in specific time.

Even if Mobile Network and Household consumers participate in the Smart

Grid program separately, in this work we studied a possible interaction which provides benefits to both. In exchange for price discounts and increased bandwidths Households can devolve part of their reduction to Mobile Network if it asks so. In this way the Mobile Network has the possibility to reduce its energy bill and avoid penalties. Hence, when the Smart Grid asks to reduce the consumption, first the Mobile Network tries to reduce by itself, then if it is not able to successfully react, it asks Household consumers to offer part of their reduction to him. In this way, the Mobile Network is able to further reduce its penalty.

6-2- **Smart Grid Model**

As has already been seen in chapter 2, the Smart Grid could meet all the challenges of today's electric power system, to improve it and obtain a more reliable, efficient, resilient and sustainable system. Among all changes that this new concept brings to the current grid, we focus our attention on the informed participation of the consumers in order to build our grid model. Smart Grid allows a bidirectional flow of electricity and information, which permits the utility to send price information or incentives to the customers so that they can change behaviour and actively manage their consumption. Thus, the utility developed demand side management programs to encourage consumers to reduce their consumption during peak-hours or move it to offpeak hours. The Demand Response program adopted in our work is the following: the Smart Grid send to the customer a request every half hour which corresponds to a specific request. The request can be an UP request, a DOWN request or a NULL request depending on the electricity price at that time. If the user is able to satisfy the request, the grid rewards him by providing a bill discount proportional to the response. If instead it is not able to successfully react to the request, the grid penalizes him by increasing the electricity bill by an amount proportional to the gap with respect to the expected outcome.

6-2-1- **Analysis of electricity prices and mapping of the Smart Grid**

requests

To build the SG requests we started analysing the electricity prices, identifying three price ranges: low-price range, intermediate-price range and highprice range. The electricity purchase prices are obtained from the GME company[26]. Information including hourly prices, purchases, sales as well as indexes for different time zones were included in the excel historical data for the year 2016. Prices in Northern Italy were used for our study. We average between hours and so we compute information for every 30 minutes prices, purchases and sales.

6-2-2- **Smart Grid commands**

Having defined the three ranges for the Smart Grid commands, all the prices in 2016 with the corresponding command were then mapped.
Excel data was set at one hour intervals, while simulator Smart Grid commands were set at half hour intervals. Therefore, electricity prices were averaged in order to obtain half hour granularity. The sequence of SG requests was built according to the electricity prices. If the price in the current half hour was high, the Smart Grid asked the customer to reduce their consumption (DOWN request) so that both the customers and the utility took advantage of this reduction. If instead it was low, the Smart Grid asked the customer to increase their consumption, so that they could benefit from this cheap price. If instead the price was in the average the customer was free to either reduce, increase or not change.

6-2-3- **Smart Grid Rewards and Penalties**

Every half hour the Smart Grid sends a request to its customers. As we have seen, the type of request reflects the price of electricity in that half hour. Depending on the customers’ reaction to the requests, they are rewarded or penalized by the Smart Grid.

6-3- **Mobile Network Model**

As we have seen at the beginning of this chapter, the scenario comprises a Mobile Network with one Macro BS and six Micro BSs. The Macro BS is equipped with PV Panels, which generate Renewable Energy in the incidence of sunlight, and with a Battery Bank, which stores RE energy stored in excess. The Battery Bank is also used to store energy from the power grid in case of UP request. The Mobile Network can also reduce its consumption by applying either Resource on Demand strategy or WiFi offloading. In this section, all these aspects are highlighted, starting from the Base Station power consumption model and the traffic profiles. Then, all the strategies used to reduce the energy consumption of the Mobile Network are presented.

6-3-1- **BS power consumption model and Traffic profiles**

The Base Stations power consumption model adopted in this work was taken from [2]. The power consumption of a Base Station includes a fixed part, which is related to the fact that the BS is active.

6-3-2- **RE and Battery Bank**

The Macro BS is equipped with a Photovoltaic Panel, which generates Renewable Energy which can be used to power the cluster. The amount of generated energy depends on the incidence of sunlight. Considering a typical sunny day, the energy produced by the PV Panel is zero during the night and reaches its peak during lunchtime. However, the amount of produced energy depends on the season and especially on the weather. The RE production model was taken from [2], where the production pattern is provided over a period of one year every half hour. The Macro BS is also equipped with batteries to store either the RE generated in excess or the extra energy supplied by the Smart Grid. The battery model used in this work is taken from [2]. Lead-Acid batteries with a Capacity of 200 Ah and 12v were used. The energy capacity of the battery is 2400 Wh and represents the power that can be supplied from the battery in one hour. A rate of 10% in charge and discharge is considered for this battery. During an half hour only 10 % of the total energy capacity can be supplied from the battery or provided to it. Furthermore, the battery cannot be fully discharged, so a Depth of Discharge (DoD) parameter was considered. DoD represents the amount of energy that can be withdrawn from the battery. It was set at 70% of the overall capacity, which means that the battery cannot be discharged beyond 30% of its capacity. Furthermore, when charging/discharging a battery, typically some loss occurs. We considered a charge/discharge loss equal to 15 %. Hence, only 85% of the supplied or received energy is the energy effectively supplied or stored. In [2] additional details can be obtained.

6-3-3- **Resource on Demand strategy**

One of the strategy used to reduce the consumption of the Mobile Network is to dynamically adapt the available radio resources by switching on or off some of the Micro BSs, depending on the traffic demand. This solution is called Resource on Demand strategy. The RoD strategy adopted in this work was proposed in [2]. Every half an hour a subset of Micro BSs is switched off, depending on their traffic, which is moved to the Macro BS. By switching off micro BSs the power consumption can be reduced since a part of their consumption is constant and does not depend on the load. Clearly, the energy due to the additional traffic that the Macro BS has to support does not overcome the reduction due to Micro BSs switching off. Otherwise, no saving is achieved. For this reason, in [2] a traffic threshold is imposed. Micro BSs are switched off only if their normalized traffic is lower than the threshold $\rho = 0.37$. Beyond this threshold no benefits are achieved. Furthermore, traffic can be moved to Macro BS only if it is able to handle it.

6-3-4- **WiFi offloading strategy**

Another strategy used to reduce the consumption of the Mobile Network is to move some traffic to nearby WiFi Access Points. This technique is useful for two main reasons. First, it addresses the network overloading moving some traffic and allowing BSs to manage more traffic during peak hours. Second, it allows to decrease the total energy consumption by switching off more Base Stations during low consumption periods [5]. The WiFi offloading strategy adopted in this work is proposed in [5]. The traffic of each Micro BSs is normalized between 0 and 1 and only a fixed amount of their traffic can be offloaded.

6-4- Household Model

The scenario of this work includes Households who live in the area covered by the cluster of BSs, which is about 2 square kilometres. According to [27] the average number of dwellings per square kilometres in Piemonte is about 40. Therefore, we considered 80 dwellings.
In this section the consumption patterns showing the electricity demand of the households are displayed. Household consumers are subdivided in five classes with a different consumption pattern and a different bent to positively react to Smart Grid requests. Then, considering the different appliance contributions, a distinction between shiftable and non-shiftable loads is made. Finally, the percentage of possible load reduction is derived, and the quote offered to support Mobile Network is defined.

6-4-1- Electricity Demand profile

To build the electricity demand pattern of the Households, electricity consumption profiles taken from a study carried out in Italy in 1000 dwellings were used [28]. This study provided mean electricity profiles in a dwelling both for weekdays and for weekends, in three different seasons. This study did not take into account winter heating since in Italy it still strongly depends on natural gas rather than electric sources. Not considering the summer conditioning, the three different profiles (winter, midseason and summer) had two main peaks in consumption, one in the evening and one in the morning. Electricity consumption was lowest from 2:00 to 7:00, when there is little use of appliances and lighting. During weekdays it was rather clear that households consume

more electricity during mealtimes, while during weekends there were also peaks in consumption in the afternoon around 16:00.
Considering instead only summer profiles with conditioning, there was higher consumption from lunchtime to late evening due to summer conditioning. What differed among weekdays and weekends was that during weekdays consumption peaked in the evening, while during weekends at lunchtime. This might be explained by the fact that people away at work during the day use air conditioning mainly in the evening. Whereas during weekends people usually go out at dinner time thus consumption is in the afternoon.

6-4-2- **Household classes of consumption**

Households have different habits and lifestyles and so their energy consumption patterns do not follow a unique profile. Furthermore, not all the customers are interested in participating in the DR program. To express this consumption diversity Households were divided into five classes depending on their flexibility to postpone loads, their consumption profiles and their time window constraints. Their consumption patterns are derived by the one considered previously by applying an increase or decrease in consumption and/or a shift in time. From now on we refer to this pattern as the base pattern. The five classes are:

- Class-1 : their consumption pattern is the base pattern.
- Class-2 : their consumption pattern is 35% less than the base pattern. They never negotiate with the Smart Grid and so are excluded by the DR program.
- Class-3 : their consumption pattern is 10% higher than the base pattern.
- Class-4 : their consumption pattern is 20% less than the base pattern and is shifted by 4 hours.
- Class-5 : their consumption pattern is shifted by -2 hours with respect to the base pattern.

6-5- **Appliances contribution to the consumption**

Each electric appliance provides a different share to the overall electricity consumption. To define the percentage of load that can be postponed when a DOWN request occurs, the different appliances contribution was considered. In this way, the distinction between loads that can be shifted and loads that cannot is made.

From these results, we made a distinction between loads that can be postponed and the ones that certainly cannot, to derive the percentage of shiftable loads. Appliances that cannot be postponed, such as Refrigerators, are considered non-shiftable loads. We considered Lighting in this category since we supposed that households turn the light on only if it is strictly necessary (no waste). Also cooking devices cannot be shifted: at lunch or dinner time delaying their utilization may create inconveniences. Flexible appliances that can be postponed to a different time without affecting the comfort of consumers are considered shiftable loads. Washing machines, dishwashers and dryers belong to this type of load. Other types of appliances are somewhere in the middle, such as office or entertainment appliances. Sometimes the use of personal computers or TV, for work or personal reasons, is needed, other times not. These appliances were associated to the shiftable category, bearing in mind that sometimes postponing their use isn't possible by assigning to each customer a flexibility parameter. Air conditioning is separated from this subdivision since we applied a different strategy. During summer, when a DOWN request occurs, instead of switching-off the conditioning system, we reduced their consumption by increasing the temperature 1-2 degrees.

Considering this distinction almost 40% of the total load can be postponed. We decided to give 35% to Households benefit and 5% to the Mobile Network. However, these percentages were modified to investigate their effects on the interaction between Mobile Network and Households

6-6- **Mobile Network and Households interaction with the Smart Grid**

In this section we highlight the interaction of the system, presented up to now,

with the Smart Grid. The Smart Grid issues a request every thirty minutes, depending on the price of electricity. Both the Mobile Network and the Households have to react effectively to save on the electricity bill. In this work, we considered the reward and penalty policy described in subsection 5.1.3 for the Mobile Network. Household consumers reaction to the requests is instead investigated only from the point of view of how much energy is saved.
First, the reactions of the Household consumers and the Mobile Network to the requests of the Smart Grid are presented separately. Then, the interaction between Mobile Network and the Household consumers is described.

6-6-1- **Household interaction with the Smart Grid**

Household consumers are powered by the Smart Grid, which proposed to them a Demand Response program to reduce their consumption and their bills. They were divided into five classes which have a different bent to successfully participate in Smart Grid DR program and a different consumption pattern. To each class is associated a flexibility parameter (f), which represents the probability that the consumer shifts its load when a DOWN request occurs. Moreover, also a time window constraint (Tpostpone) is associated to each class. Households that agree to shift their load, postpone it only for a certain interval of time. After that interval, a timeout expires and the loads must be executed. The percentage of loads that can be postponed was set to 40%. 35% is for Households own benefit, while 5% is given to the Mobile Network.
Having summarized Household characteristics, the Demand Response strategy for Household consumers follows. Every half hour the Smart Grid sends one of three messages, UP, DOWN and NULL, and each of them triggers a different reaction on the Households. All the decisions are made as a Class, not as single consumer. Hence, all consumers within the same class perform the same operations.
UP request when the SG asks Hoseholds to increase their consumption, the only chance is to check if there are postponed loads. Consequently, each Household executes postponed loads if any.

6-6-2- **Mobile Network and Households interaction with the Smart Grid**

NULL request When a NULL request occurs, Households are free to either increase or decrease their consumption. In this work, we considered the following strategy. Household consumers do not postpone any load. Furthermore, previously postponed loads of which timeout has expired are executed.

DOWN Request In case of a DOWN request Households have to decrease their consumption otherwise are penalized. In case of Summer each consumer, except for those of Class 2 (which never reduce their consumption), reduces their consumption due to air conditioning by 7%. This reduction corresponds to the increase of air conditioning temperature by about 1 or 2 degrees. Then, postponed load of which timeout has expired are executed. Finally, depending on the specific characteristics, each Class can decide whether to postpone 35% of its load or not.

The best situation occurs when no postponed load must be executed and when the Class agrees to reduce its consumption. 35% of the consumption of the Class in that half hour can be saved. In situations in which postponed load must be executed and the Class do not agree to postpone some of its load, no savings occur (worst situation). As we can notice from the above steps, if a class postpone its load, it does not accept further reduction until the postponed loads are executed.

6-6-3- **Mobile Network interaction with the Smart Grid**

The Mobile Network is mainly powered by the Smart Grid, but also the local RE generator and the Battery are alternative sources. Indeed, the cluster is equipped with PV Panels and a Battery Bank. Renewable Energy increases the Mobile Network self-sufficiency and can be also used to reduce the energy required from the SG in the case of a DOWN request. Moreover, if it is generated in excess it can be stored into batteries. Batteries can either store energy from the Smart Grid in the case of an UP request or supply energy to the cluster. The Mobile Network can also reduce its consumption by applying Resource on Demand strategy and/or Wifi offloading. Depending on the Smart

Grid request, the Mobile Network react in a different way.

UP request When the Smart Grid issues an UP request, the Mobile Network has to increase its consumption. The only way to increase it is to demand extra energy to charge the battery. This is possible only if the battery status is not full. Hence, when the Mobile Network receives an UP request it performs the following step:

1. If the battery is full, the cluster is not able to successfully react and it can be penalized.
2. If the battery is not full, the amount of missing battery charge is computed. Then:
    a. If it is lower than the amount of charge that can be stored in a half hour, the battery is fully charged.
    b. therwise, only the amount of charge that can be stored in a half hour is required.

NULL request When a NULL request occurs, the Mobile Network is free to either increase or decrease its consumption. In this work, the Mobile Network during NULL request retrieves energy from the PV Panel and/or from the battery, and asks the Smart Grid for the difference. In this way “green” energy is used and the carbon emissions are reduced.

DOWN Request To successfully reply to a DOWN request from the Smart Grid, the cluster of BSs can perform one of several options or even combinations of them, to reduce the energy from the power grid. Energy can be retrieved from Photovoltaic Panels or from the Battery Bank.

6-6-4- **Mobile Network and Households interaction with the Smart Grid**

on Demand and WiFi offloading strategies can be adopted. Finally the Mobile Network can ask Household consumers to give part of their reduction to it.

6-6-5- **Mobile Network interaction with the Household Consumers**

As we have seen so far, Mobile Network and Household consumers participated in separated Demand Response programs. However, if the Mobile Network is not able to properly react to DOWN requests, it can ask Households for support. This support is provided in terms of reduction of consumption. Whenever a DOWN request occurs, if the Mobile Network is not able to reduce its consumption below the Forecast Energy, it incurs into a penalty. To avoid being penalized, it asks Households to further reduce their consumption and devolve the reduction to itself. The percentage of consumption that Households can reduce for the Network is 5%.

6-7- **Electric Vehicles Model**

In this research, we also used electric vehicles in the model so that these vehicles can be charged in the model and three separate scenarios have been considered for charging these vehicles:

1- Electric vehicles start charging at a fixed time and are discarded after charging, and this charging is possible only at a fixed time for which we specify, which we consider here from 10 pm to 8 am. We consider In this scenario, all electric vehicles have zero initial energy and only one electric vehicle is placed for charging.

2- In second scenario Electric vehicles start working at a specific time, but they have different initial energy, so vehicles may have initial energy at 10 o'clock at night when they start charging, for which we used a random mode. In this case, we considered vehicles have a battery of 50, which when charging each of these vehicles may have different energies, but can be charged up to a maximum of 50 units.

3- In this scenario, we used smart charging, it means during chaging between 10 pm and 8 am, if there is a lack of energy in the meantime vehicles should be intelligently disconnected from the charge, and we even considered that this disconnection of electric vehicles should be done if their energy reaches a certain level and there is a shortage of energy at the same time. Also in this scenario, we considered that the electrical appliances should be charged a few days a week, that is, for example, 3 days a week. So in this scenario, we considered that if the battery has a power of 50, in the smart charging mode, we can say whether it will be fully charged or not. It should be charged three days a week, and if there is a shortage of energy, it should be stopped charging at the same time, which means that it operates quite intelligently in this scenario.

6-8- **Conclusion**

In relation to the different parts of the system model, which is suggested, it was fully explained and the model was completed. In the next chapter, this model will be implemented and examined and analyzed. In order to have better results we use real dataset. We use dataset from [32].

Chapter 7: Results

7-1- **Introduction**

In this work, we consider a scenario composed by a LTE Mobile Radio Access Network, Household consumers who live within its coverage and a Smart Grid which supply energy to both. The Mobile Network is composed of one Macro BS, able to provide coverage over a wide area, and six Micro BSs which provide additional capacity over the same area. In addition, the Macro BS is equipped with a set of PV Panels. The locally produced Renewable Energy can be used as source of energy for the whole cluster, instead of the Smart Grid. Unfortunately, RE generation is typically intermittent since it depends on weather conditions. Hence, the Macro BS is also equipped with storage devices to save RE when produced in excess, or provide it as needed. The presence of RE generators and storage devices allows the Mobile Networks to answer to Smart Grid requests in a more suitable way.
We use dataset from [32] because data of consumers was real from world it can be better to get real results.
Household consumers live within the area covered by the cluster of BSs. They are supplied energy from the grid to support everyday activities, such as cooking, watching TVs, washing their clothes or charging their electric devices. Some of them participate in the Smart Grid Demand Response program reducing their consumption as needed.
Even if Mobile Network and Household consumers participate in the Smart Grid program separately, in this work we studied a possible interaction which provides benefits to both. In exchange for price discounts and increased bandwidths Households can devolve part of their reduction to Mobile Network if it asks so. In this way the Mobile Network has the possibility to reduce its energy bill and avoid penalties. Hence, when the Smart Grid asks to reduce the consumption, first the Mobile Network tries to reduce by itself, then if it is not able to successfully react, it asks Household consumers to offer part of their reduction to him. In this way, the Mobile Network is able to further reduce its penalty.
In this proposed model, it is considered what hours, what days and what seasons are more consumption and when is less consumption, so that much better

management can be created on energy consumption. In this proposed model, a parameter for wasted energy is considered, so that we can understand when energy is wasted and not used (note that this is for the time when the batteries are completely full and in this case it cannot be stored). By identifying wasted energy production times, energy loss can be prevented because in this case energy has no place to be stored and is directly wasted.

The Smart Grid could meet all the challenges of today’s electric power system, to improve it and obtain a more reliable, efficient, resilient and sustainable system. Among all changes that this new concept brings to the current grid, we focus our attention on the informed participation of the consumers in order to build our grid model. Smart Grid allows a bidirectional flow of electricity and information, which permits the utility to send price information or incentives to the customers so that they can change behaviour and actively manage their consumption. Thus, the utility developed demand side management programs to encourage consumers to reduce their consumption during peak-hours or move it to offpeak hours. The Demand Response program adopted in our work is the following: the Smart Grid send to the customer a request every half hour which corresponds to a specific request and if we use smart charging for EVs, in low energy EVs should be disconnected so in this case we can manage energy very carefully.

To build the SG requests we started analysing the electricity prices, identifying three price ranges: low-price range, intermediate-price range and highprice range. The electricity purchase prices are obtained from the GME company Information including hourly prices, purchases, sales as well as indexes for different time zones were included in the excel historical data for the year 2016. Prices in Northern Italy were used for our study.

At present, the clock information was available, so in order to be able to examine it more accurately, in this proposed model, we changed it to 30 minutes, which means that every 30 minutes the energy consumption is considered, and this is obtained by averaging between two different hours. Come. Using this diagram, the amount of energy consumption can be clearly seen in every 30 minutes.

In this study, to examine the research model, all 30-minute, monthly, and quarterly separation modes have been considered for a period of one year, in which very useful information can be extracted.

In all graphs we inserted in this chapter W in graphs means watts per hour.

7-2- **Results**

In this proposed model, a detailed evaluation of the data has been done for one year and in the study, interesting results can be obtained.
Implemented in Visual Studio 2017 and Matlab R2017b environments, c++ and matlab programming languages have been used for implementation.
At first, different seasons were evaluated to see in which seasons the consumption is higher and according to the chart below, it can be seen that energy consumption is different in different seasons. This image shows the average energy required to charge the battery of PV panels. In general, the higher the average in a season, the more it is used. With this chart, it can be seen that it is most used in summer and spring, and this is definitely due to the use of cooling devices. Used during the season, however, it should be noted that even the conditions of the season depends on the year, because in some years, for example, the spring may be very hot, such as summer, and as a result, the amount of energy consumed is much higher. In this picture, you can also see that the use of cooling devices have been high this season, and as a result, it has increased the use of energy.

