**An-Najah National University**

**Faculty of Graduate Studies**

# Smart Grid as a Potential Solution for Problems of Local Electric Network in Tulkarem City/ Palestine

**By**

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**This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Electrical Power Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus -Palestine.**

**2017**

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# Dedication

*To our prophet Mohammed*

*Blessings and Peace be upon him*

*To my father*

*To my mother*

*To my wife*

*To my sons (Malek, Yousef, & Awus), and daughter (Nada)*

*To my brother, and sisters*

*To my big family*

*To my teachers*

*To all friends and colleagues*

*To all of them,*

*I dedicate this work*

## Acknowledgment

To begin with, acclaim is to Allah for helping me in making this thesis possible.

I might want to express my honest gratitude of my advisor Dr Mutasim Baba, for his direction, motivation, support and giving me trust to complete the research.

My parents, wife, brother, sisters, friends, and all my family thank you for being a wellspring of support and motivation. I am appreciative to every one of you for your love, and support.

My thanks and respects go to the staff of Electric Power Engineering Master Program at An-Najah National University, especially Dr Maher Khammash for his valuable suggestions and assistance.

At long last, I might want to thank, everyone who was vital to the successful realization of the thesis, as well as expressing my apology that I could not mention personally one by one.

## الاقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

**Smart Grid as Potential Solution for Problems of Local Electric Network in Tulkarem City/ Palestine**

اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة اليه حيثما ورد، وان هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أي درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

## Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

| | |
|---|---|
| **Student Name**: | **اسم الطالب:** |
| **Signature:** | **التوقيع:** |
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# Table of Contents

# List of Table

# List of Figure

**Smart Grid as a Potential Solution for Problems of Local Electric Network in Tulkarem City/ Palestine**

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## Abstract

In the twenty-first century, the most critical and important issues relating to energy systems are smart grid technologies and renewable energy technologies. The development of the current centralized generation in the form of distributed generation and smart grids offers a great opportunity to eliminate many issues related to energy efficiency, energy security, energy quality and the defect of the outdated energy system infrastructure. The current electrical systems in Palestine are decades old and dependent upon equipment that is approaching the end of its usable life. Smart grid gives an opportunity to update power network infrastructure, ensuring that safety standards continue to be met, that power is delivered consistently, and that the system is managed efficiently.

For the specific case of Tulkarem city, the power network suffers of major problems. These problems include peak load violation, high technical and non-technical losses, lack of control over loads and the new evolving distributed generation. Peak demand puts considerable stress on the grid, increasing the risk of blackouts in very hot or cold days. It also significantly raises the year-round price of power for consumers. Better information and decision-making during times of peak demand could significantly reduce generation costs and the risk of power outages.

In this thesis, the researcher studied the possible strategies for converting the existing grid in Tulkarem to a smart grid. Some demonstrated technologies will have a part pretty in pushing ahead. This incorporates advanced digital meters (Smart meter), low-cost communication systems, distribution automation, and distributed energy resources. At the end, the researcher investigated the possibility to solve the chronic problems of existing power grid. Through data analysis and simulation, the researcher proves that it is possible to reduce peak loads and flatten the daily load curve by using an integral approach that includes smart metering, load control, distributed generation of PV systems and reasonable energy storage. This approach only possible with a smart grid with a suitable data communication network.

# Chapter One
# Introduction

## 1.1. Problem definition

With the increasing demand for energy, the numerous problems facing the electric grid in the city of Tulkarem of frequent power outages, voltage drop, and increasing losses in the grid. The Electricity Department in Tulkarem Municipality tends to solve the shortage in capacity by increasing contracted purchased capacity from the Israeli Electric Company (IEC). The system operators do not use moderate administrative means to meet the demands of consumers rather than purchasing extra capacity, as potential solution. This approach, unfortunately, makes a completely untapped energy systems and consumption patterns of customers increasingly irresponsible. In addition, the Municipality pays for this huge long term investments, which usually have to wait for long times before an approval from IEC is received. This electric distribution body at the Municipality never tried to implement modern technologies of energy management to solve such problems. The failure to meet the increasing demand for electricity in days with harsh weather usually leads partial or complete power interruption from the supplier (IEC).

## 1.2. Research Objectives

In order to divert the current situation, others fully exploited, make the best use of the available energy without the urgent need to import new energy, using existing capacity more efficiently, and great care must be taken to allocate resources optimally. The easiest way, cleaner, and safer for better matching between demand and supply, and improve network performance, are deploying demand side management practices at various loads through network flow control, integrate the renewable energy generation systems accordant with the grid, and working to reduce losses; in particular non-technical losses, through intelligent control.

The objective of this research is to highlight the current network performance, and the possibility of switching to a smart grid, to be the potential solution for different problems in the network. Smart grid has the capacity to manage the loads to reduce peak electricity consumption according to utility controls and consumer preferences, the exploitation of renewable energy generation systems in response to the request, management of energy storage, and detect the illegal use of energy. Thus improving load factors to subscriber demand, and therefore the benefits on the grid.