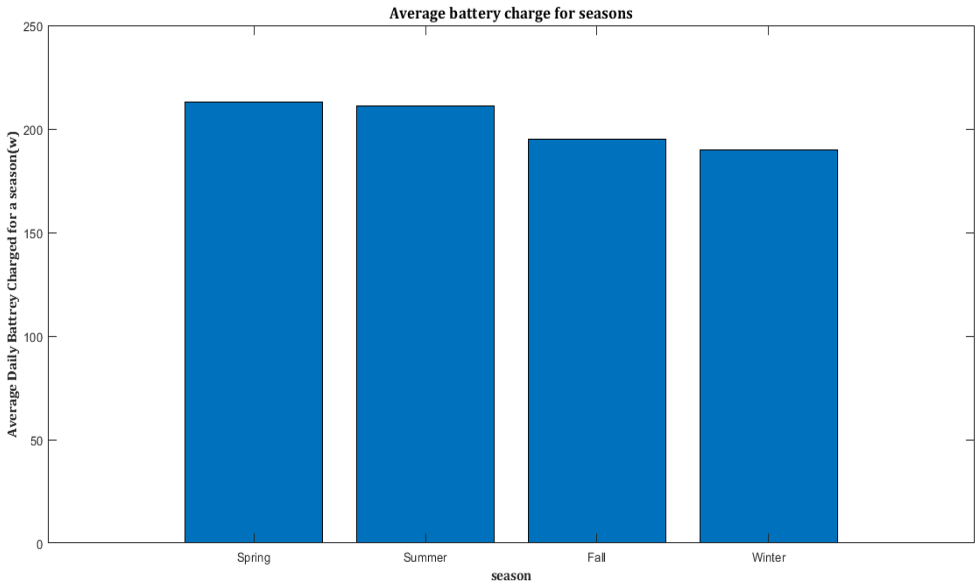


Figure (7-1) - average battery charge for seasons

In order to better understand the results, we tried to divide the results into different modes. Therefore, in the following, we will analyze the results for different modes. The program receives the following input:

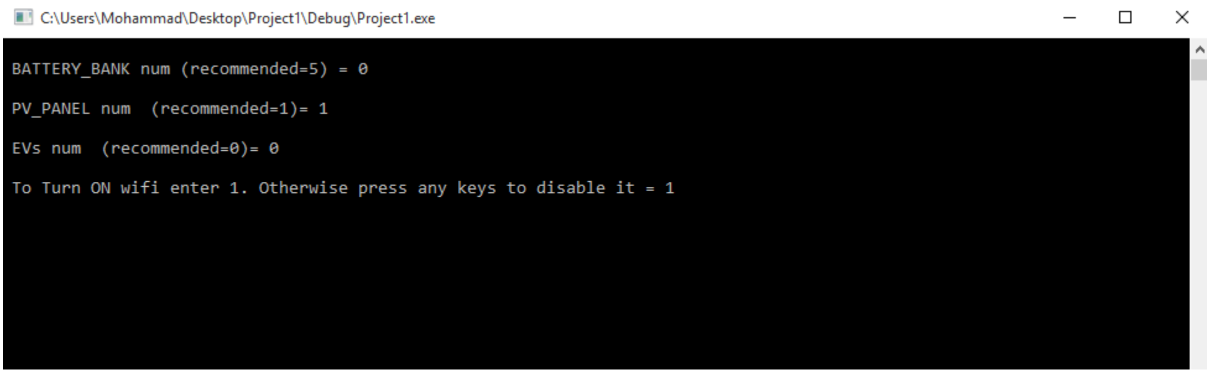


Figure (7-2) - proposed program

In this study, we considered two types of energy source and an electric power source, which include batteries, solar panels, and electric power sources which are available during the hours. They are charged to a certain extent.

In this implementation, wifi is also considered, which is available in homes, and this feature can be considered or discarded. If the power is on, the power consumption will increase slightly.

According to Figure (7-2) , it is considered that there is no battery and therefore no extra energy is stored. In this study, it is considered that bat = battery usage, ev = electric vehicles and pv = panel, which according to the inputs of Figure (7-2) , pv = 1, ev = 0 and bat = 0. In this case, the energy is not stored and as a result, more solar panels are used. This can be seen in Figure (7-3) . In the absence of battery, energy is not stored and the energy produced by the panels is very high throughout the year. This is the amount of energy that is produced and used directly by the panels, and the rest of the energy produced is not stored and lost. According to Figure (7-4) , it can be seen that the energy is stored in the batteries and as a result, all the energy produced is not lost, but the energy is stored in the batteries, and thus its uncontrolled waste can be prevented.

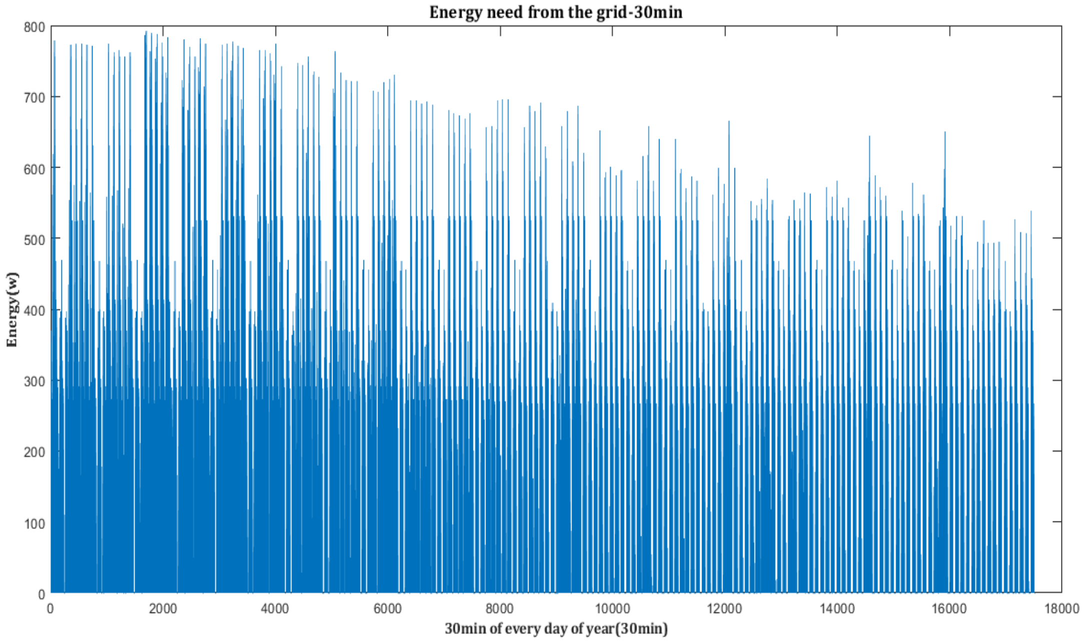


Figure (7-3) - Energy need from the grid (pv = 1, bat=0, ev=0)

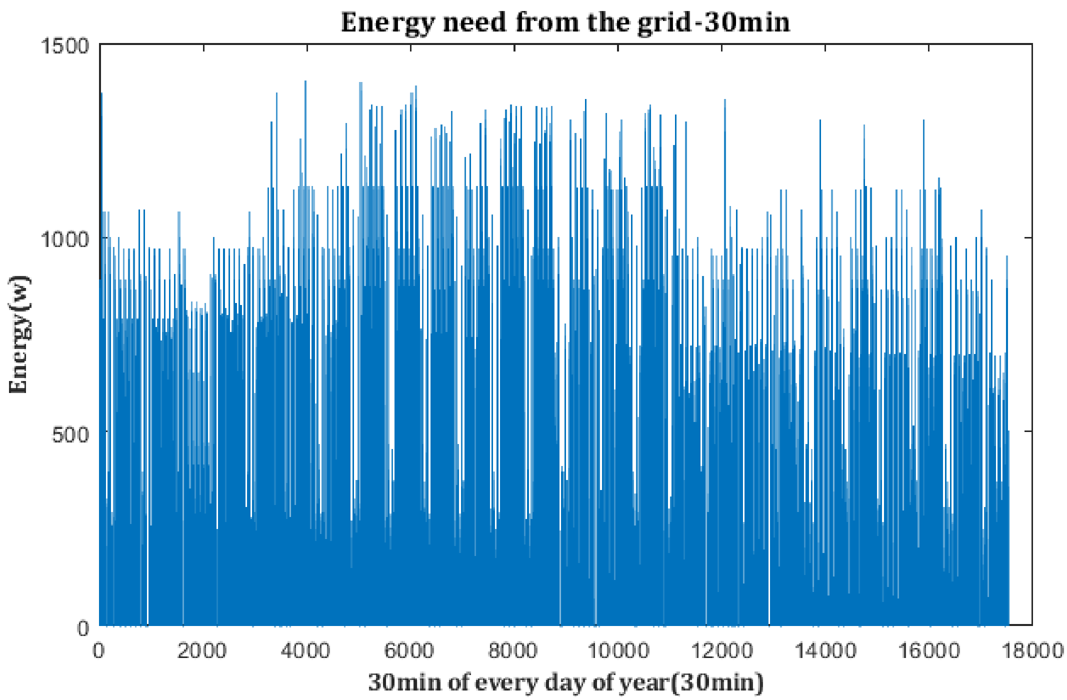


Figure (7-4) - Energy need from the grid (pv = 1, bat=5, ev=0)

7-3- **Comparison between Energy need from the grid in 2 different cases**

Case A : when we have not used battery (PV=1 , battery=0) :

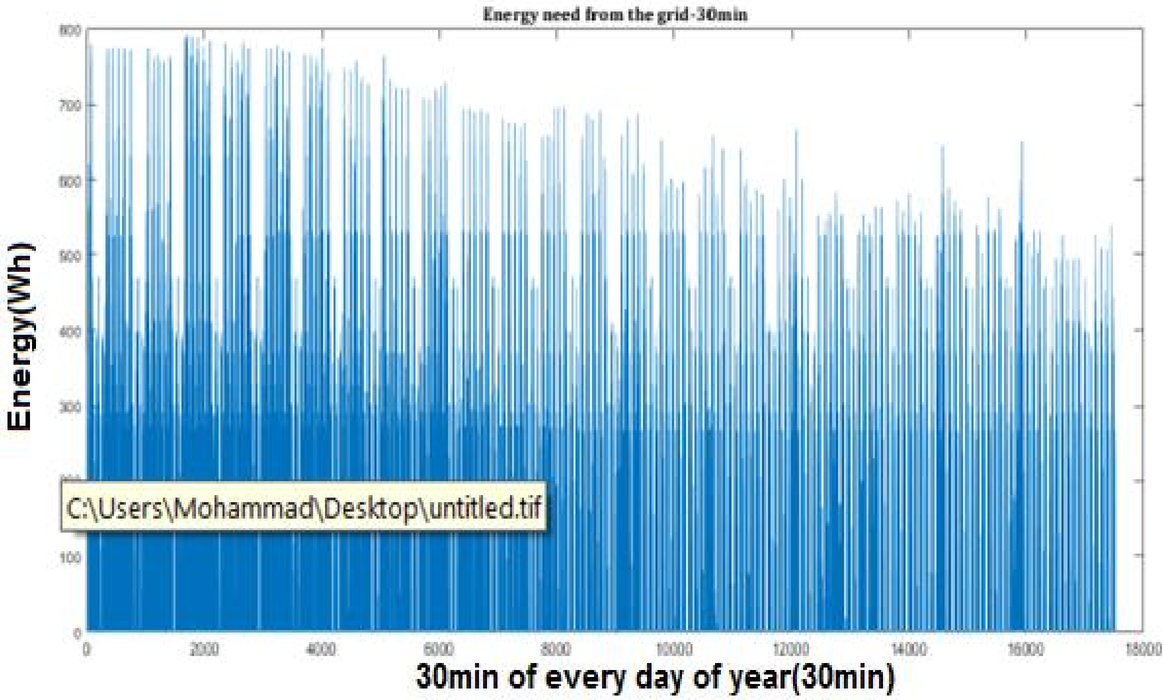


Figure (7-5) - Energy need from the grid-Case A

Case B : when we have used battery (PV=1 , battery=5) :

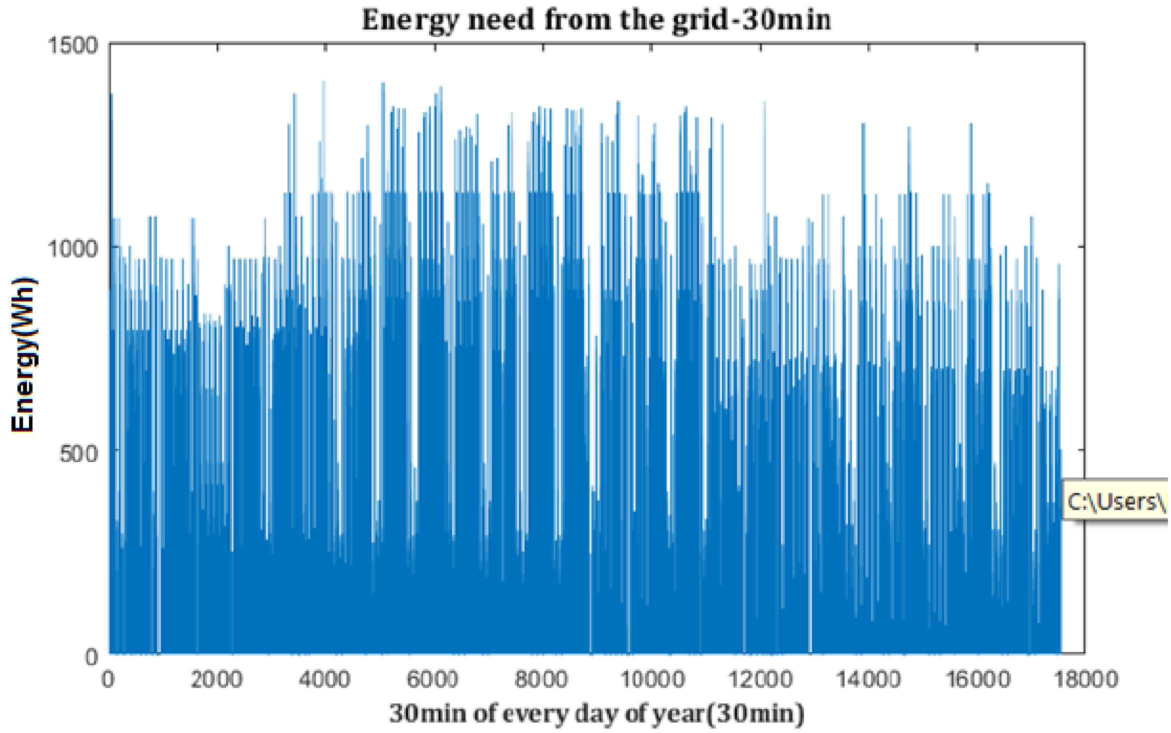


Figure (7-6) - Energy need from the grid-Case B

In the case A, the maximum energy produced is not enough, and therefore it feels like that energy has been used to such an extent, but it is not, and the maximum amount of energy produced is the same. If more energy is produced, more energy would definitely be consumed and more could be seen in this graph, but since the energy produced is not more than this, so in a full day more energy can not be consumed because this energy must exist to be consumed.

In this simulation, it is considered how much energy is needed at any given time according to the energy dataset, and with the use of existing producers or batteries, we try to provide this amount of energy, and we also have an additional energy parameter. We also considered that when it is not possible to provide as much energy as energy consumed, it is placed in this parameter at any time, it means that the extra energy parameter is actually the amount of energy at each moment that is needed and the system at that moment could not provide as much as needed.

In the case B, during the night when less energy is used, the batteries can reach full charge because the energy demand is less and during the day because the demands are more, so the batteries are not used much, and in the day mode, because the energy was stored during the night, it can act as an auxiliary panel

During the day and it is able to provide the energy required by customers. In case A there is no battery and as a result not enough energy is produced and it is thought that the energy consumed In mode A is low but in fact it does not produce more energy that can be demanded more than this amount and in mode B because the batteries are charged during the night, so during the day it acts as an auxiliary panel and more energy can be provided to customers. Therefore, more energy can be provided than mode A. For a better understanding of the difference between these two case, we can pay attention to the extra energy required in these two cases, which in case A requires more extra energy and in case B this extra energy is less because the energy is sufficiently high enough.

7-4- **Comparison between extra energy(Case A and Case B)**

Case A : when we have used battery :

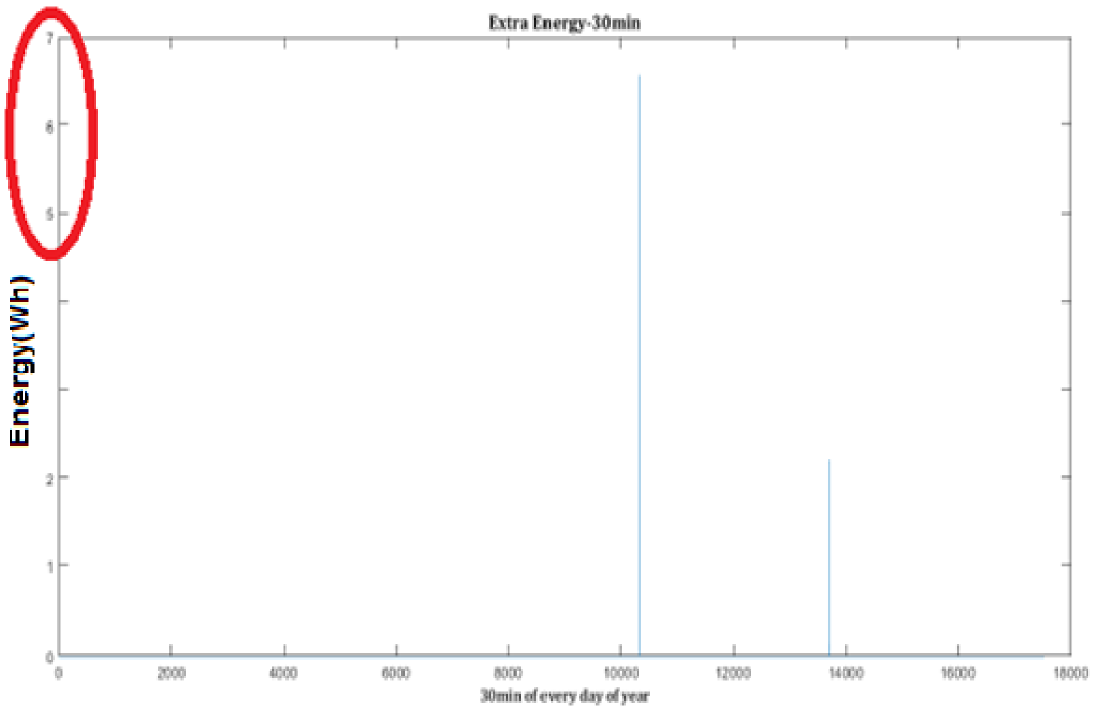


Figure (7-7) - Extra Energy-Case A

Case B : when we have not used battery :

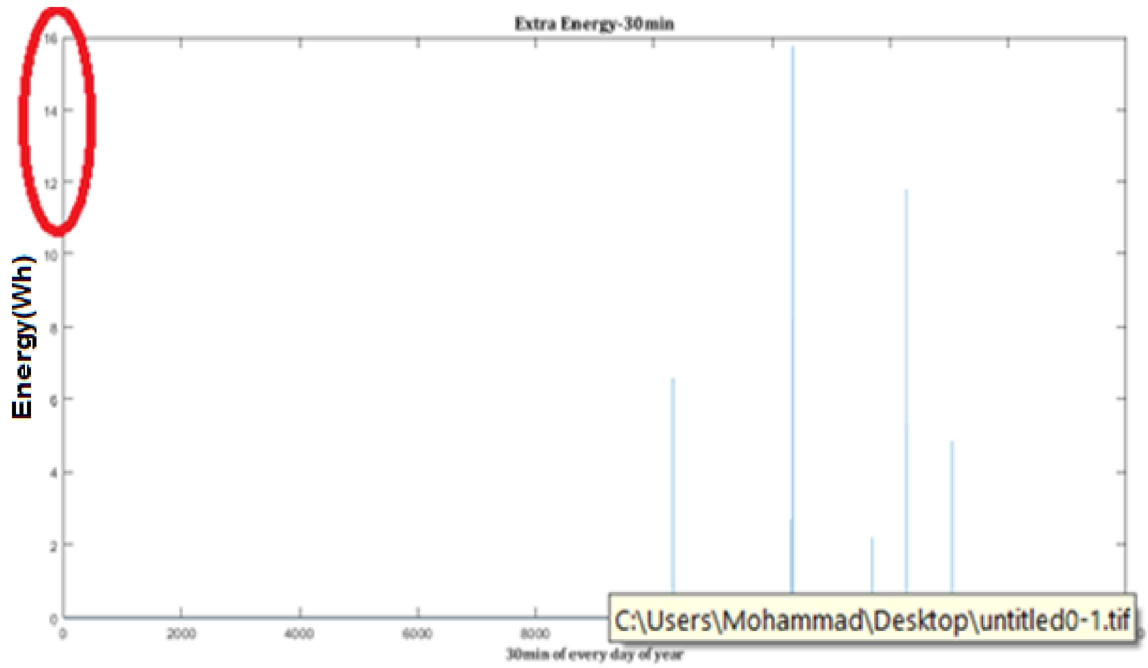


Figure (7-8) - Extra Energy-Case B

Extra energy means energy requested at that moment and in the same time all energy was consumed so lack of energy happened. This means required energy is not fully supplied and more panels are needed for supplying additional energy which is needed in this case.

For computing extra energy, we have used Switch command and we have considered 3 cases:

- Case 0 or Case UP: When the Smart Grid issues an UP request.
- Case 1 or Case DOWN: When the Smart Grid issues a down request.
- Case NULL: When a null request occurs.

In the first graph(Case A), we have used battery and in the second one there is no battery.As I have specified in the graphs , we can see that in the case of using battery , the extra energy is reduced and the loss of energy is considerably prevented. In Case B, we can see that due to lack of battery, the number of times which extra energy is needed and we are facing a power outage, has been increased.

From this part, we follow with pv = 1, bat = 5 and ev = 0, and with these conditions, the results are examined.

According to Figure (7-2) and Figure (7-3) it can be seen that when the battery is used next to the solar panels. The power generated by the panels is used to some extent, and the rest is stored in the batteries, so the extra energy needed produced in this case is low. Figure (7-9) shows the extra energy needed in the absence of a battery. Figure (7-10) also shows the extra energy needed in the state of the battery.

It can be seen that if the battery is used, the lack of energy or more energy that is needed is reduced. Therefore, batteries should be used in this direction to provide the full energy required. In this part, if the pv number increases, due to the very small amount of energy required in Figure (7-9) , energy shortage will not occur at all.