The benefits of switching to smart grid are numerous: postpone capital-intensive investments in increasing the amount of new energy, reduce the maximum power requirements and overall energy consumption, improving system operation, and improve the reliability, flexibility and durability of electrical grid. These benefits will produce a positive impact on the environment by reducing greenhouse gas emissions.

## 1.3. Research Methodology

This research aims to identify the smart grid's capacity in solving problems the conventional network cannot solve. The primary aims are to study the impact of smart grid combined with distributed generation, the impact of smart grid in flow control to detect illegal use and its relevance to reduce losses. Another aim is to examine the impact of the administrative policies on smart grid stability and reliability.

## 1.4. Thesis Layout

The thesis is composed of seven chapters. This part presents the problem definition, the research objectives, and the research methodology in handling the problem in core interest. Chapter two presents the state of the art of Smart Grid technology and its framework. This chapter also includes a variety of communications systems for Smart Grid applications.

An overview on Smart Grid devices and applications is presented in Chapter three. It also gives a basic description for Smart grid-provided policies to improve the functioning of the electricity distribution service.

Chapter four gives an overview of Tulkarem City and electric supply in it focusing on the challenges ahead, with a focus on electricity system statistics.

Chapter five gives details on Smart Grid experimental setup and trial procedures. Case studies, results and examinations on the above work is incorporated in this chapter. Discuss the significance and a detailed feasibility study of the practical implementation of Smart Grid in Tulkarem is the purpose of chapter six. Conclusions and recommendations for future extension of this work are presented in Chapter seven.

# Chapter Two
# The Smart Grid

## 2.1. Introduction

The existing electric grids in most developing countries use the technology of 1970’s, which is a centralized controlled in unidirectional flow. Moreover, the aging power grid will suffer from different problems, such as low quality, high running costs, theft, and lack of consumer’s satisfaction. Therefore, we require a modernized grid, which is less centralized, and more consumer interactive. Such a grid is called a “smart grid” which has the intelligence to improve power network reliability, flexibility, efficiency, and economy.

## 2.2. Definition

The smart grid does not have one definition as standard, and there are many definitions around the world. For example, the International Energy Agency (IEA of the US) defines the smart grid as “an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability” [1]. Moreover, U.S Department of energy (DOE) defined smart grid in 2009 as “A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources" [2]. In another country, according to Ontario smart grid forum in Canada, smart grid is defined as "a modern electric system, It uses communications, sensors, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system. It offers consumers increased choice by facilitating opportunities to control their electricity use and respond to electricity price changes by adjusting their consumption. A smart grid includes diverse and dispersed energy resources and accommodates electric vehicle charging. It facilitates connection and integrated operation" [3]. And according to Gharavi & Ghafurian (fellow IEEE) they define smart grid as "an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable" [4]. As for the European technology platform for the electricity networks in the future define the smart grid as "an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies" [5]. Ali Keyhani defines the basic concept of smart grid: " it can provide a platform to maximize reliability, availability, efficiency, economic performance, and higher security from attack and naturally occurring power disruptions" [6]. In another words the initiative of smart grid can be characterized by the integration of many of technologies that will help rectify the reliability and efficiency of electricity supply and reduce the cost of supplying electricity to the consumers [7].

## 2.3. Variations between traditional network and smart grid

The Smart grid has different key applications that make it a future choice for all electric companies. As shown in figure 2-1, these applications include transmission automation, renewables integration, energy efficiency, distributed generation and storage, demand side management and smart metering.