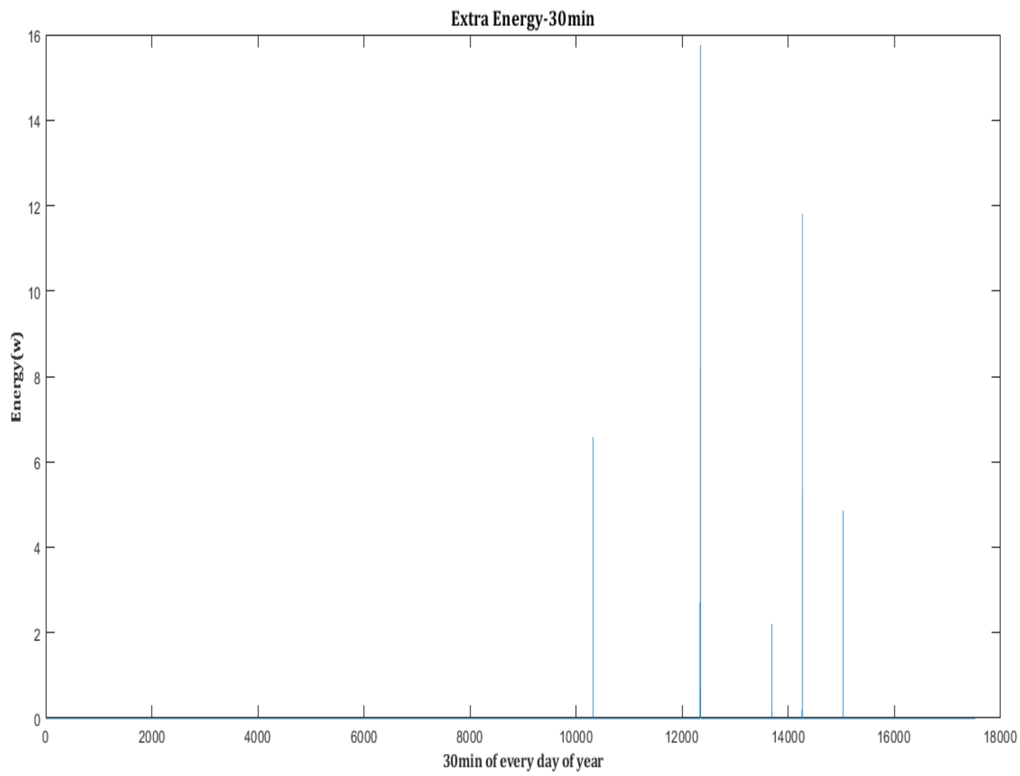


Figure (7-9) - Extra Energy in no battery

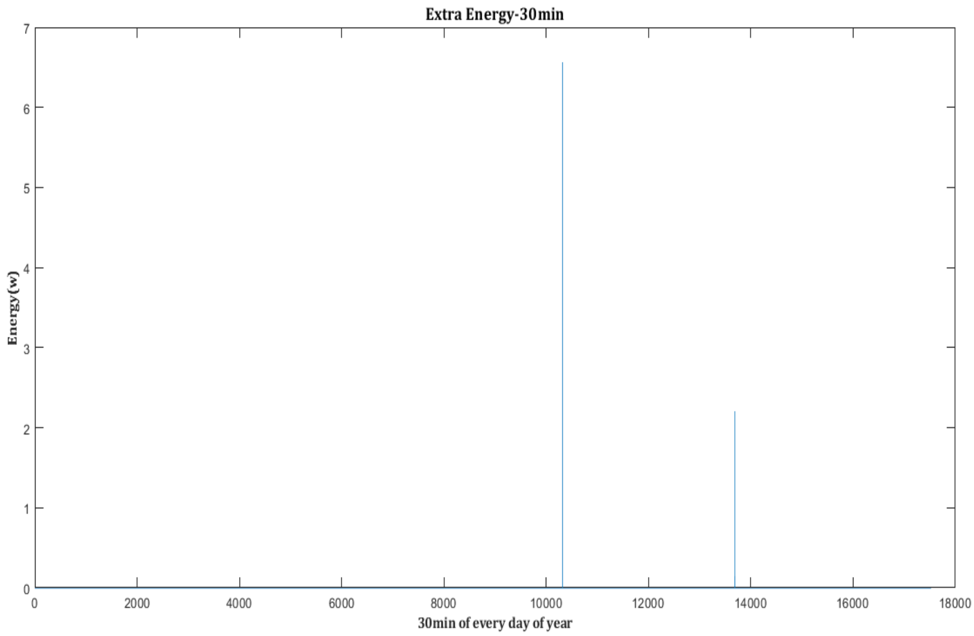


Figure (7-10) - Extra Energy with battery

It can be clearly seen that in the case of using the battery, the extra energy is greatly reduced, that is, the loss of energy produced is prevented, and in this case, the amount of consumers can certainly be increased.

According to Figure (7-9) and Figure (7-10) , it can be seen that in the case of batteries, wasted energy is greatly reduced and only in two times the batteries are filled in the whole year and the energy consumption has definitely decreased drastically, which is no longer the case. Energy is wasted, but it's much better than no battery, and it's able to support a larger number of consumers.

Figure (7-11) below shows the average energy in batteries during each 30 minutes. It can be seen that the consumption rate is lower at the beginning of the year and this amount is gradually increasing.

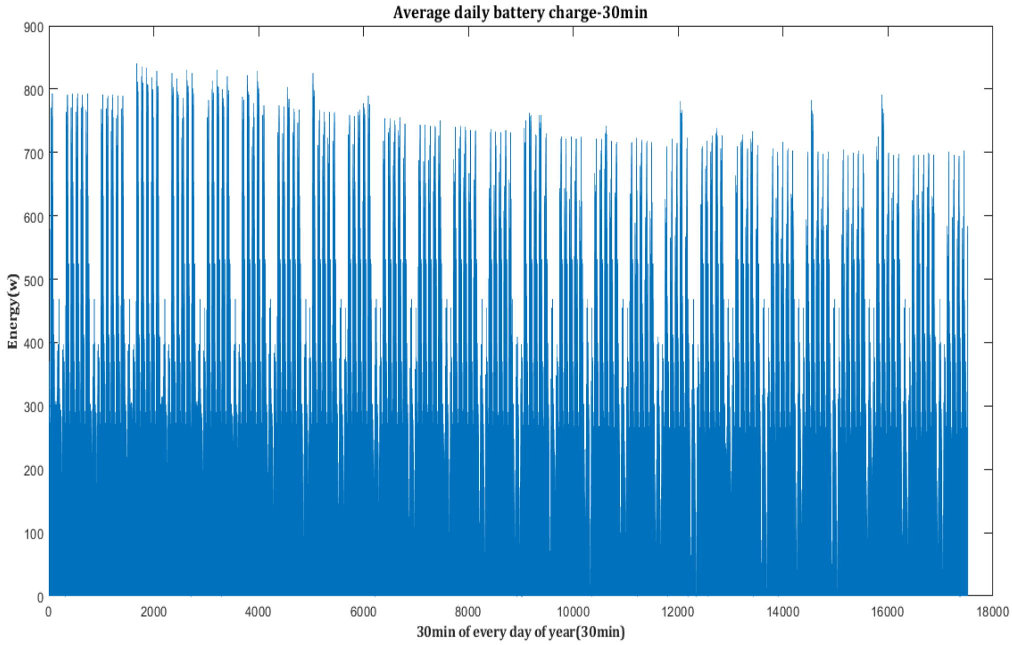


Figure (7-11) - average daily battery charge in 30 min of all year

According to better understanding and better analysis, the result can be seen in Figure (7-12) , which is the average battery usage during the days of the year.

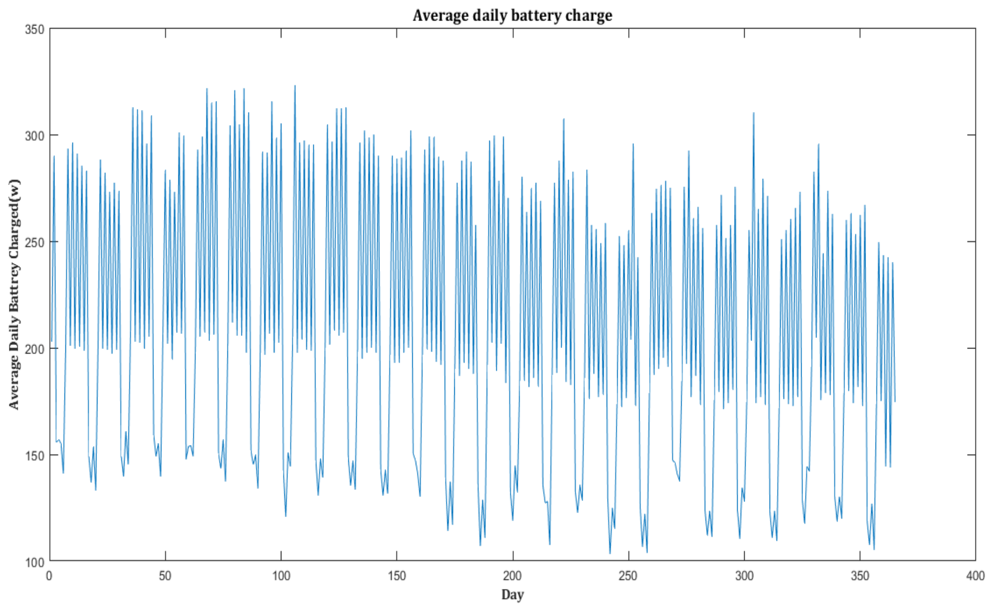


Figure (7-12) - average daily battery charge in day of all year

In order to better understand this consumption for different months, the amount of energy in the batteries for the 12 months of the year is shown below.