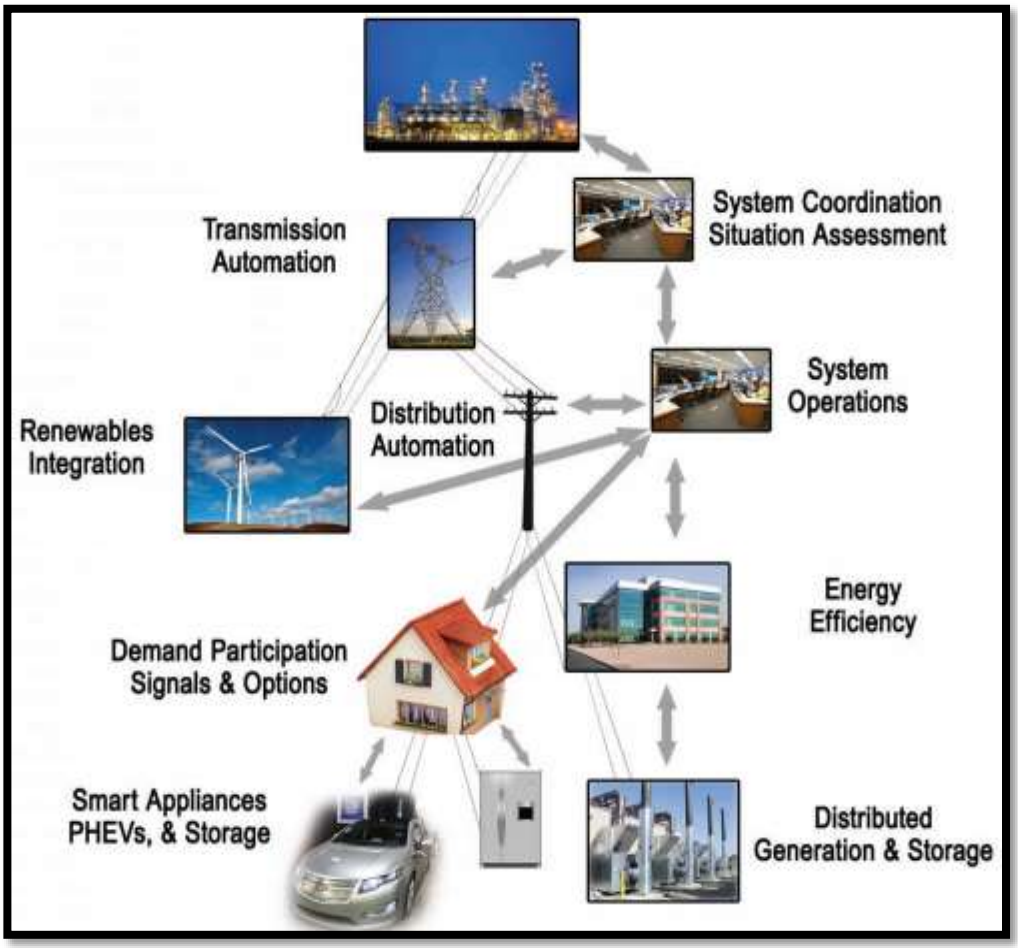


***Figure* 2-1*: Key components and applications of smart grid*** (Source: U.S Department of Energy, Smart grid system report, USA, 2009).

Smart grid will be clearer by comparing it with traditional grid, a general summary differentiation of the two grids is illustrated in table 2-1.

**Table 2-1: A Comparison between the current grid and smart grid**

| Application | Current Grid | Smart Grid |
|---|---|---|
| System communication | Limited to power companies | Expanded, real time |
| Interaction with energy users | Limited to large energy users | Extensive two-way communication |
| Operating & maintenance | Manual ad dispatching | Distributed monitoring and diagnostics, predictive |
| Generation | Centralized | Centralized and distributed, substantial renewable resources, energy storage |
| Power flow control | Limited | More extensive |
| Reliability | Based on static, off-line models | Proactive, real-time predictions, more actual system data |
| Restoration | Manual | Decentralized control |
| Topology | Mainly radial | network |

*(Source: Ali keyhani, Design of smart power grid renewable energy systems, USA, 2011).*

## 2.4. Infrastructure

Referring to previous definitions of Smart Grid, future smart grid can be modeled as shown in figure 2-2, which present an integration of electricity infrastructures and communications. Historically, The energy industry has been organized, planned and modeled to maintain low costs. Therefore, its modernization has always been of low priority in the past. For the modern and digital world of twenty-one century, however, it is important to have a smarter network capable of facilitating a sound economy, to enhance energy security, provide more efficient and more environmentally friendly service. As indicated in the IEEE 2030 standard [8], the smart grid structure is based on linking three sub-systems:

- Electric power system.
- Communication system.
- Information system.

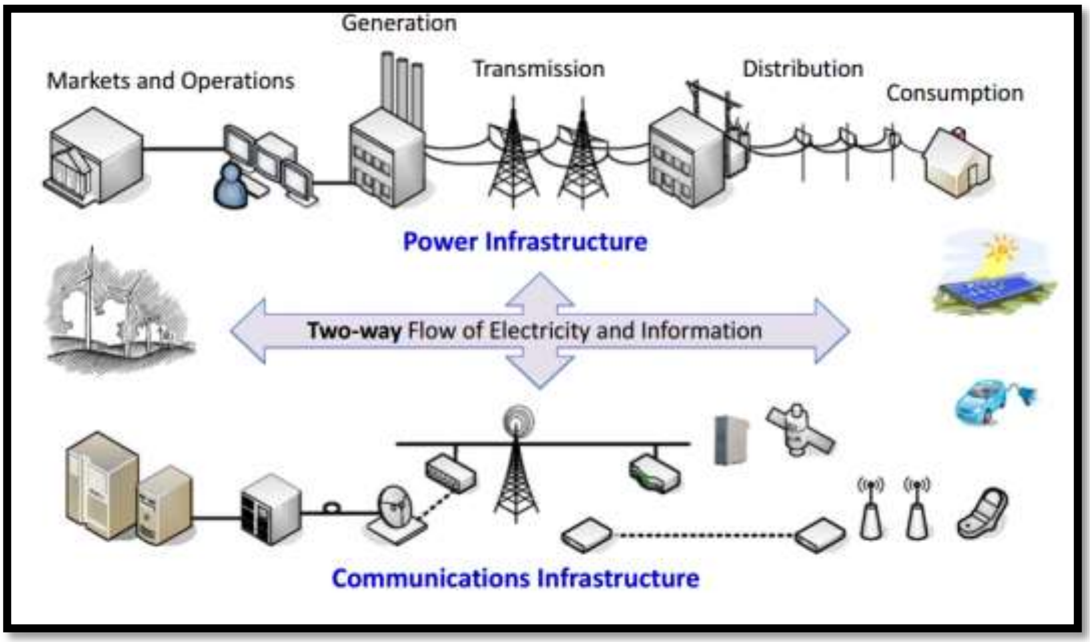


***Figure* 2-2*:*** *future smart grid* (Source: Dr. Hamed Mohsenian-Rad, Communications and Control in Smart Grid, Texas Tech University, 2012).

The smart grid components can be summarized as follows:

- Communication systems: different technologies (WAN, LAN, PLC,..etc.) to support two-way exchange of real time information among all players in grid [9].
- Advanced metering infrastructure (AMI): smart meters are crucial in providing the communication link between the utilities and end users.

Wood et al, shown that through the smart meter the electrical consumption decreases by 5-15% [10].

- Advanced sensors and measurement's tools: these components and technologies are critical for monitoring, and reporting to control, and decision makers.

- Intelligent switching: control power flows as well as support self-healing.

- Distributed generation & Energy storage systems: support the power grid during high peak periods through discharging the previously stored surplus power [11].

- Electric Vehicle (EV): These days more loads that worrisome to electric companies is the EV. Many of the research now is how to take advantage of the infrastructure that regulate the demand and exploit the charging and discharging. Vehicles can act as storage units for the grid, In the case of peak demand the EV situation will be studied and the stopped and fully charged one will be discharged and feed the grid vehicles to grid (V2G), and in the under peak demand the grid will charge the EV grid to vehicles (G2V). Through smart grid can optimize scheduling of EV charging [12]. The different technology areas including related hardware and software used in smart grids are summarized in table 2-2 below.

**Table 2-2: Hardware and software used on smart grid.**

| Technology area | hardware | System and software |
|---|---|---|
| Wide-area monitoring and control | Phasor measurement units (PMU) and other sensor equipment | Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide-area adaptive protection, control and automation (WAAPCA), wide area situational awareness (WASA) |
| Information and communication technology integration | Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers (servers) | Enterprise resource planning software (ERP), customer information system (CIS) |
| Renewable and distributed generation integration | Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology | Energy management system (EMS), distribution management system (DMS), SCADA, geographic Information system (GIS) |
| Transmission enhancement | Superconductors, FACTS, HVDC | Network stability analysis, automatic recovery systems |
| Distribution grid management | Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors | Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS) |
| Advanced metering infrastructure | Smart meter, in-home displays, servers, relays | Meter data management system (MDMS) |
| Electric vehicle charging infrastructure | Charging infrastructure, batteries, inverters | Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies |
| Customer-side systems | Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat | Energy dashboards, energy management systems, energy applications for smart phones and tablets |

*(Source: International Energy Agency, Technology Roadmap Smart Grids, 2011, France)*

## 2.5. Communication System

A variety of communications systems can be implemented for data transmission in smart grids. However, choosing the right communication system for any Smart Grid application should consider certain requirements such as:

- High reliability
- Real time capability
- Cost effectiveness
- Low operational and maintenance costs
- Flexible and open structure

In the following sections, we will highlight some of the communications systems that can be utilized in a modern future smart grid.

### 2.5.1. Power Line Communication (PLC)

PLC is a grown technology, with the evolution has become capable of transmitting high bit rates [13]. One of the benefits of PLC is using electricity cables rather than using dedicated communication lines. Moreover, this system can be created quickly and cost effectively. Nevertheless, the nature of the noise in the power cables may affect data and information transfer, which is one of the most important disad vantages. [14]

### 2.5.2. Public Telecommunication Network (PTN)

The public telecommunication network is an easy and comfortable way of communications. It can be used in applications with no firm restrictions on time delay, for instance in Automatic Meter Reading (AMR). This type of system can be created quickly and cost effectively. Nevertheless, its major disadvantage is the dependent on telecom operator's policies.

### 2.5.3. The Internet

The internet technology that became potential support solutions for many applications. Intelligent development taking place in this area has enabled a lot of monitoring systems, remote controls, cost-effective way, and widespread all over the world. However, the wide spread has become a major security risk [13].

### 2.5.4. Wireless Communication

The modern development of information and communication technologies at accepted cost can offer potential solutions for the electrical system. These options have been unbelievable just few years ago. Different wireless communication technologies can be implemented these days for electric power system grid. When compared with traditional wired communication systems, wireless communication systems have prospective benefits for remote supervision and monitoring, but at the same time, they still have some disadvantages, such as lower capacity of data, and limited coverage.

### 2.5.5. Optical Fiber Communication

Optical fiber communication systems present respectable feature over copper-based communication systems. Due to much lower attenuation and interference, optical fiber has advantages over existing copper wire in long-distance and high-demand applications. However, optical network development within cities is difficult and time-consuming, and fiber-optical systems are complex and expensive to install and operate. For that, this system is not recommended in the distributed grid with large number of short branches.