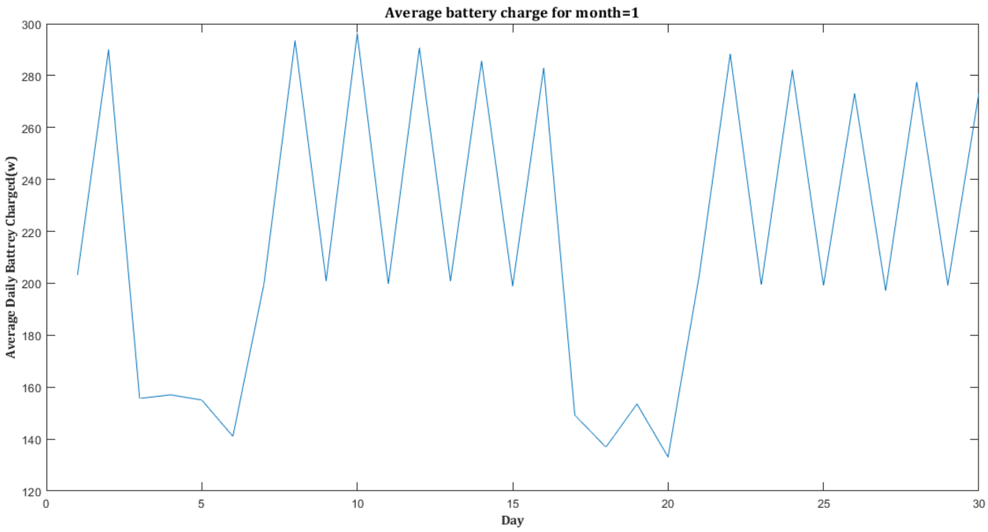


Figure (7-13) - average battery charge for month 1 of year

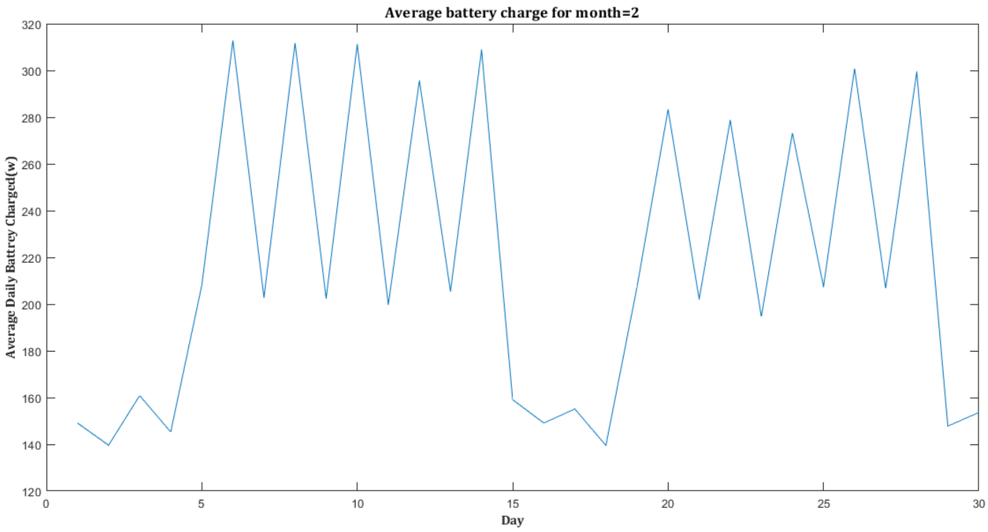


Figure (7-14) - average battery charge for month 2 of year

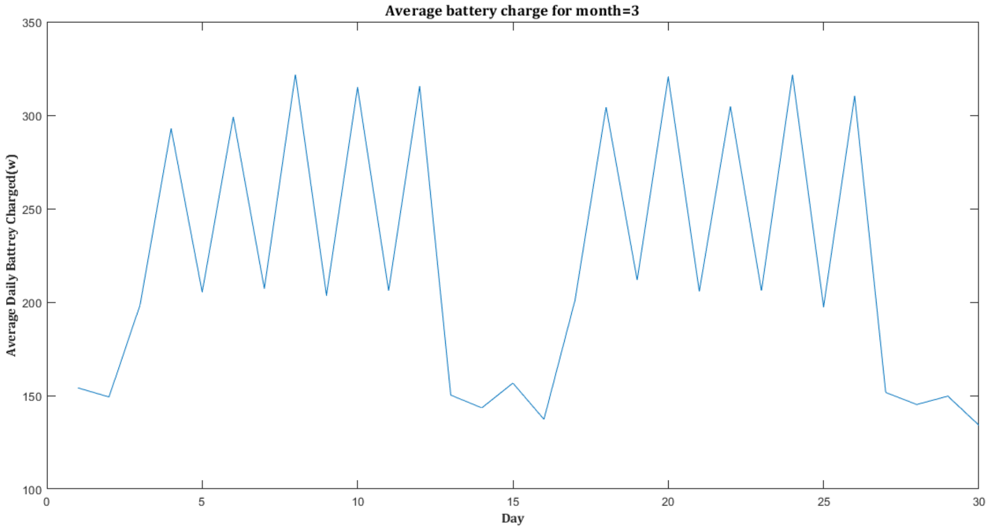


Figure (7-15) - average battery charge for month 3 of year

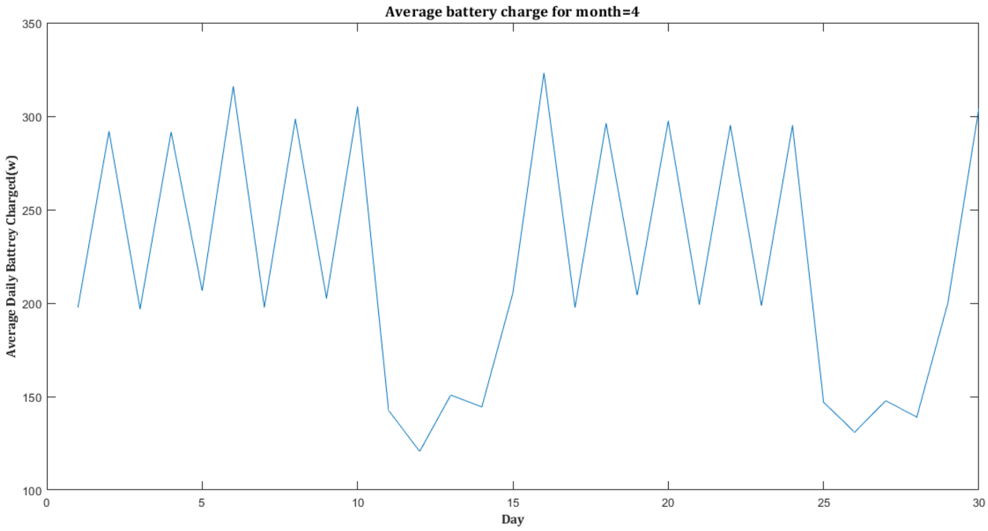


Figure (7-16) - average battery charge for month 4 of year

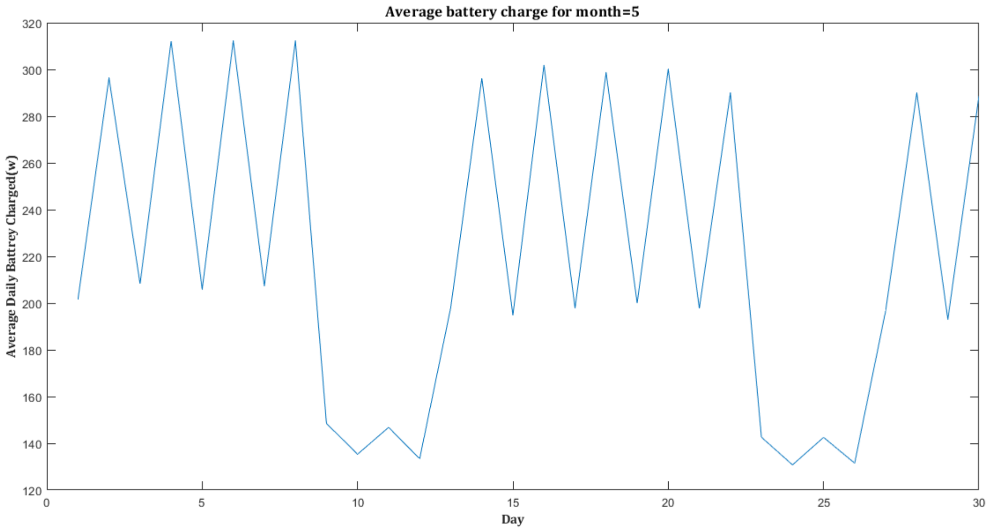


Figure (7-17) - average battery charge for month 5 of year

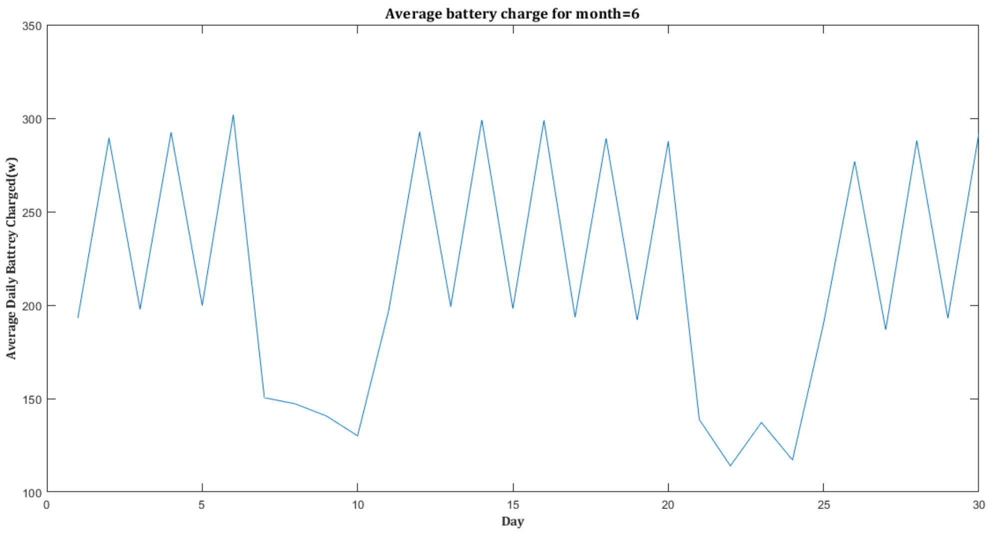


Figure (7-18) - average battery charge for month 6 of year

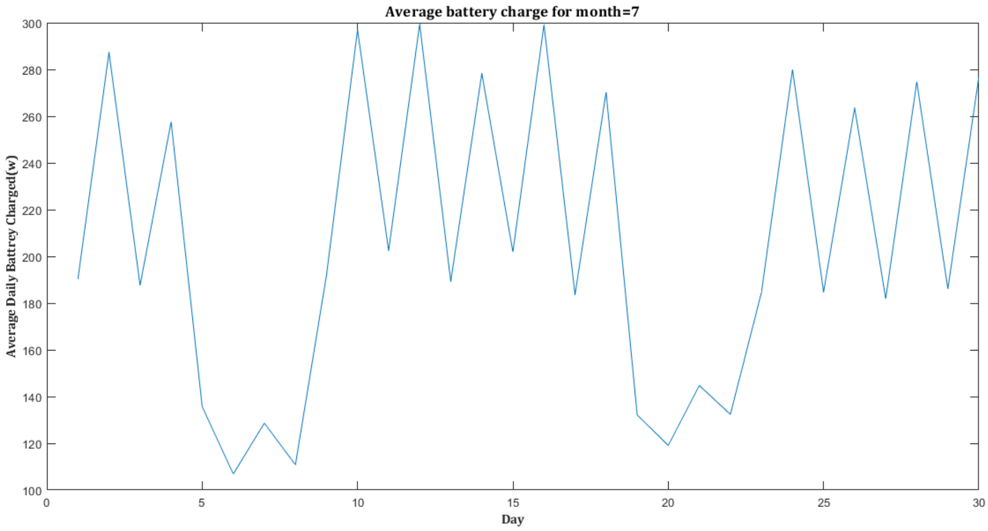


Figure (7-19) - average battery charge for month 7 of year

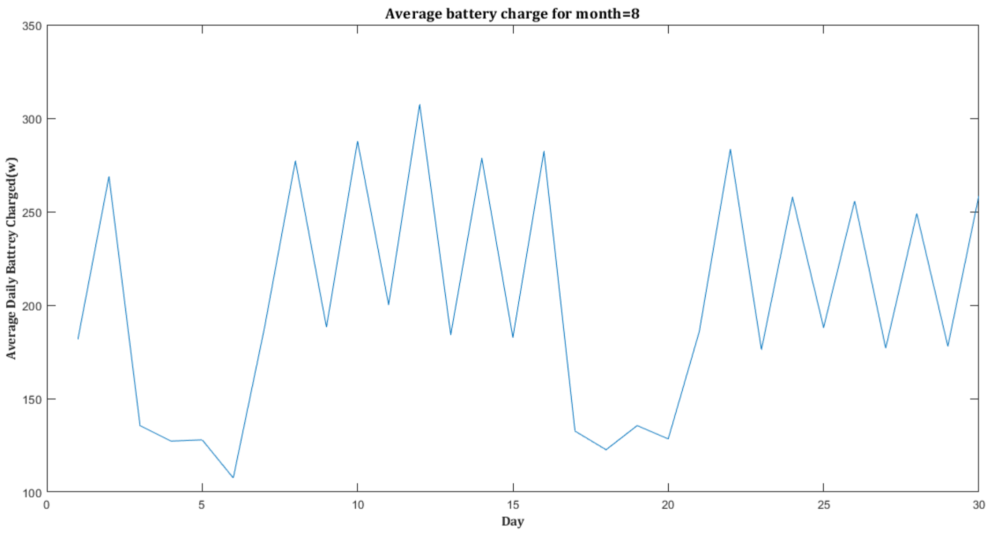


Figure (7-20) - average battery charge for month 8 of year

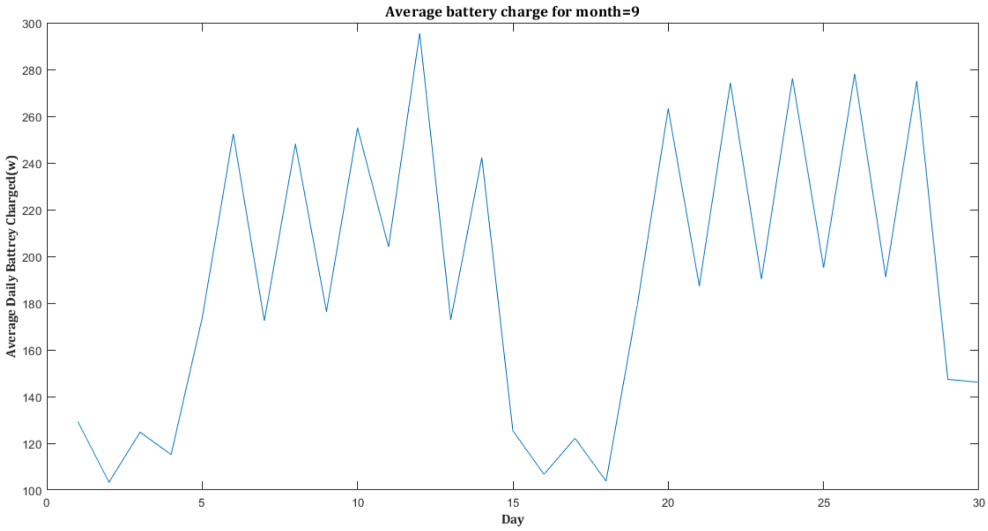


Figure (7-21) - average battery charge for month 9 of year

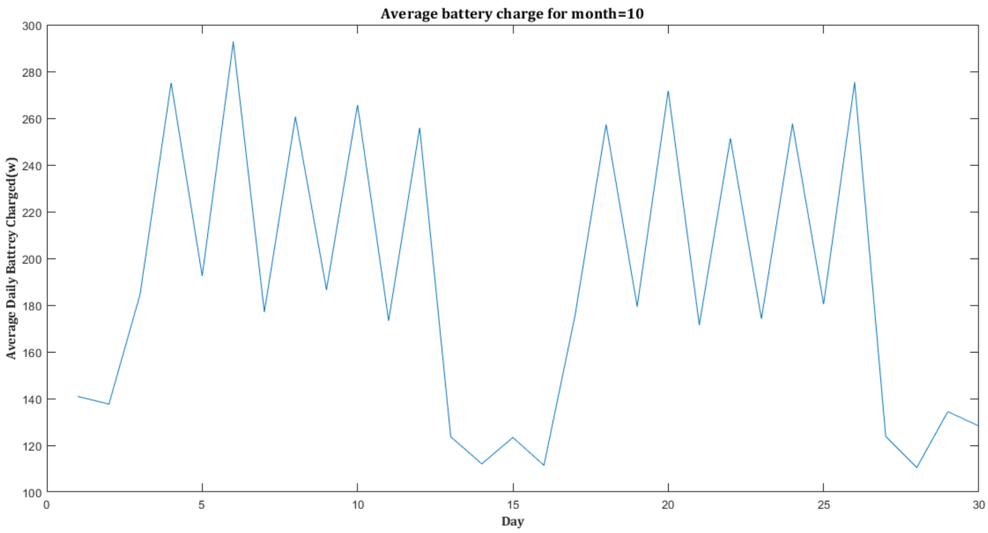


Figure (7-22) - average battery charge for month 10 of year

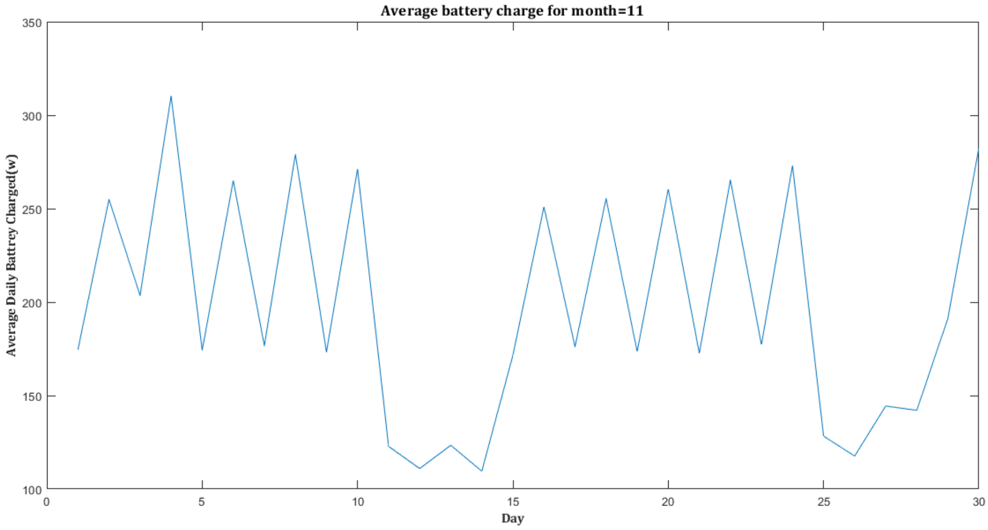


Figure (7-23) - average battery charge for month 11 of year

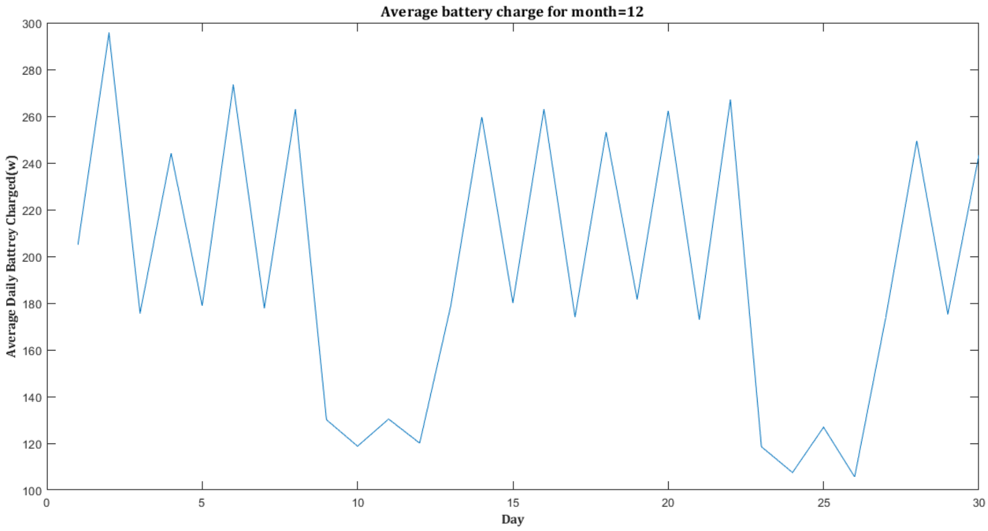


Figure (7-24) - average battery charge for month 12 of year

7-5- Analyze about average battery charge for month October

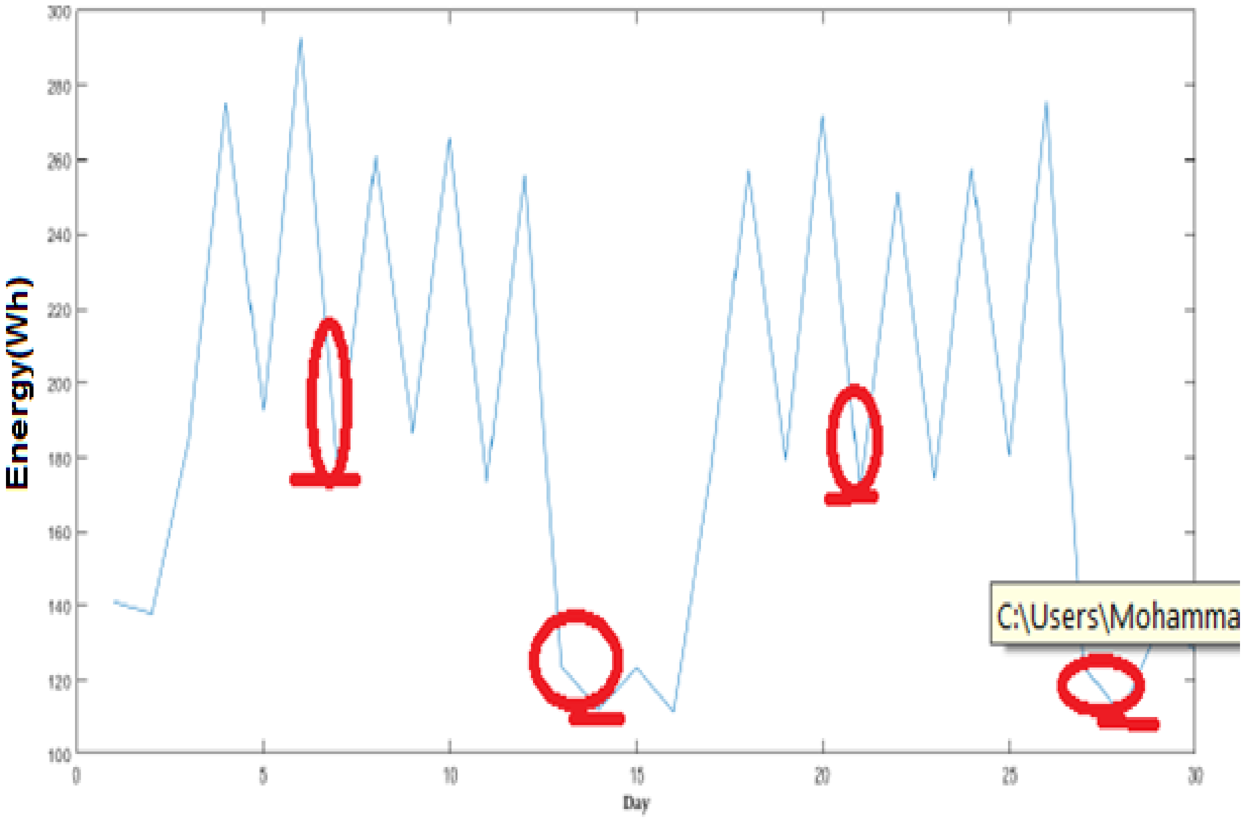


Figure (7-25) - average battery charge for month

As I have specified in the graph, we can see that at the end of the weeks, less energy is remained in the battery because people consumption is more in comparison to other days and we can see sharp increase by starting work days. We have considered instantaneous values and for this reason small intervals are considered, it is oscillating and sharp movements are displayed in the graph. When the intervals gets bigger, smoother movements will be appeared.
You can see the amount of charge in the batteries for different months of the year in Figure (7-26) (this figure is cumulative values).

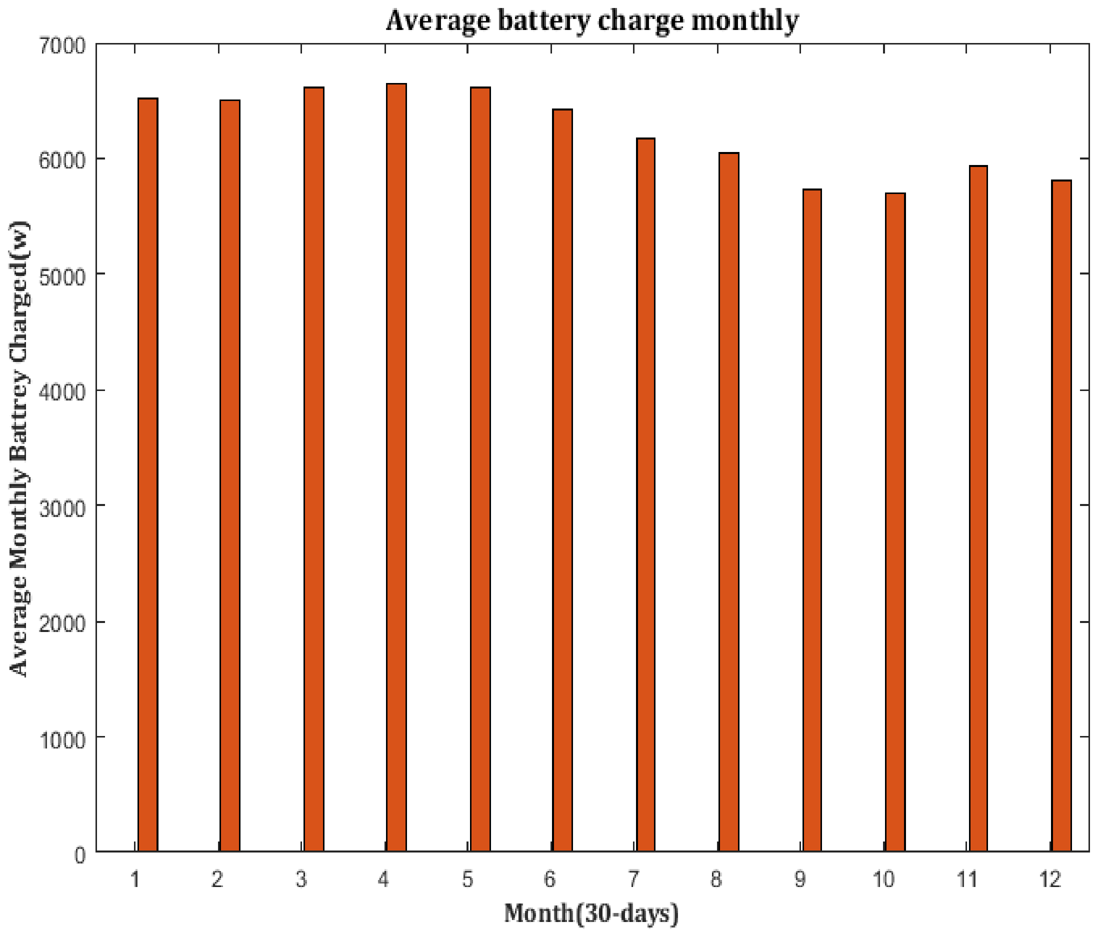


Figure (7-26) - average battery charge for all month of year

In order to be able to examine this issue for separate chapters, Figure (7-27) were examined.

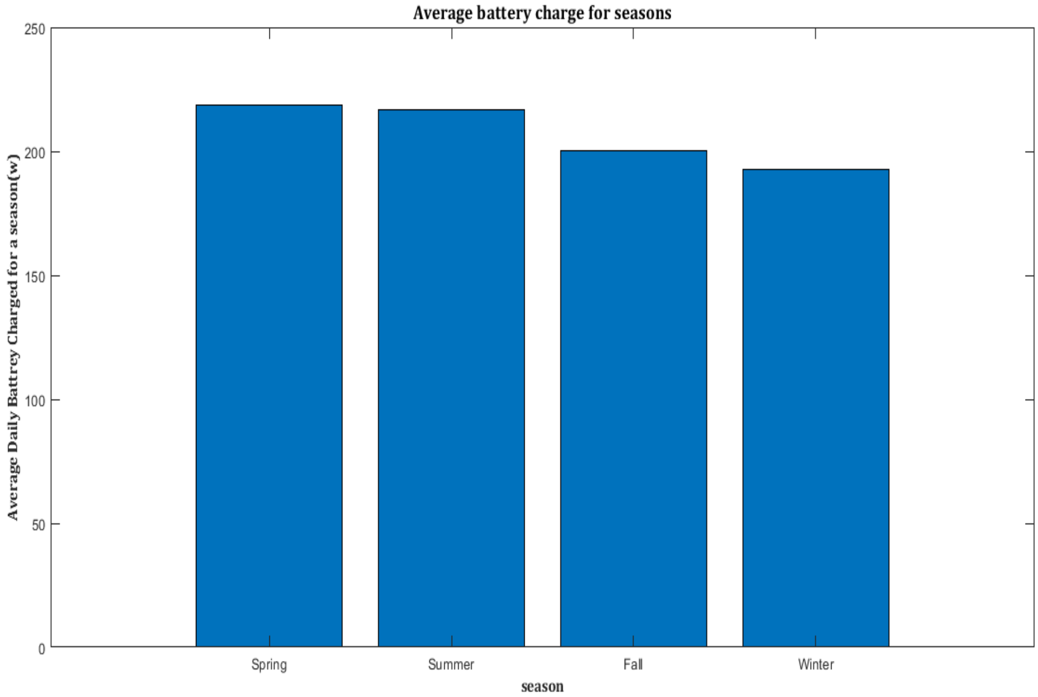


Figure (7-27) - average battery charge for seasons

It can be seen that in the fall and winter seasons when the weather is cold, more energy used and this is obvious because in the fall and winter seasons, when it is peak, different warming devices are used. Due to the fact that electric warming devices consume more energy than cooling devices. The amount of energy remaining in the batteries is also greatly reduced in these seasons. This can also be seen in Figure (7-27) , where the charge in the batteries increases during the first 6 months and then decreases. The amount of charge in the batteries in the 9th and 10th months, ie the months of September and October, is the lowest possible because these months are among the very hot months and the peak of heat.

The energy required by the grid is shown inFigure (7-28) . It can be seen that in the 3rd to 6th months, more energy is needed, which is related to the same summer season, and this is due to the use of high cooling devices such as coolers. Given this, it can be seen that the number of batteries should be increased in the summer in order to save more energy and thus prevent energy wastage, and consumers can also be offered this season. For this reason if they reduce their consumption, they will be given special discounts this season, and since it is expensive to provide solar panels, it is much better to apply a discount for consumption, and it is economical for both parties, ie. Consumers and providers. Also, in this case, there will be no power outage, because enough energy is used in that case, and there is definitely no power outage.

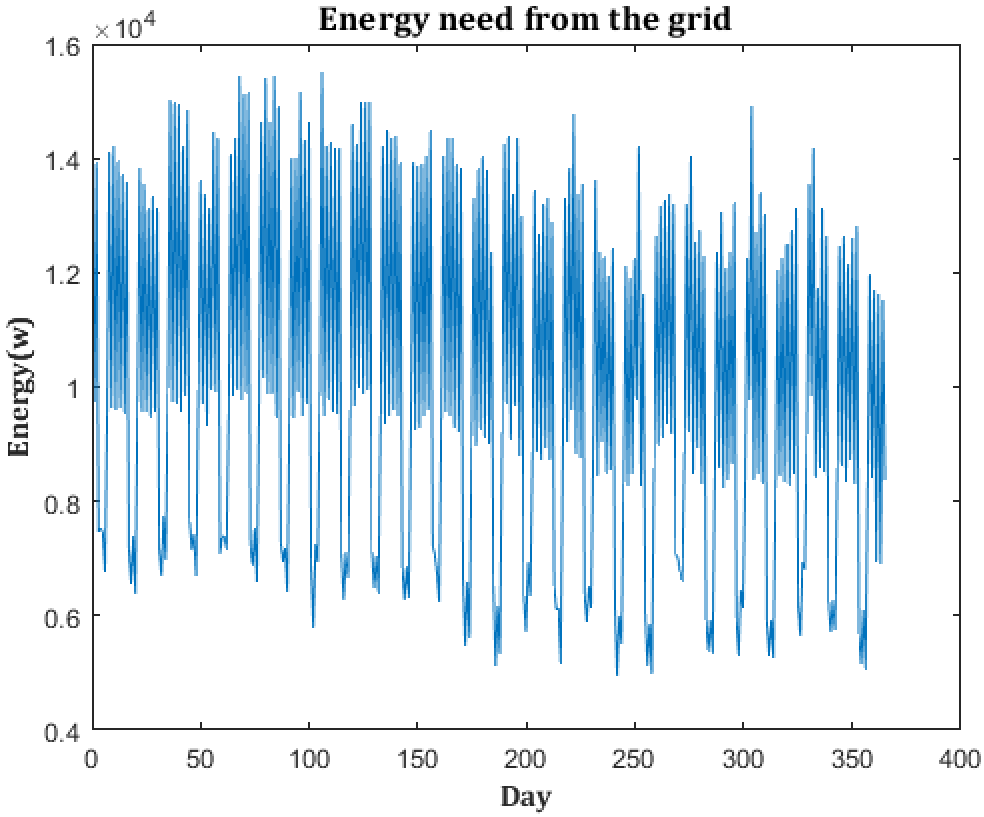


Figure (7-28) - energy need from the grid

To better understand Figure 6-24, the energy diagram required for every 30 minutes for the whole year is shown.

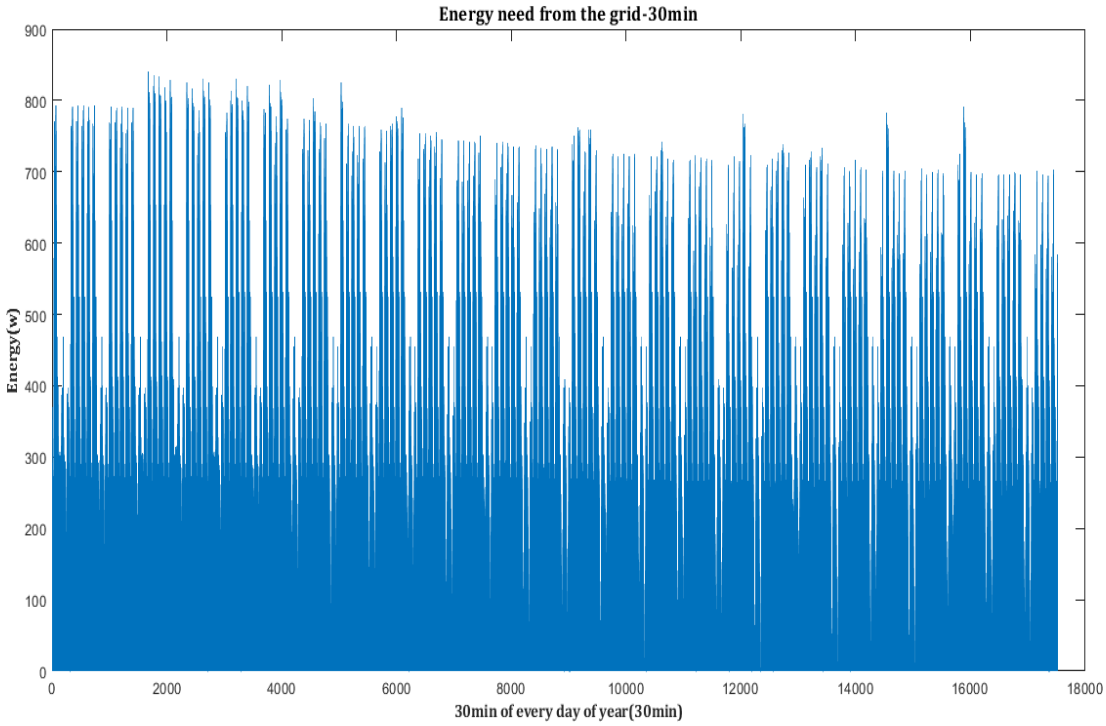


Figure (7-29) - energy need from the grid in 30-min

Figure 6-25 shows the energy required for the grid for one day of the year (the first day of the year). It is observed that in one day, the consumption increases in the last hours of the night, and this is due to the greater use of people in the hours that they are at home, and in the hours that are not at home, the consumption is relatively less. It should be noted that in this study, the consumption of houses has been studied and companies are not in the middle of this, that is, during the day when companies and organizations are working and the energy consumption of these organizations and companies is currently has not been considered in this research.