## 2.6. Smart Grid Benefits

The existing electrical system in our country is decades old and dependent upon equipment that is approaching the end of its usable life. Smart grid has the capacity to update this infrastructure, ensuring that safety standards will be met, that power will be delivered continuously, and that the system can be managed efficiently. Reliability, energy independence, and cost savings are just three of the many benefits of smart grid. These and more benefits make it the energy technology not just for the future, but also for today. According to the National Energy Technology Laboratory in U.S.A, the benefits of smart grid covers six vital areas: Reliability, Efficiency, Economics, Security, Environmental, Safety, and Security [15]. The technology of smart grid will ensure the reduction of recurrence and interval of power outages making it high reliability. Over that, it will improve efficiency, and power quality. Moreover, it will reduce the cost of consumption due to the interaction between supplier and consumers.

The smart grid also it has an impact on the life of the investment and reduce costs. Besides that, the smart grid has environmental impact in reduce carbon (CO2) emission. In addition, it has a relationship with clean renewable energy techniques to integrate with the grid

Some smart grid benefits over traditional networks may include:

- Power quality (reliability, security, and efficiency): Smart grid through the real time data of power flow can be adjusted to obtain maximum efficiency automatically, in addition, to use the network assets more effective [16]. As grid growing in size, it needs a modern network to build a stronger reliability foundation through new analytical methods [17].

- Self-healing: Smart grid improve fault detection and allow self-healing, that support the success of the grid to cover the end user’s need [18].

- Integration of distributed generation: The aggregation of all sources such as renewable technologies and storage can help meet regular power demand. Intelligent nodes will be used to control a number of network assets, instead of centralized [19].

- Allow demand side response: Demand response make the customer more attractive, and they can reduce or shift their electricity consumption at peak period, saving money, and improving overall system performance. One of the goals of modern network designers and planners is to emergence techniques and technologies for demand response [20].

There are also many benefits as a result of the above characteristics, such as reducing maintenance, and reduce congestion, reduce peak demand, the exploitation of larger capacity, increase capital investment efficiency, thereby reducing the negative environmental impacts [21].

## 2.7. Smart Grid and Smart City

Many conferences periodically organized worldwide, consecrate to smart city, achievements, projects, and feedback. Sometimes, the smart grids are discussed in these conferences. However, there is no incident worldwide, which is totally consecrate to linking smart grid concepts to smart city growth.

## 2.8. Smart Grid and Smart Buildings

Smart Home Information Management is an Application in buildings for improved building operations, performance and Smart Grid interaction. Smart Grid like a gateway for smart buildings application.

# Chapter Three
# Research in Smart Grid

## 3.1. Introduction

In modern power systems, a smart grid has the capacity to manage supply and demand of electricity efficiently. The increasing share of renewable and distributed energy sources bears two major challenges: Lack of continuity, and a lack of controllability of power generation. This chapter introduces major elements of a smart grid which address these challenges: smart metering, distributed generation (DG) opportunities, load control and demand side management

## 3.2. Smart Metering

The role of “Smart meters” is not only to record and to display the amount of energy consumption like traditional meters, but they have two-way communication capabilities to transfer data between utilities and consumers.

Smart meters use a secure communication network to automatically and remotely send actual energy usage to your supplier. This means households will no longer have to provide their own regular readings, rely on estimated energy bills, or have meter readers come into their homes to read the meter.

In general, Smart Meters have the following capabilities: [22]

- Monitoring and recording of Real-time data of electricity load flow.
- They offer the possibility to control both locally and remotely.
- Ability to integrate power networks and distributed generation.

A smart meter opens a broad range of chances for utilities to save energy and energy security purposes. Figure 3-1 shows several basic functions of smart meters, which measure imported or exported electricity, switching and controlling the maximum electricity consumption remotely.