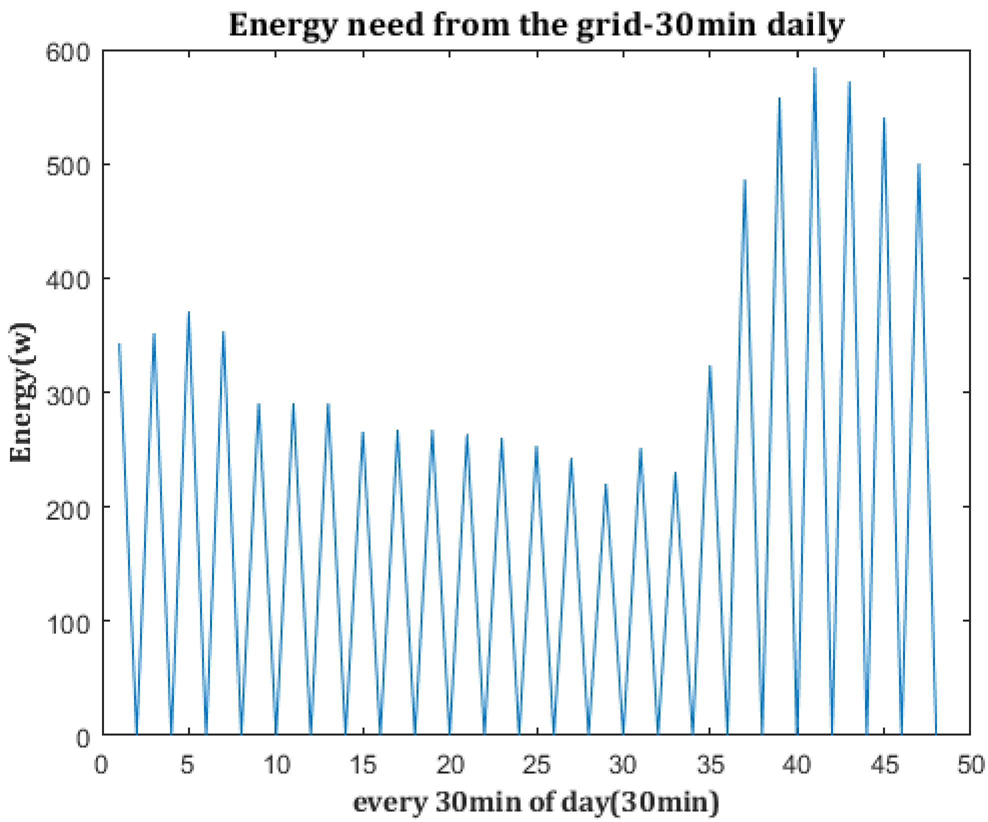


Figure (7-30) - energy need from the grid for 1st day of year

7-6- Adding EVs(Electric vehicles)

In this section, we intend to include ev in the results and perform the analysis under these conditions (pv = 2, bat = 5).

Consider each ev has battery of 50, and we simulate 3 scenario to include EVs in our thesis wich explained in previouse chapter:

1- Electric vehicles start charging at 10 pm to 8 am. We consider in this scenario, all electric vehicles have zero initial energy and 10 electric vehicle is placed for charging.

2- In second scenario Electric vehicles start working at a specific time, but they have different initial energy, so vehicles may have initial energy at 10 o'clock at night when they start charging, for which we used a random mode. We use random function to calculate initial energy for each EV.

3- In this scenario, we used smart charging, it means during chaging between 10 pm and 8 am, if there is a lack of energy in the meantime vehicles should be intelligently disconnected from the charge, and we even considered that this disconnection of electric vehicles should be done if their energy reaches a certain level (20) and there is a shortage of energy at the same time. Also in this scenario, we considered that the electrical appliances should be charged a few days a week that is 3 days a week in this scenario. We considered that if the battery has a power of 50, in the smart charging mode, if there is a shortage of energy, it should be stopped charging at the same time, which means that it operates quite intelligently in this scenario.

7-6-1- **Scenario 1(10 EVs, 0 initial energy)**

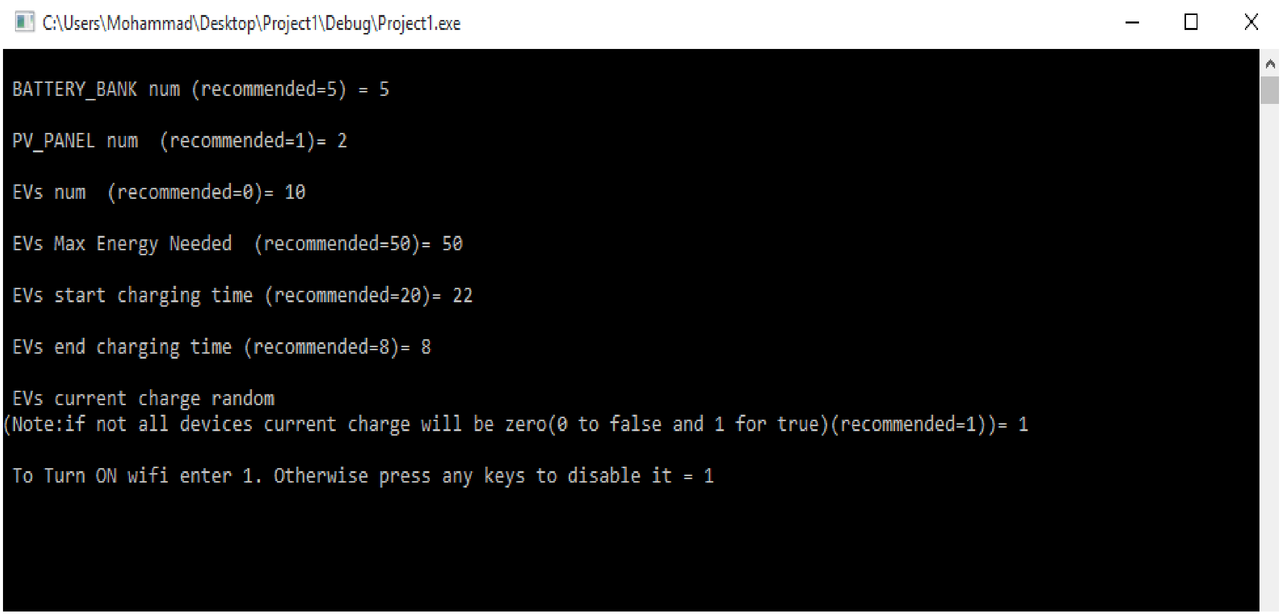


Figure (7-31) - inputs for including evs

It can be seen that in the case of EVs are added to the work and in this case more energy is consumed. The trend of energy use in EVs for the whole year is shown in Figure (7-32) .

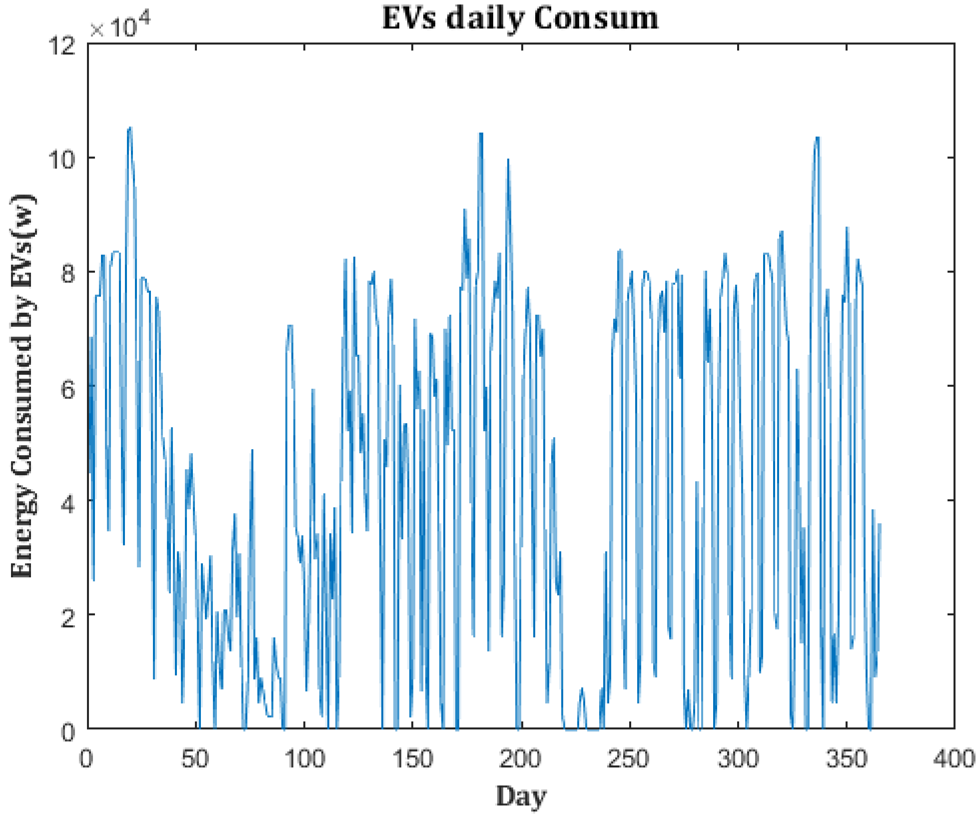


Figure (7-32) - EVs daily consum

Figure (7-33) shows the average energy remaining in the batteries throughout the year. If this shape is compared to the shape in the EV-free mode, it can be seen that the battery is used more in this mode, and as a result, more energy is used in this mode.

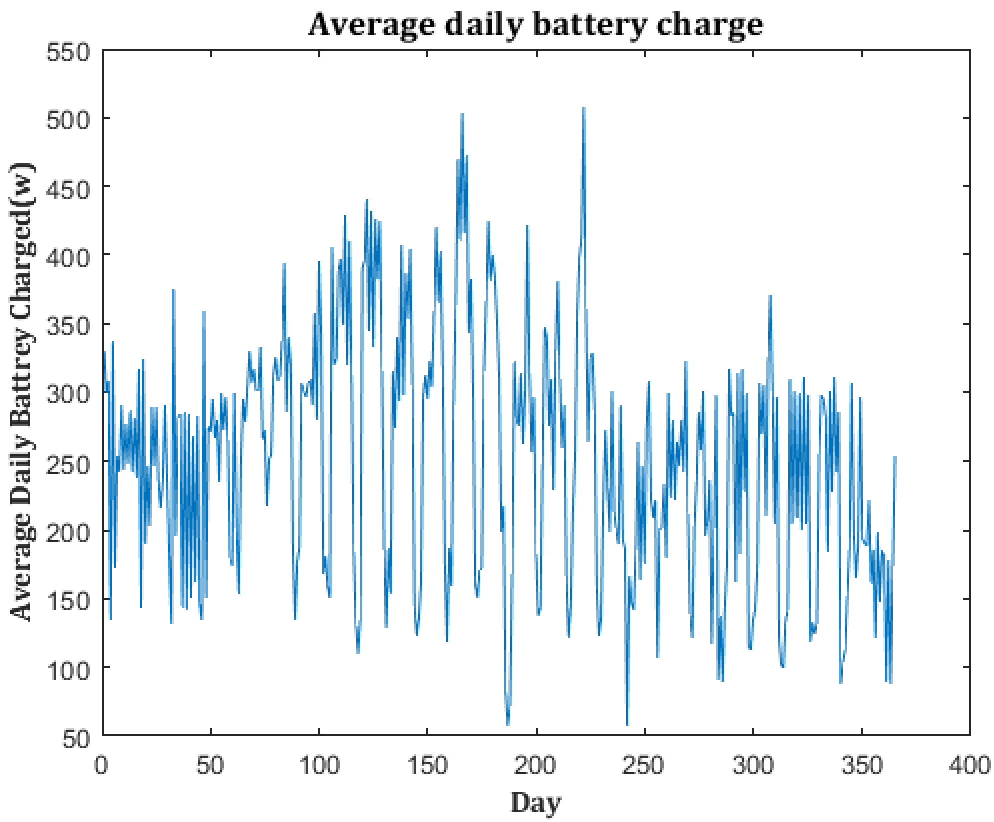


Figure (7-33) - Average daily battery charge

The following shows the average energy in batteries for each month seprately, as well as in a separate image for each month, to make it easier to understand and analyze.