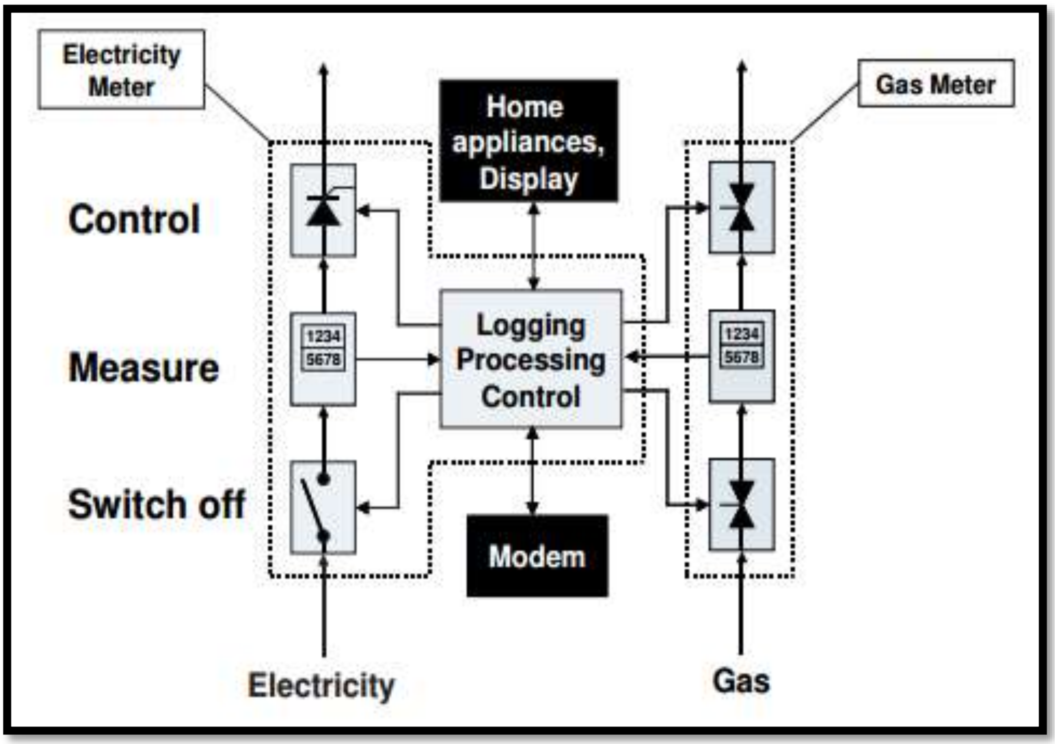


***Figure* 3-1*:*** *Schematic overview of a typical smart meter configuration* (Source: Gerwen RV, Jaarsma S, Rob Wilhite K (2006) The Netherlands, smart metering).

### 3.2.1. Smart Meter Network Components in the Distribution System

Components of Smart Meter Network may include some or all of the following components:

- Intelligent measuring devices, which record, store, and transfer detailed data for energy use to the supplier.
- Telecommunications Infrastructure, Which provides the exchange tool for information in real time and in both directions.
- Data analysis systems and the integrated application.
- Smart sensor for home or office appliance.
- Monitoring devices throughout the network to ensure secure flow of energy, and quality of performance.
- Advanced switches and automatic controls that enable the detection of problems and provide self-healing solutions.

### 3.2.2. Advantages of Smart Meter in Distribution Networks

There is a wide range of other technologies, applications, and devices that are often linked with smart meters in the distribution networks, such as renewable energy supply, customer load management, and energy storage technologies as shown in figure 3-2.

Smart Meters can add attributes to the characteristics of a smart distribution network by: [23] [24].

- Improving the assets, optimize operations, and reduce maintenance costs.

- Enhancing demand-side management, by enabling consumers to manage their consumption and energy savings.

- Enabling distributed generation and energy storage systems to actively participate with the network.

- Integration of devices and sensors with a network of secure communications for automatic processing errors, called self-healing.

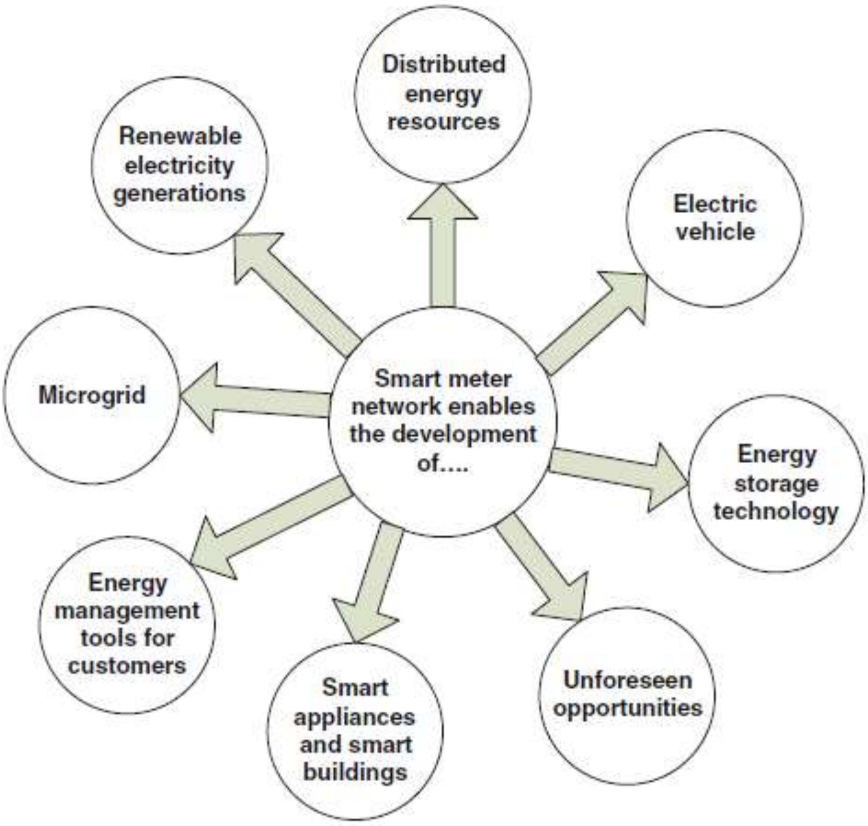


***Figure* 3-2:** *Smart meter network components and opportunities* (Source: Smart networks position paper, technical report: energy network associations, Australia, 2009).