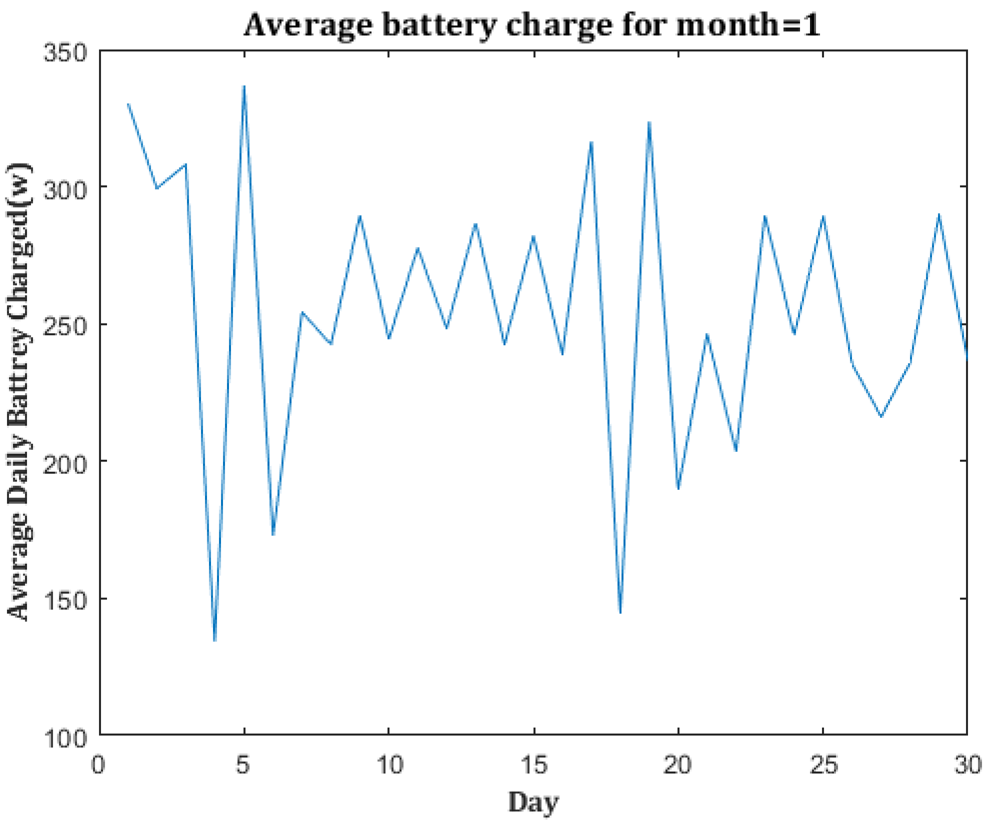


Figure (7-34) - average battery charge for month 1 of year

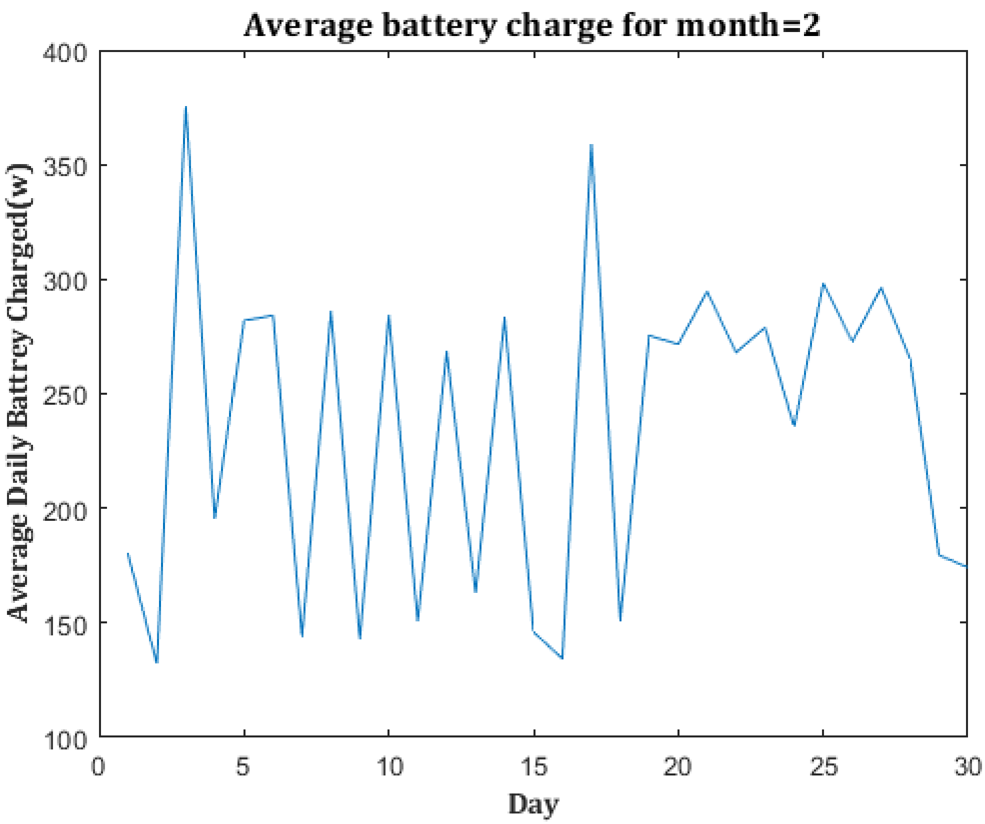


Figure (7-35) - average battery charge for month 2 of year

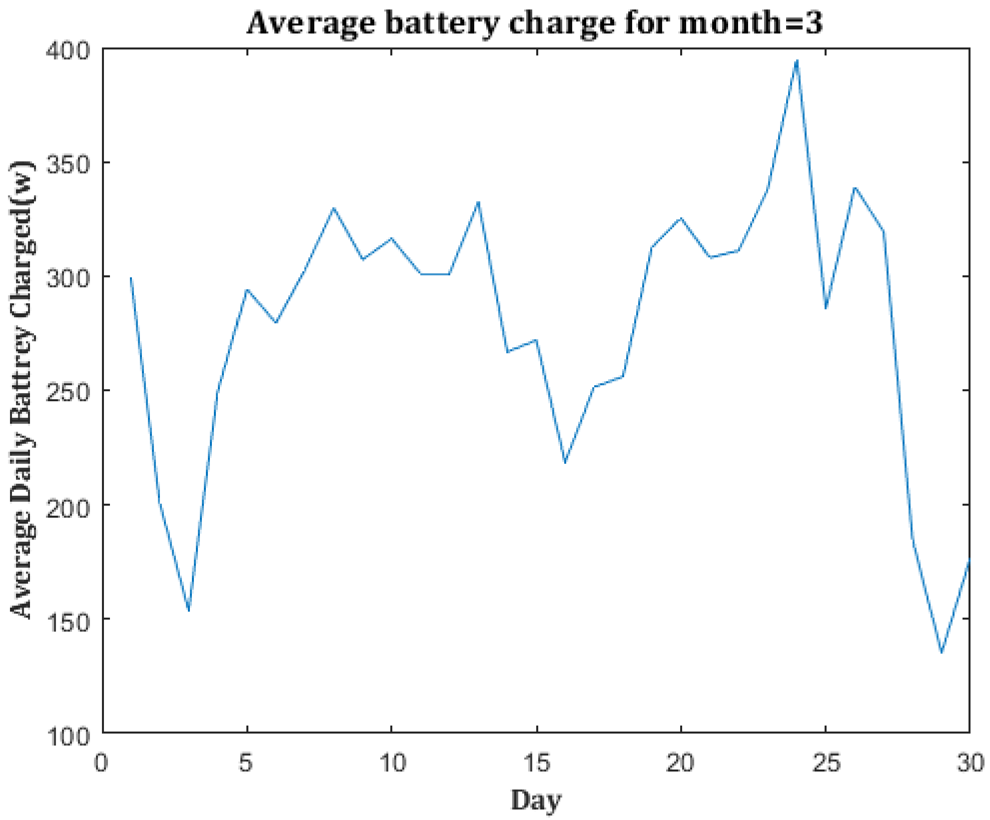


Figure (7-36) - average battery charge for month 3 of year

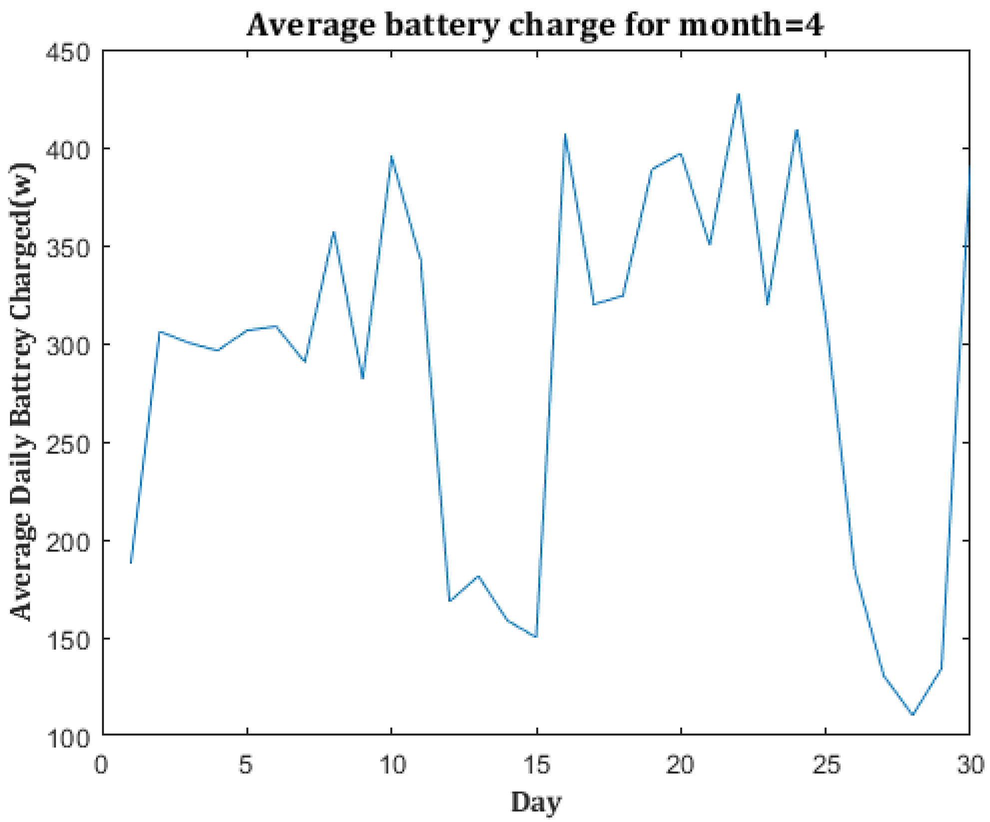


Figure (7-37) - average battery charge for month 4 of year

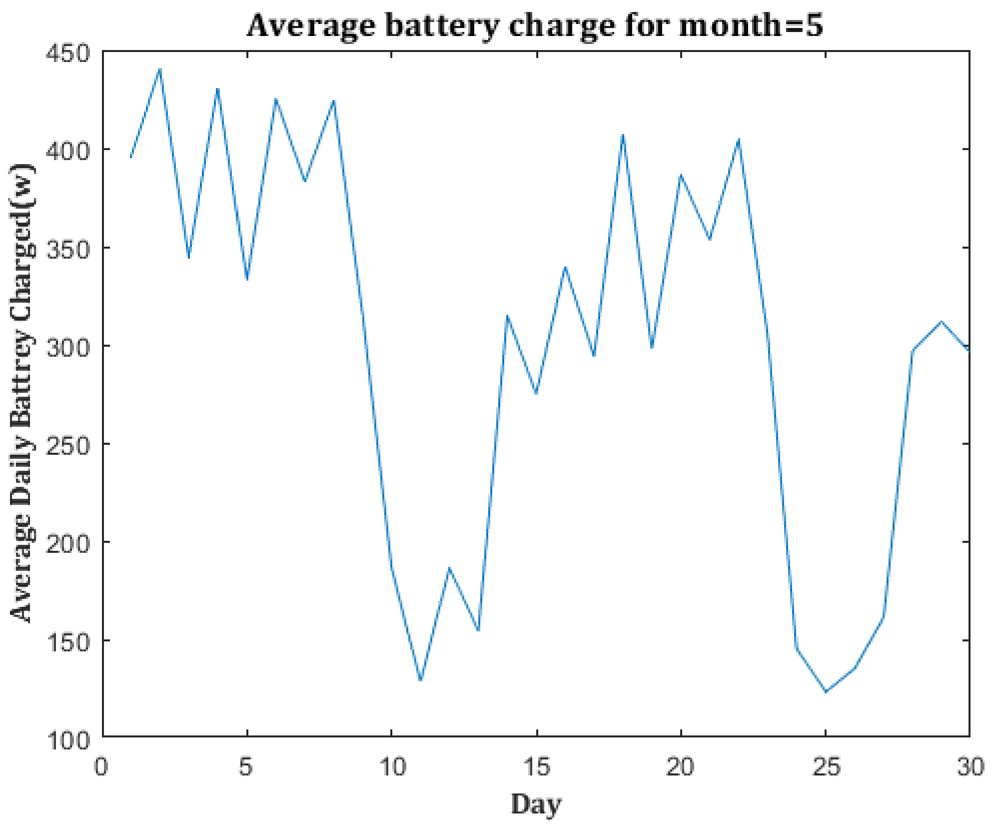


Figure (7-38) - average battery charge for month 5 of year

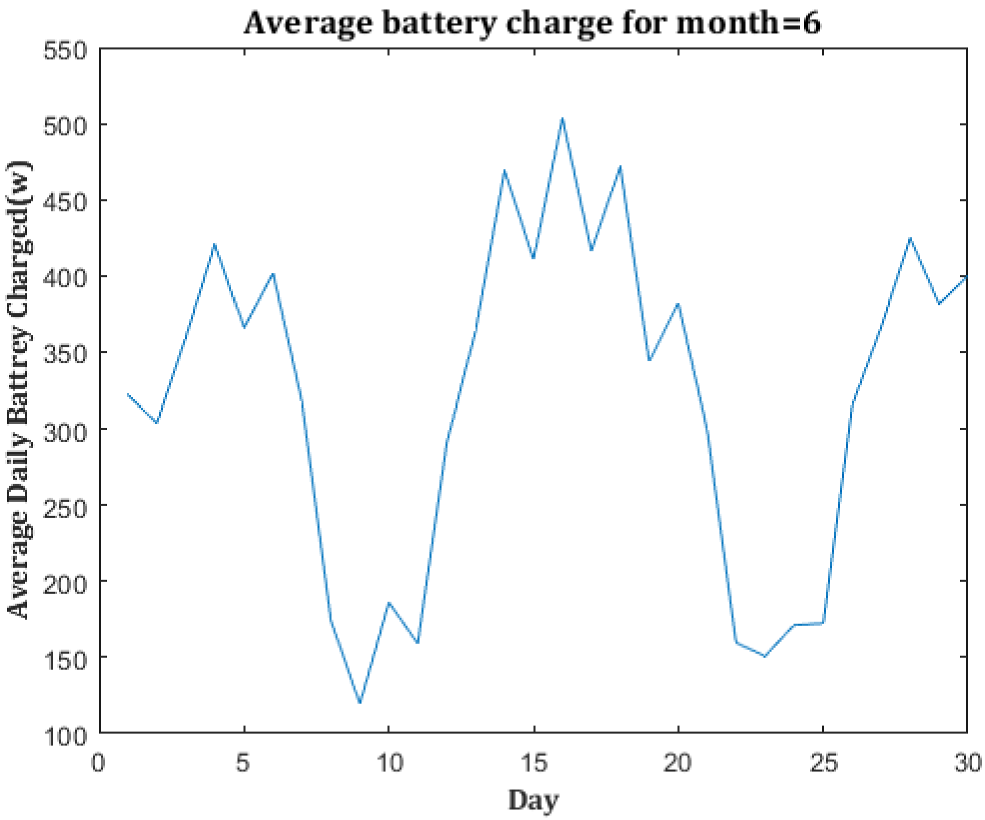


Figure (7-39) - average battery charge for month 6 of year

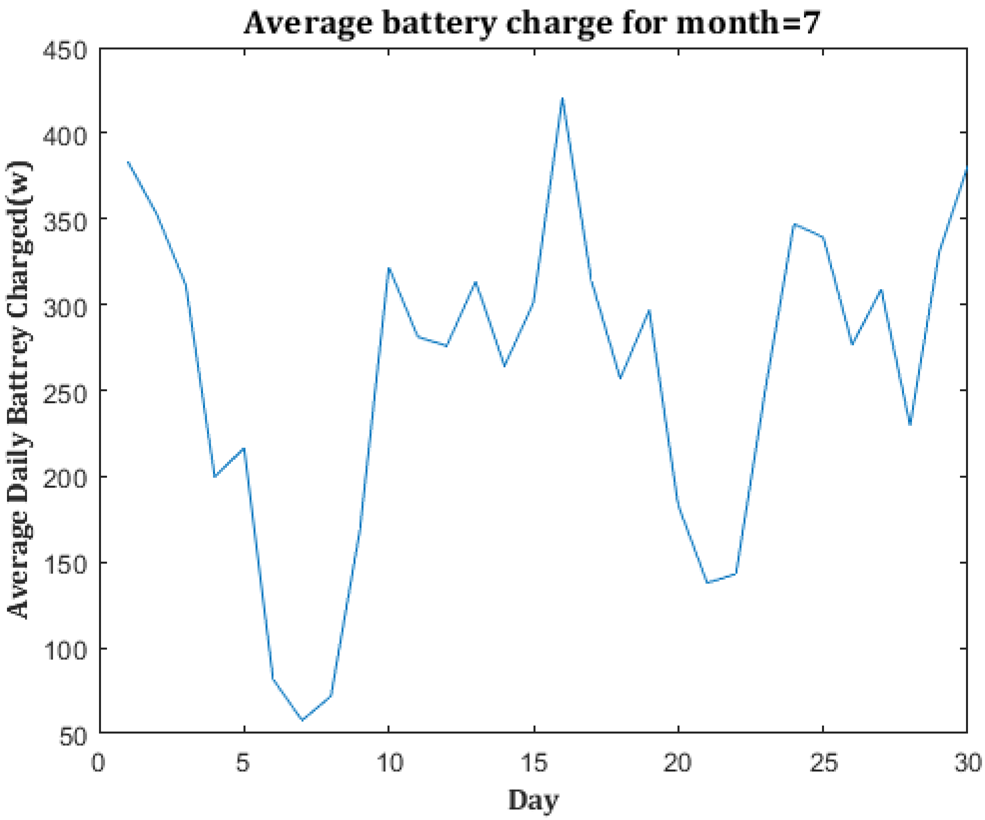


Figure (7-40) - average battery charge for month 7 of year

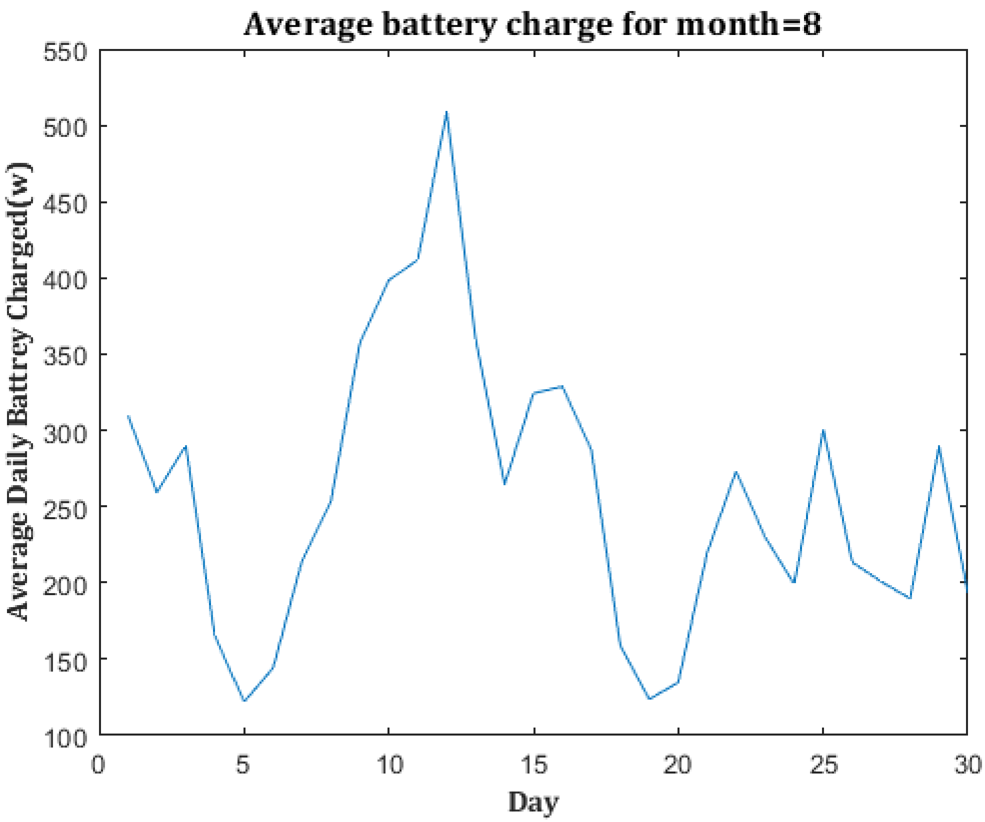


Figure (7-41) - average battery charge for month 8 of year

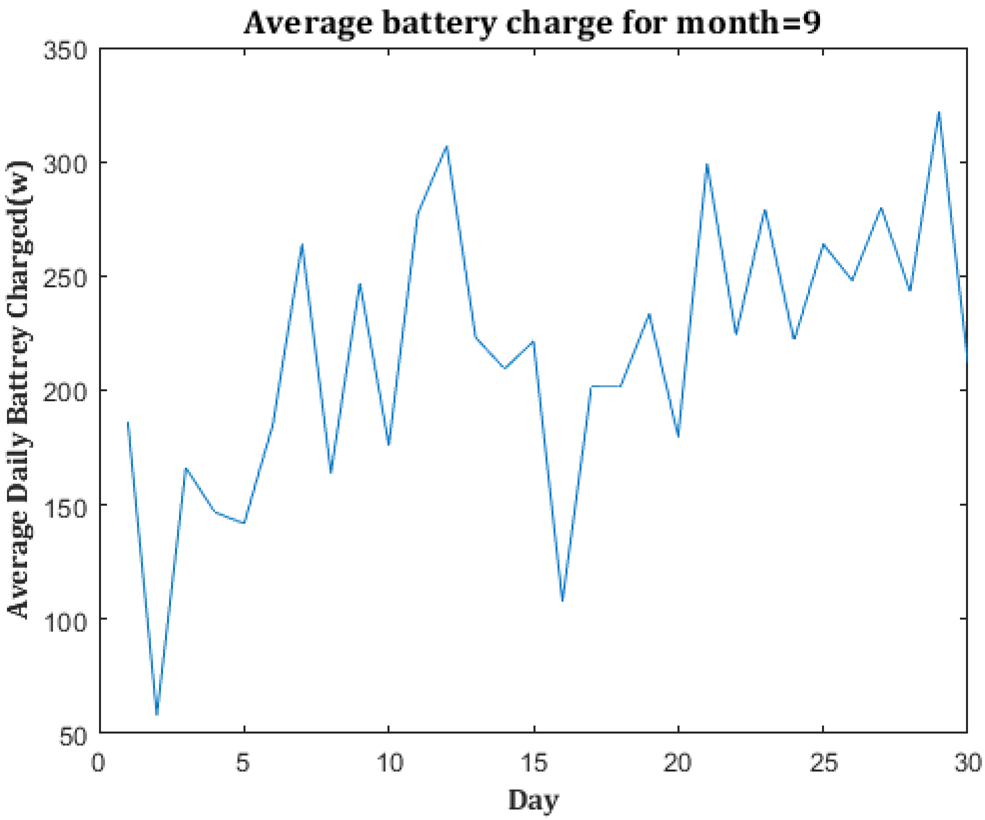


Figure (7-42) - average battery charge for month 9 of year

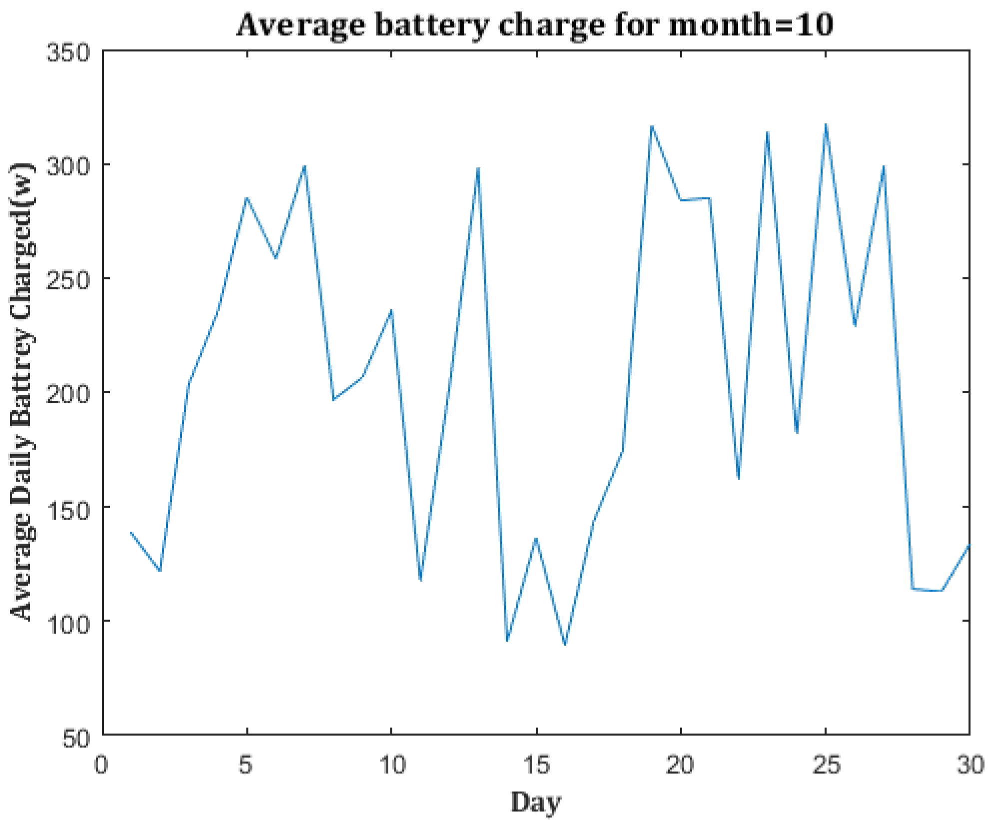


Figure (7-43) - average battery charge for month 10 of year

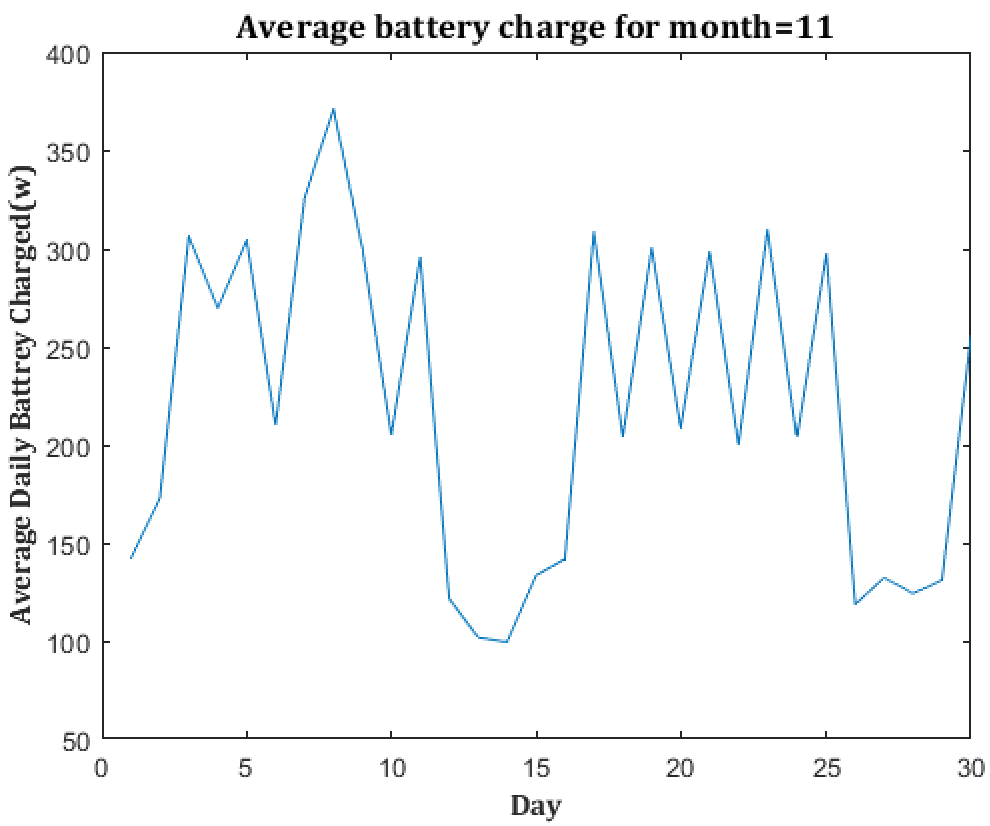


Figure (7-44) - average battery charge for month 11 of year

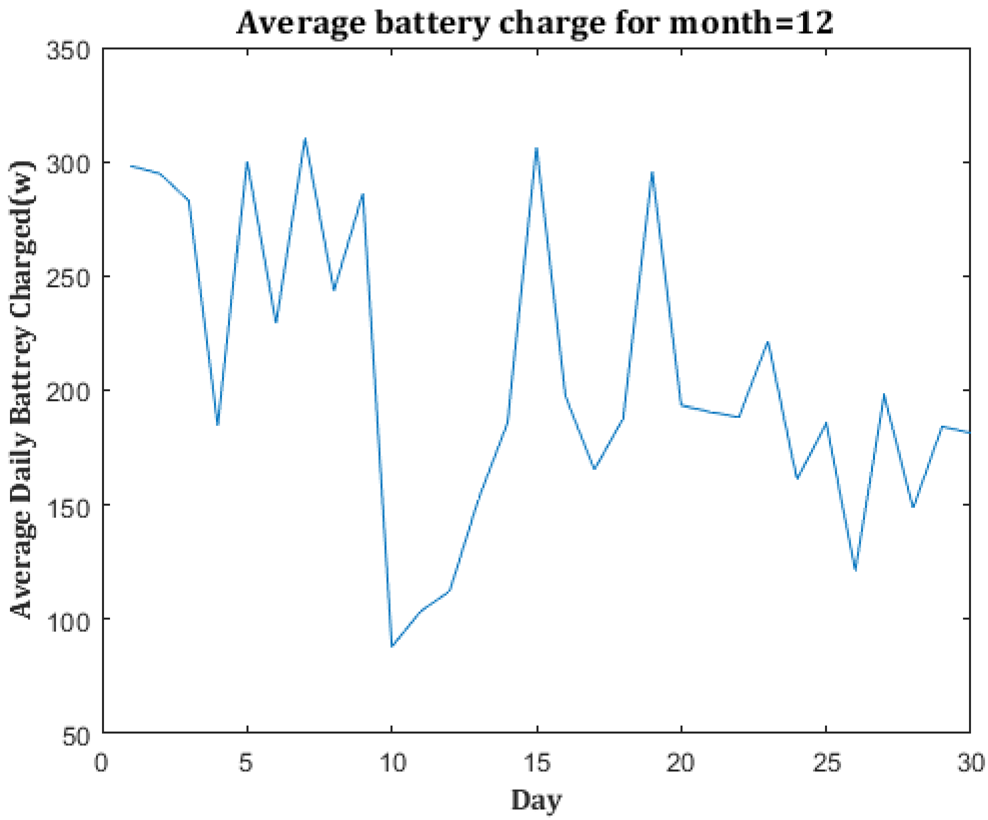


Figure (7-45) - average battery charge for month 12 of year

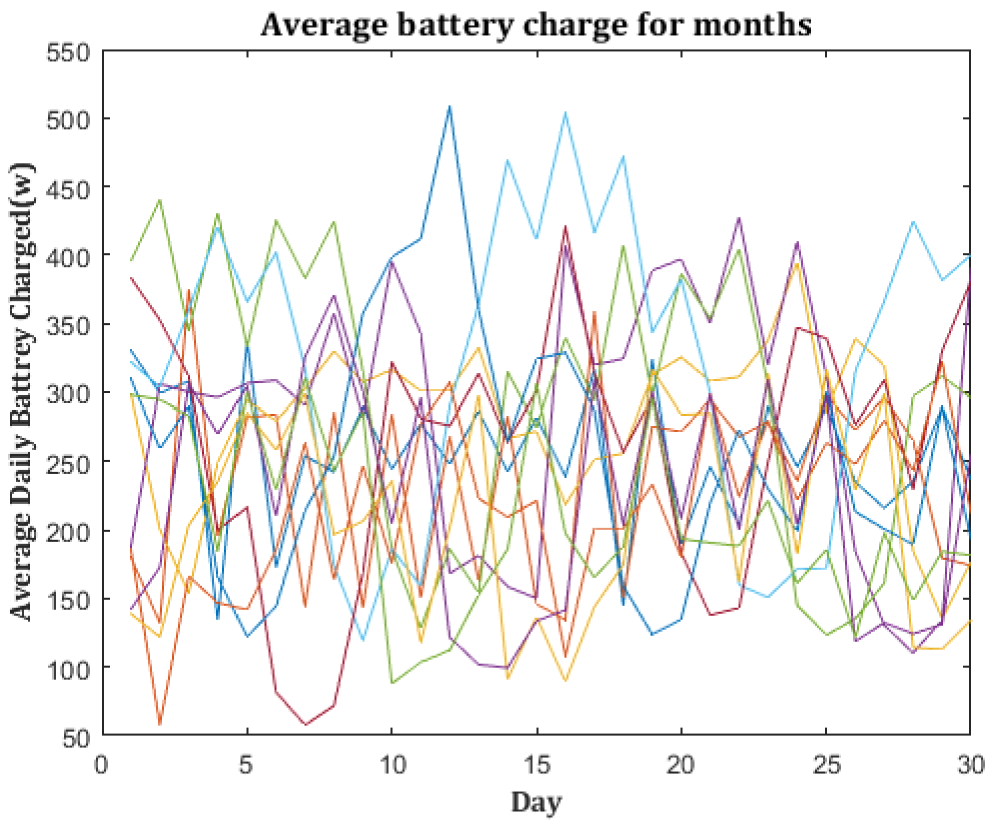


Figure (7-46) - average battery charge for all month of year

Figure (7-47) shows the additional energy required, ie the energy that consumers need to have so that there is no power outage, in which case it can be seen that the excess energy required is very high, and this energy It should definitely be provided by increasing the solar panel.