## 3.3. Distributed generation (DG) Opportunities

There is no specific definition of “Distributed Generation”, but it can be defined as a method of generating electricity from multiple small energy sources very near to where the electricity is actually used [25]. Others defined it as only small-scale, environmentally technologies such as wind turbines and photovoltaic (PV) that are installed on customer's site [26]. Some definitions limit the size of DG between 10 kW to 50 MW of capacity [27]. Figure 3-3 shows Distributed Generation Classification and Types.

Distributed generation have multiple benefits, including support the voltage, economic savings, improve power quality, improve system reliability, improve environmental performance, reduce energy loss, and reduce the transmission and distribution costs of about 30% [26].

In smart grids, users have impacts on electric grid by installing DG such as photovoltaic (PV), energy storage units, and responding to pricing signals. DG and smart grid technologies support each other economically and technically. Smart grid technologies can provide the elasticity and effectiveness to integrate DG technologies such as wind or solar (PV) through metering, sensors, continuous monitoring for energy conservation, reduce cost and improve reliability [28].

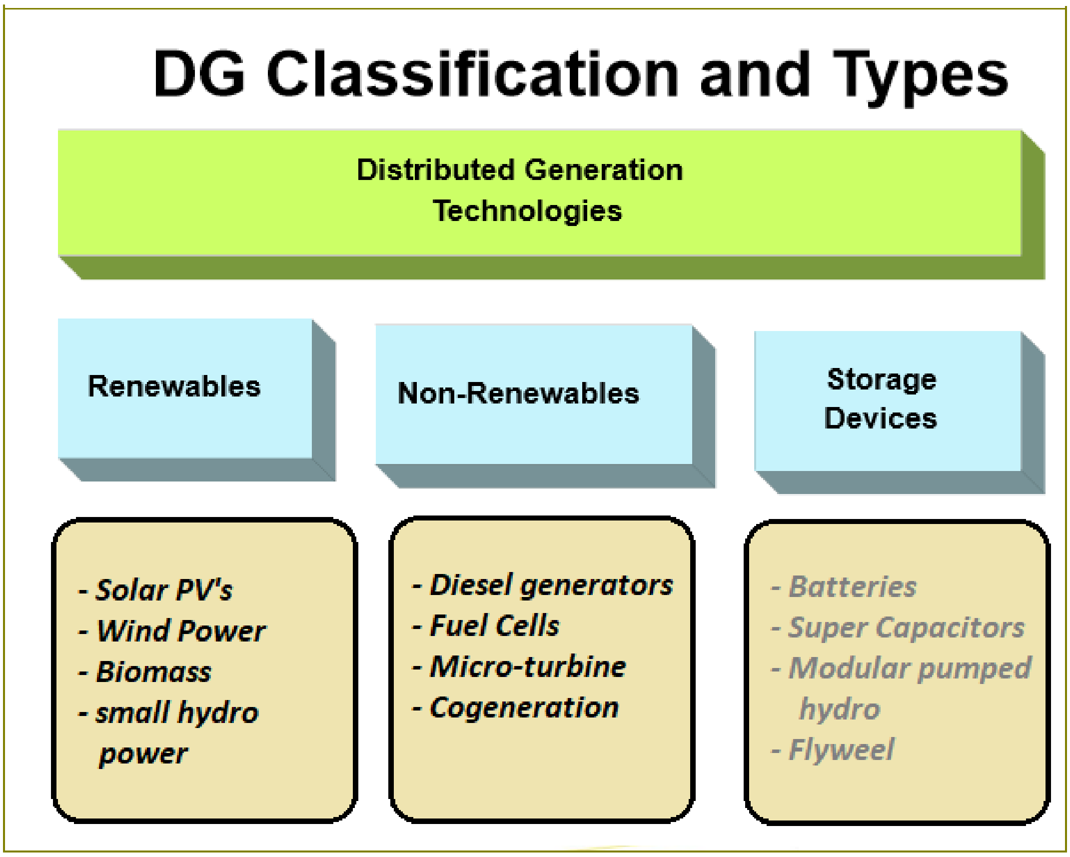


**Figure 3-3**: Distributed Generation Classification and Types.

DG technologies can provide ancillary benefits to society. Large, centralized power plants emit significant amounts of carbon monoxide, sulfur oxides, particulate matter, hydrocarbons, and nitrogen oxides. Using clean and renewable DG systems will cut these emissions and reduce environmental pollution in the power system.

Distributed generation also have economical operation benefits. DG affects distribution systems losses and consequently have impacts on the operating costs of distribution networks.

- Central Generation Scheduling and Cost will be affected.

- Generated power from some types of distributed generation are intermittent and very difficult to be predicted. This results in increasing the uncertainty in the generation scheduling.

- Reduction in the net generated power from central generation plants, might affect the overall generation cost, especially the startup and fuel saving cost.

Regardless of these benefits and positive impacts of DG on power systems, they have different challenges and setbacks that requires special attention and practical solutions. Table 3-1 shows some of Distributed Generation challenges and solutions within Smart Grids.