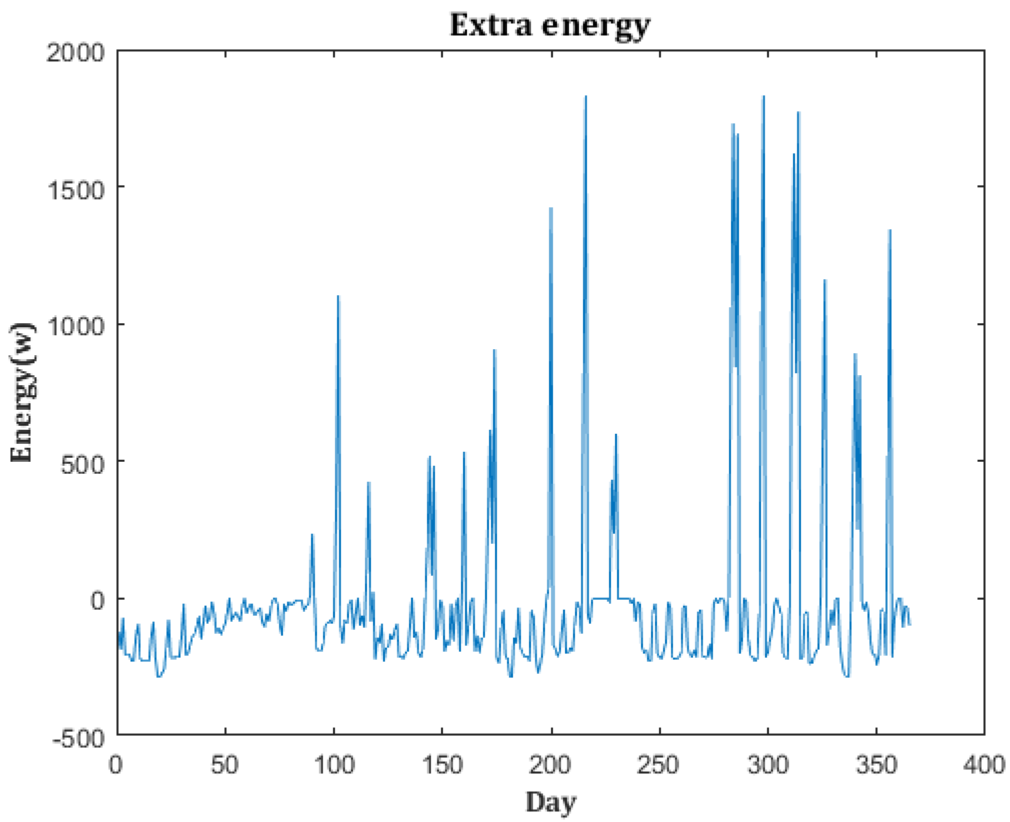


Figure (7-47) - Extra energy needed

If you look at Figure (7-48) , which shows the energy required for one day of the year every 30 minutes (the first day of the year), it can be seen that energy shortages occur during the day, and this is due to use during the day. And the reduction in use is during the night, and it should also be noted that this day is in the warm season of the year, and certainly during the day, due to the higher heat of the air, more energy is needed.

It can also be seen that considering that we considered the charging hours of EVs to be at the end of the night, exactly before 8 o'clock, a certain amount of energy is needed, which is approximately one third of the energy required for the day and during the day due to the use of equipment. Cooling requires more energy.

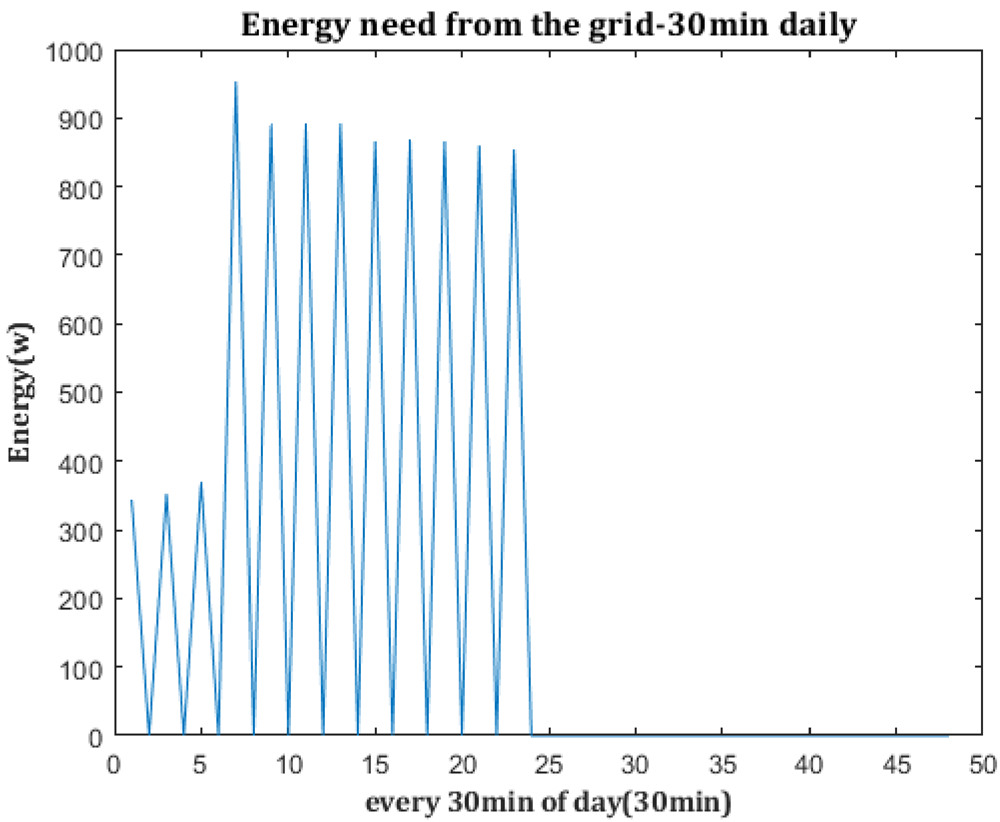


Figure (7-48) - energy need from the grid (30 min)

Figure (7-56) shows the additional energy required for the length of the year every 30 minutes. Carefully in this form, it can be seen that more energy is needed with the hot season, and this is a completely logical process.

7-6-2- **Scenario 2 (random initial value for EVs)**

In this scenario stochastic mode is enabled and EVs have initial values in charging time and they are not empty. EVs start charging time is 10 p.m and end time is 8 a.m but EVs can be fully charge before 8 a.m because they have initial values in this scenario.

We can see EVs daily consumption is less than scenario 1 which EVs have 0 initial values.

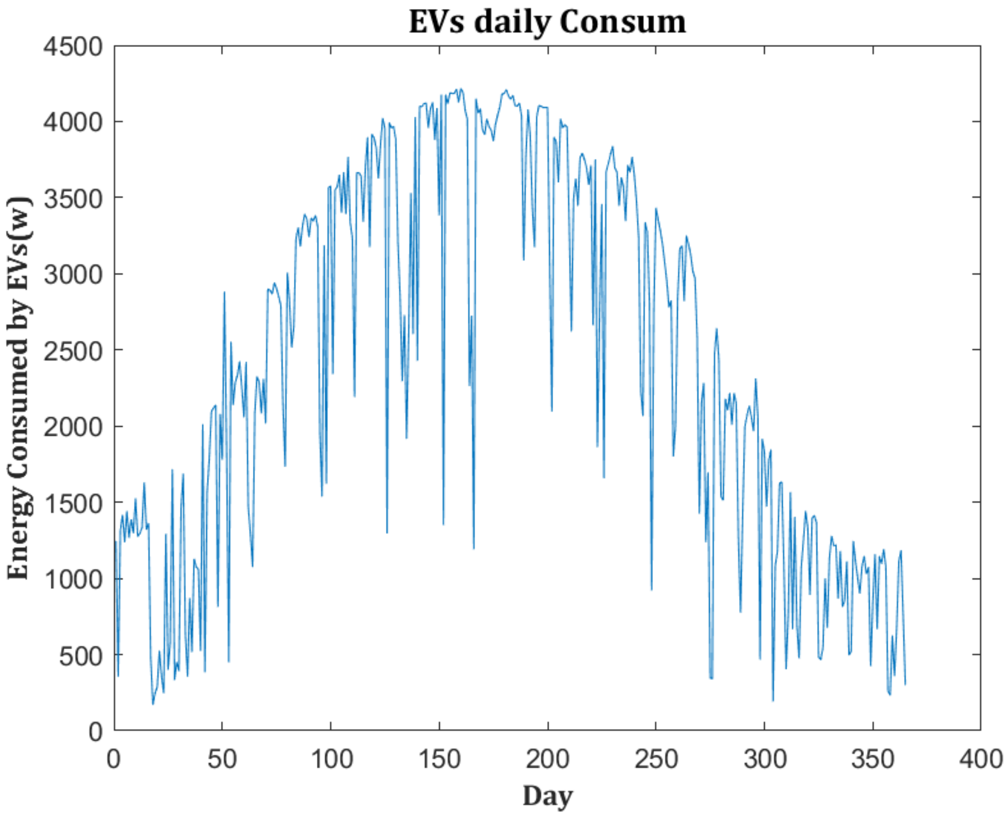
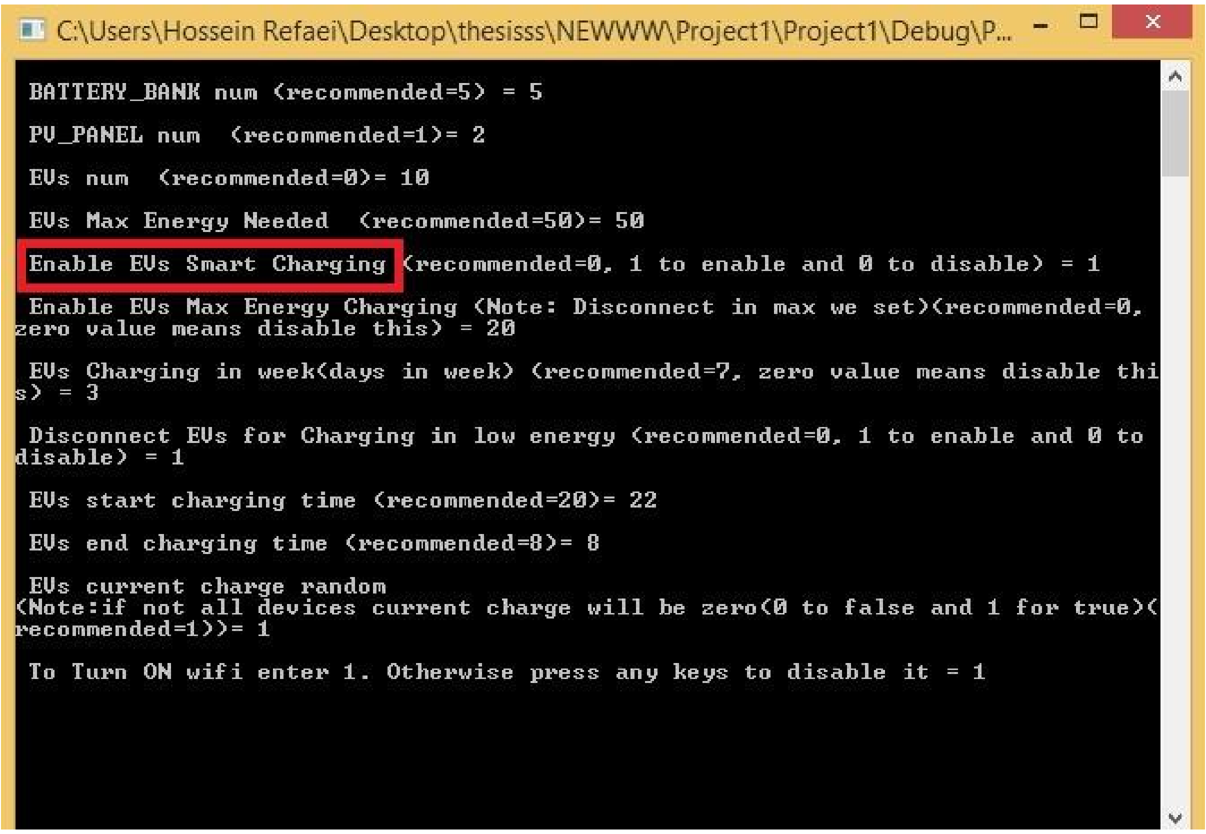


Figure (7-49) - EVs daily consume-scenario 2

7-6-3- **Scenario 3 (EVs smart charging)**



In this scenrioa stochastic mode and smart charging are both enabled for EVs. So EVs can be disconnected in low energy times.

In this scenario we have 3 policies:

For the input data, after giving value to 'EVs max energy needed, I have defined a new parameter 'Enable EVs smart charging. If we give value 0, it is normal routine, it means that charging will be done during a specific time, if the charge is full, it must be set aside and if the charge is not full, it must continue charging.

If we give value 1, smart charging is enabled. After that we have parameter 'Enable EVs Max Energy Charging'.This parameter is used when we want to specify a limit for charging.For example a mobile battery needs 50 units to be fully charged but we define smart charge 20 units, it means that when the battery reaches 20 units, it will be disconnected.If we set the value of the parameter (Enable EVs Max Energy Charging) to 0, it means that we do not want to apply this policy.

The next parameter is 'EVs charging in week (days in week)'.It means that how many days during the week we want it to be charged.For example if we set the value to 3 , it means that charging will be done just in 3 days of the week.

The next parameter is 'EVs for charging in low energy'. It means that if the panels and batteries were in the low energy mode (I have defined low or high modes), we don't want charging anymore and devices must be disconnected and so we don't need extra energy anymore because the devices are disconnected now. If we set the value of the parameter ('EVs for charging in low energy') to 0, it means that we do not want to apply this policy.

The next parameter is 'EVs start charging time'. I have set the value to start charging at time 22 (10 p.m)

The next parameter is 'EVs end charging time' that I set it to 8 a.m.

The next parameter is 'EVs current charge random'. If we set the value of the parameter to 1, we will have a stochastic mode, it means that a random amount of charge will be assigned to the device which wants to be charged.For example the charge period for a device is between 0 and 50.If we enable stochastic mode, a random charge (for example 25) will assigned to the device.So based on this stochastic (random) mode, a device can arrive at 8pm and it can be fully charged at 10pm. If we set the value of the parameter to 0, stochastic mode will be disabled.

In this scenario we can see in below gragh that daily Evs consum is less than scenario 1 and 2 so we can decide wich scenario is better in here. Scenario 3 is very better because in scenario 3, EVs charged smartly and in low enery times they can be disconnected automatically so this scenario is better than others.

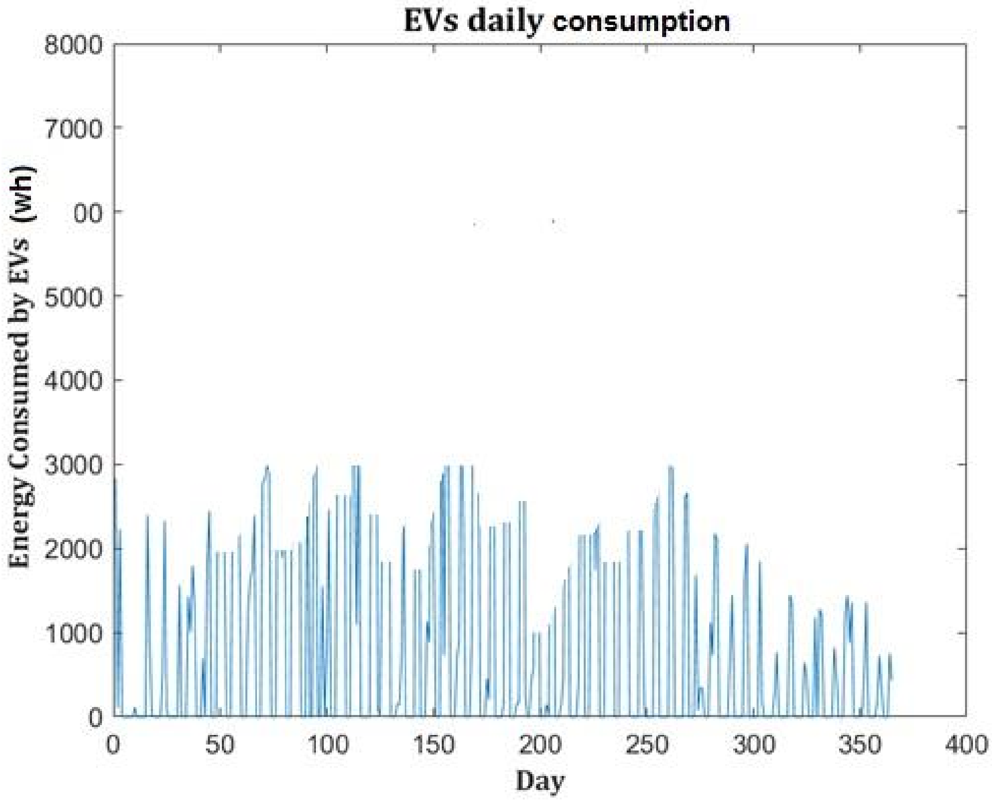


Figure (7-50) - EVs daily consume – scenario 3

- **Comparison between Scenrios for EVs daily consumption**

EVs daily consumption when we have enabled stochastic mode (scenario 2):

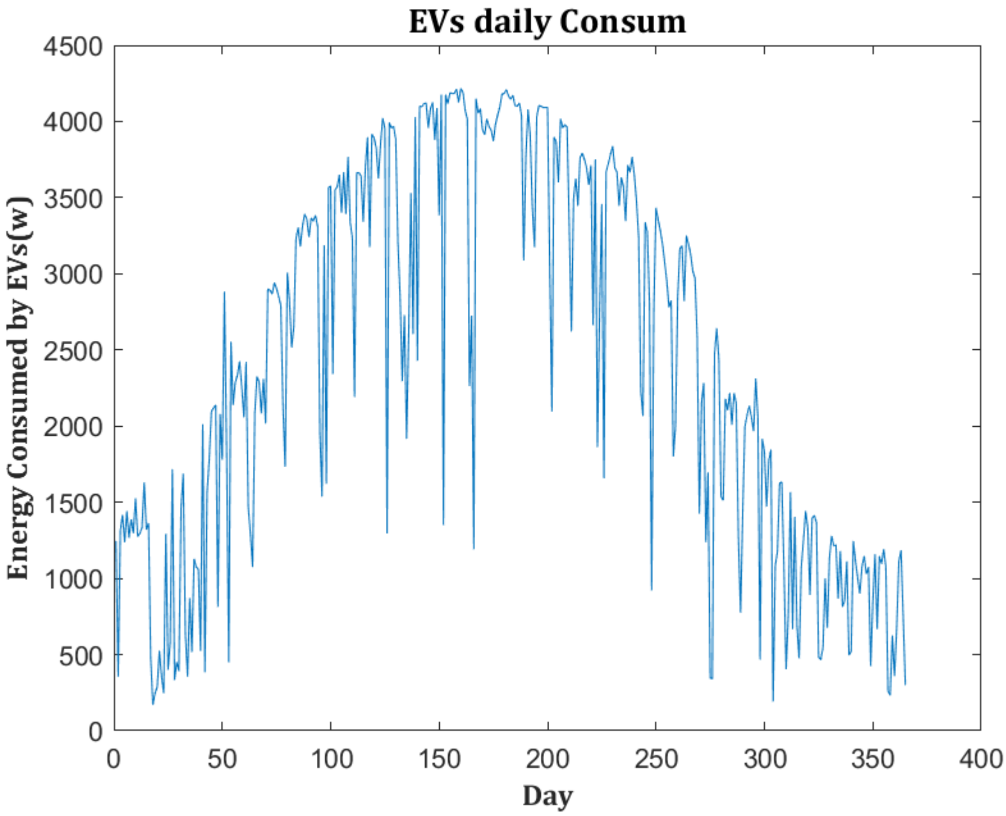


Figure (7-51) - EVs daily consumption(stochastic mode)

EVs daily consumption when we have enabled smart charging (scenario 3):

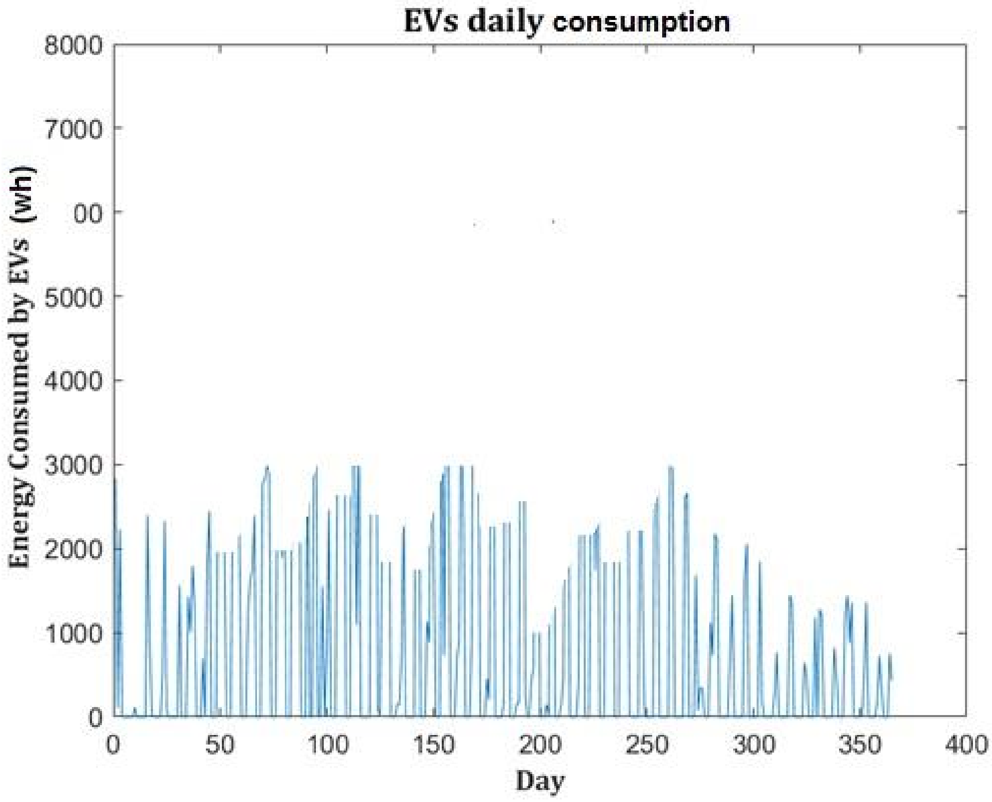


Figure (7-52) - EVs daily consumption(smart charging)

In the first scenario, we have one Ev and based on the inputs, the output result for daily consumption during year is shown.

For scenario 2, we have added some electrical vehicles and we can see that overall energy consumption has increased during the year. Also in this case, we don't have any limitation for our Evs to get charged and they can reach the maximum charging capacity.

For scenario 3, the number of Evs is the same as scenario 2 but we have enabled smart charging and based on our policies (which I explained them before), some limitations have been defined by us and it is clearly obvious that the energy consumption has been decreased in comparison to previous scenario.

- **Comparison between Scenrios ffor Average battery charge in days of month May**

When we have enabled stochastic mode:

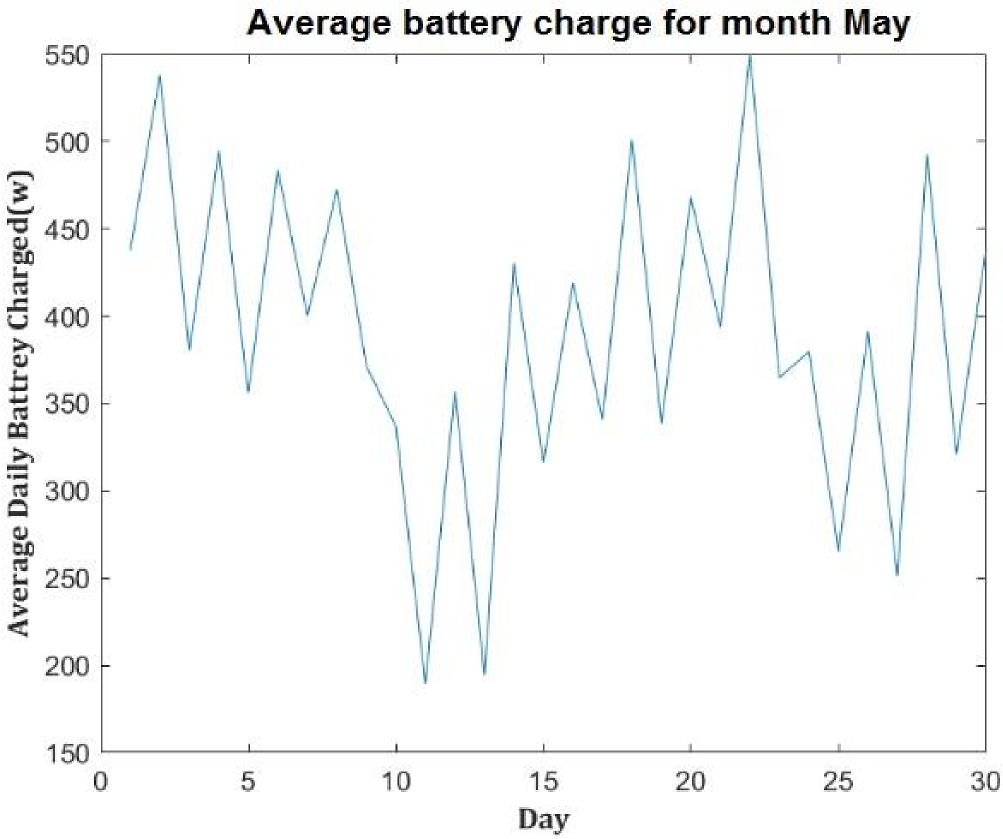


Figure (7-53) - Average battery charge(stochastic mode)

When we have enabled smart charging:

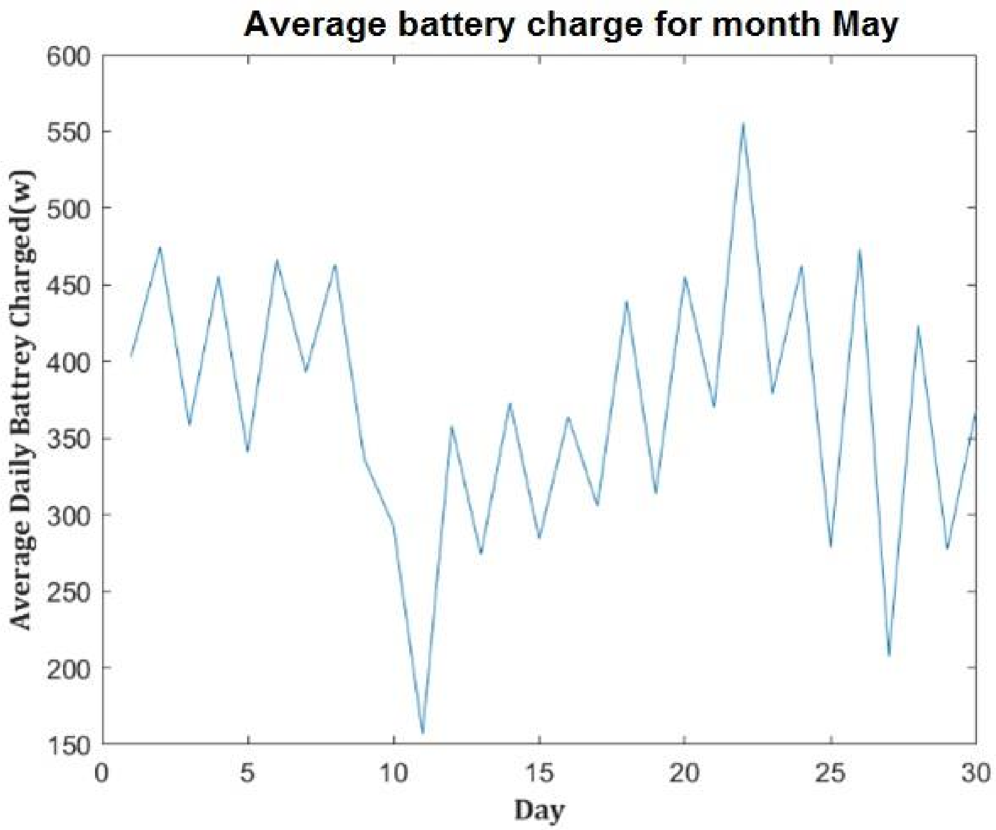


Figure (7-54) - Average battery charge(smart charging)

As we can see in the graphs, when we have enabled our policies in smart charging, the amount of average battery charge is reduced in comparison to first graph.In the first graph, we don't have any limitation for our devices to get charged and they can reach the maximum charging capacity .

7-7- Energy need from the grid-30 min daily(including EVs)

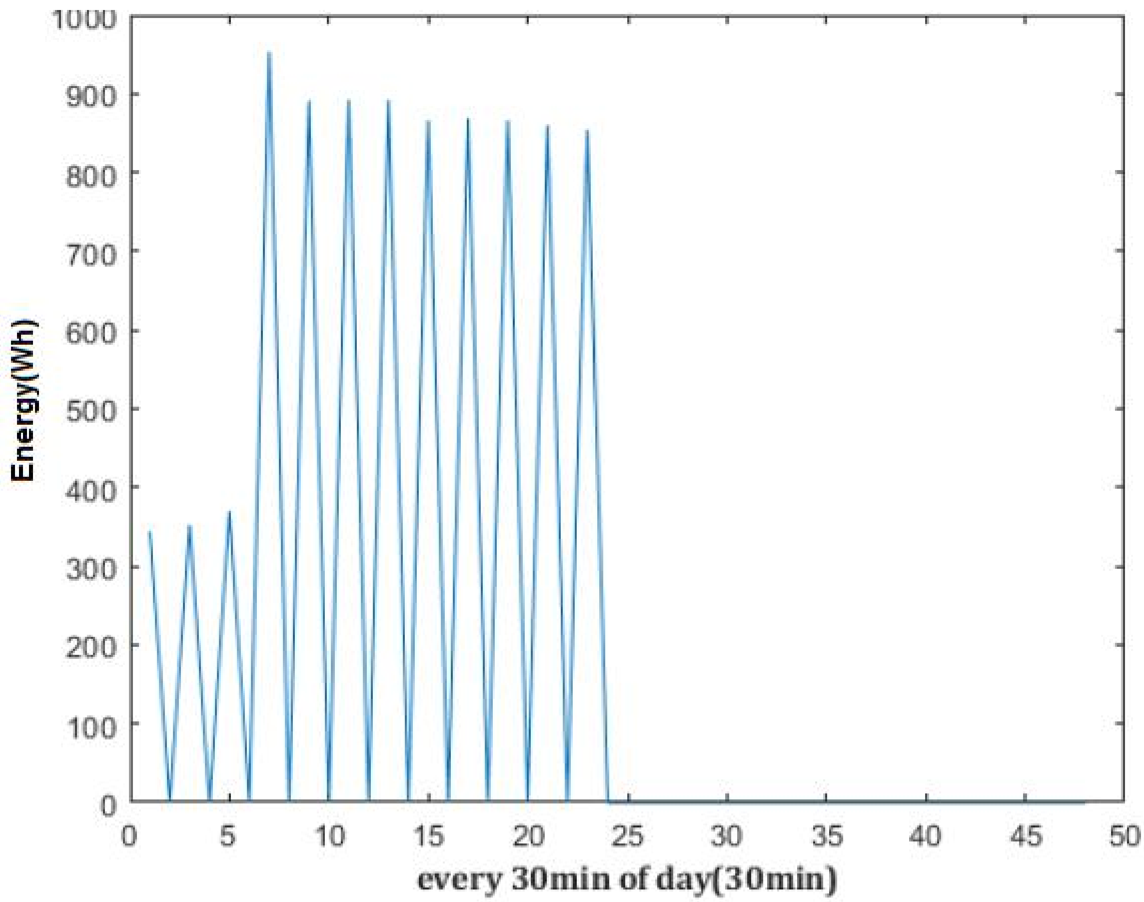


Figure (7-55) - Energy need from the grid-30 min daily(including EVs)

This graph shows the energy required for one day of the year every 30 minutes (the first day of the year), it can be seen that energy shortages occur during the day, and this is because of more energy usage during the day. And the reduction in use is during the night(as we can see in the graph), and it should also be noted that this day is in the warm season of the year, and certainly during the day, due to higher temperature, more energy is needed.

It can also be seen that considering the charging hours of EVs to be at the end of the night, exactly before 8 o'clock, a certain amount of energy is needed, which approximately one third of the energy is required for the day and during the day requires more energy.

Initially, when these electric devices are going to be charged, they have a battery, which does not necessarily have a power of 0, and each of them may have an initial energy level, so in this simulation, it is considered that these electric devices have some initial energy, and then in the simulator, the start and end time is received, and how long it takes for the charge to start and end. The capacity of the batteries of these electric devices is also considered different, so that the simulator can be closer to the real values. At the beginning of the work, the number of electric devices is received as an input to know how many electric devices need to be charged and how much charge for these electric devices in each unit of time.

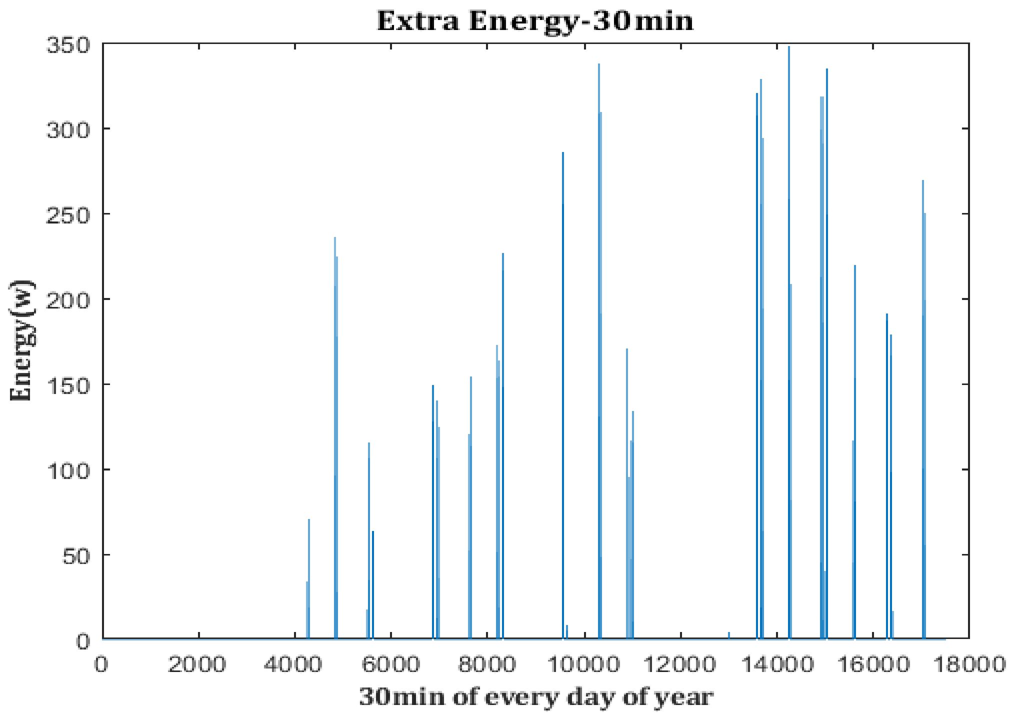


Figure (7-56) - Extra Energy needed for a year 30 min step

Figure (7-57) shows the energy required to charge batteries in different seasons separately. Due to this shape, consumption is higher in spring and summer, and it should be noted that due to the existence of EVs, energy consumption generally increases throughout the year.

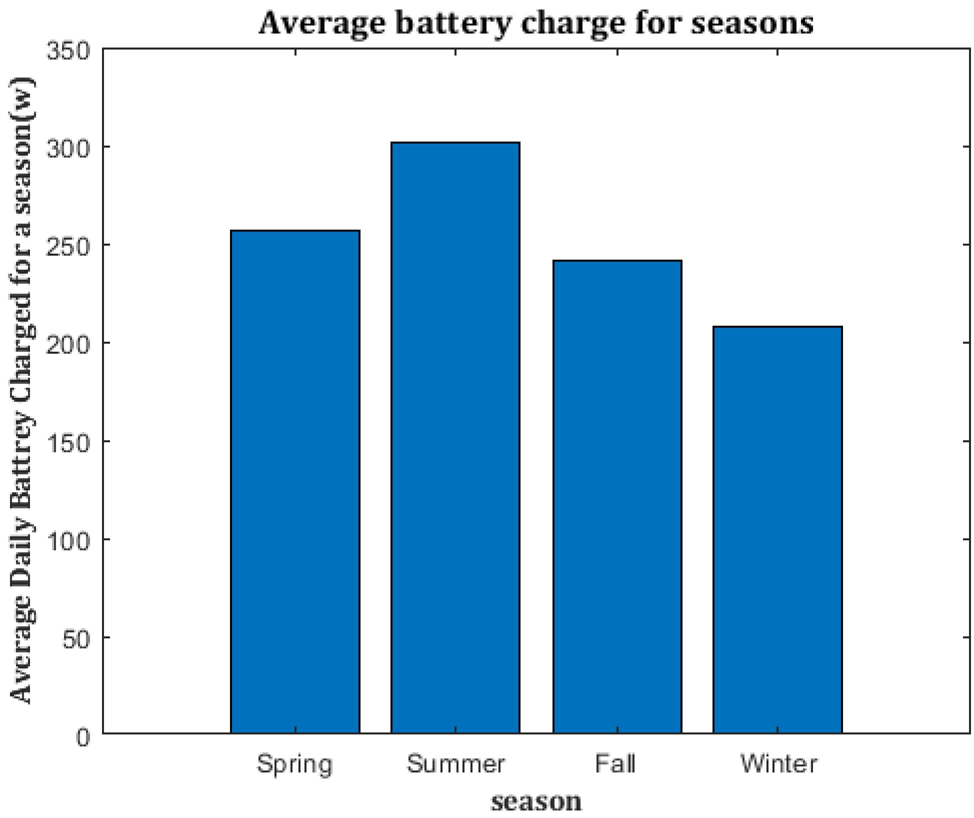


Figure (7-57) - average battery charge for seasons

6-12-Conclusion

This chapter examines system model and emphasizes its importance in energy consumption.In this chapter we implemented different scenarios and we could see the different results on the output results.

Chapter 8: Conclusion and Recommendations

8-1- **Introduction**

This chapter summarizes the research and offers suggestions for future work.

8-2- **Conculsion**

In this work, the interaction between the Mobile Network and Household consumers was investigated to see whether it improves the Mobile Network response to the Smart Grid requests. Mobile Network and Household consumers were modelled in a Demand Response framework. Their reaction to Smart Grid commands was described along with their collaboration. Whenever the Mobile Network is not able to effectively react to a DOWN request, it asks support to Household consumers. Households, depending on their bent to accommodate the Mobile Network requests, give a percentage of their energy reduction to the Mobile Network, so that it can better satisfy the Smart Grid requests.
In addition, home consumption was considered and in 30 minutes it was analyzed at what hours and under what conditions these uses become more or less. Consumption was also analyzed throughout the year, and it was observed that in summer and spring, consumption is much higher due to the use of cooling devices, and there must be more energy to prevent power outages.
If the battery is not used, energy will be lost, ie the energy produced in the panel will be lost if there is no consumer, and this is not a good practice, so you must use the batteries next to the solar panel to This energy can be properly collected and used the energy stored in batteries is very useful in high consumption seasons such as summer and spring and can prevent severe power outages, as well as wasted energy.
It was shown that the impact of the Households support to the Mobile Network does not depend on the strategies that the latter uses to manage its energy consumption (such as WiFi offloading and Resource on Demand). Indeed, the energy given to the Mobile Network depends on the distribution of Smart Grid requests and on the percentage of energy that Households decided to give to the Mobile Network for improving its response to the Smart Grid requests.
It was shown that the amount of energy and bill saving that Households can

provide to Mobile Network increases as the number of DOWN requests from the Smart Grid increases. Depending on Smart Grid values, as much as 1.5% energy and up to 6% bill savings were obtained. Furthermore, by increasing the percentage of energy that the Households give to the Mobile Network, the amount of saving increases. With the values considered in this study, up to 2.7% energy and 11% bill savings can be achieved. Yet it is also shown that this increase is not proportional to the percentage increase. This is because, with high percentages, the corresponding amount of energy can exceed the Mobile Network needs.

However, the distribution of Smart Grid requests cannot be known in advance and increasing the percentage of energy reduction that the Households give to the Mobile Network is not suitable in reality. Smart Grid requests depend on real electricity prices and so their value cannot be known in advance.

Hence, also the amount of saving cannot be predicted. Furthermore, even if Network response to the Smart Grid commands were further improved by increasing the percentage of energy that Households could give to Mobile Network, its increase is unrealistic.

Nevertheless, even in the worst case, considering that in reality Mobile Networks dimensions are much higher than the one considered in this study, an improvement in response to Smart Grid commands can be obtained. The energy consumption can be reduced by 0.7% and a savings of 2.5% is possible.

It was also shown that varying the PV Panels and Batteries sizes a considerable reduction in the annual expenditure of the Mobile Network can be obtained. With five Photovoltaic Panels and ten Batteries up to 30% savings was obtained.

We use different scenrios for EVs and we saw that scenario 3 that use smart charging is better than other scenarios. In scenario 3 can be happen in real world to because in this case EVs can be disconnected in low energy mode and in some cases, we face the problem of lack of energy, and in these cases, electric vehicles do not have the priority of using energy, and it is better to set them aside or to consider some energy to charge these appliances, which in this simulation as well. It was considered and observed that it also includes much better results.

8-3- **Future works**

It is possible to consider every 1 minute in the study and for a full day to study when exactly the consumption is reduced or increased and for those hours limited life batteries are used, thus Costs are drastically reduced.

It is possible to use data mining in this research and predict when or at what times we will face a decrease in energy, and in this regard, we will use the energy of batteries only for those hours and try to peak consumption for these hours. The batteries are fully charged and in some cases we can even use more panels if needed to avoid power outages. Renewable energy are low and in this case we must be very diligent in maintaining and using them and we must always look for solutions to reduce consumption and optimal use of this type of energy so as not to suffer from energy shortages.

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