**Table 3-1: Summary of Distributed Generation challenges and solutions with the use of Smart Grid.**

| | **Challenges of DG** | **Solution with smart grid** |
|---|---|---|
| Safety | Can affect the ability of the work of the protection program in optimal conditions. | Low cost monitoring devices to detect reverse flow of power, operating conditions and status of DG. |
| Islanding | Possibility for the DG to run in islanding mode, with the utility unable to provide ensure voltage and appropriate frequency. | Applications can guarantee the act of the system. |
| Quality impacts of energy | DG may be detrimental impacts on neighboring consumer, with voltage variation, and harmonic distortion. | Using the qualification of smart meters to monitor and detect negative DG impacts. |
| Infrastructure management | DG output can result in overloading of the distribution network conductors, transformers etc. | Distribution systems management (DMS) provides an alarm intelligent processing and load management applications, especially with a huge amount of DG connected. |
| System operation and planning requirement | Increasing DG will be complex and release issues in the planning and operation of the distribution system. | Processing applications allow the utility to act with the increasing levels of data coming from monitoring of DG and distribution network. |

*(source: Connecting the Grid to Distributed Generation, Kevin Cornish, Digital magazine Power grid International,2011)*

## 3.4. Photovoltaic (PV) Systems

According to Palestinian energy and natural reassures authority (PENERA), the Palestinian government had set a goal in which 10 % of electricity generated in Palestine is going to be generated through renewable resources by the year 2020. As part of its renewable energy strategy, PENERA target is to achieve 130 MW through the installation of various renewable energy technologies by 2020 [24]. This amount of capacity will be distributed as follows:

- 50 % from different solar sources (on ground, small PV and Concentrated solar).
- 16.2 % from biogas sources (Biogas landfill, Biogas animal).
- 33.8 % from windmills and small-scale wind.

To achieve this target, PENERA developed the Palestinian solar initiative (PSI) which aims to achieving a target of 5 MW generation by 2015 through installing 5 kW-peak PV panels at rooftops of Palestinians households. Up to this date, this goal has not been achieved, but there is a clear increase in PV systems especially at schools rooftops. Other renewable energy sources such as wind power and biogas still far from reaching the target levels with very slow progress. For this reason, we will concentrate on PV-systems as a DG application of smart grids in Palestine.

PV systems are classified into three kinds:

- Residential rooftop.
- Commercial rooftop.
- High scale generating station.

Due to the decrease in system modules prices and improved efficiency, the capacities of installed PV systems are increasing. In the last decade, the cost of PV system reduced more than 50% [29] [30]. The payback period for such systems dropped to 4 to 6 years in Palestine depending on electric tariff. Such increase in capacity will impose a new challenge for the classical power networks in Palestine. Therefore, smart grid technologies are badly needed to improve monitoring and controlling of such systems, and will play a crucial role for helping customers manage the PV systems [31].

### 3.5. Energy Management

The key role of Smart Grids is the control of loads on the grid and the adjust of supply and demand in cooperation with electric power suppliers. Smart grids monitors the volume of demand for electricity in real time and forecast demand so that an appropriate volume of power can be supplied from renewable energy generators or from storage units. The system maintains a balance between supply and demand to reduce the amount of energy consumed by effectively using renewable energy and reducing power loss.

Energy management will implement different smart grid technologies to reduce operation and maintenance costs, improve reliability, and strengthen management of existing assets.

## 3.6. Demand Side Management (DSM)

Demand side management is the planning and operation of different actions beneficial to the impact on customers' use of electricity in ways that will bring about required changes in the load shape [32]. It includes the planning, implementation and monitoring of utility activities that affects customer use of electricity. As a result, it changes the load time pattern and magnitude of utility’s energy consumption. Usually, the main objective of demand side management is to encourage users to consume less power during peak times or to shift energy use to off-peak hours to flatten the demand curve or to follow the generation pattern. In each case, there is a need to have a sequence of control patterns over customer energy use.

The impacts of the DSM can be divided into two parts; impacts at the side of the utility and impacts at the customer side as follows:

− Utility needs:

- Ensure efficient operation
- Improve the performance of financial and billing systems
- Reduce capital investment
- Provide requirements and high quality services to customers
- respond to the continuous evolution of regulatory requirements

− Customer needs:

- conserve energy in order to reduce electricity bills
- maintain the same life style and comfort levels
- reducing the environmental impacts associated with the use of electricity
- Coverage of demand needs by utility

DSM is divided into three main activities as follows [33]:

- Load management
- Energy efficiency
- Demand response

### 3.6.1. Load Management

Load management is an essential part for reducing peak demand and backing power grid. Controllable loads such as heat pumps, water heaters, space heaters and other residential devices are the main tools of load management. On an economic level, the encouragement of managing the loads by customers is to reduce the costs of energy consumption and reducing the electricity bill.

The techniques used to manage the load are shown in Figure 3-4.

### 3.6.2. Effects of the Implementation of DSM programs

- Improve the efficiency of the energy system by improving the efficiency of generation and load factor system.
- Reduce implementation costs for new installations of energy by reducing peak demand.
- Increase system reliability.
- Lower consumer electricity bills through monitoring of electricity consumption, as well as the use of energy-saving devices.
- Reduced CO2 emissions.

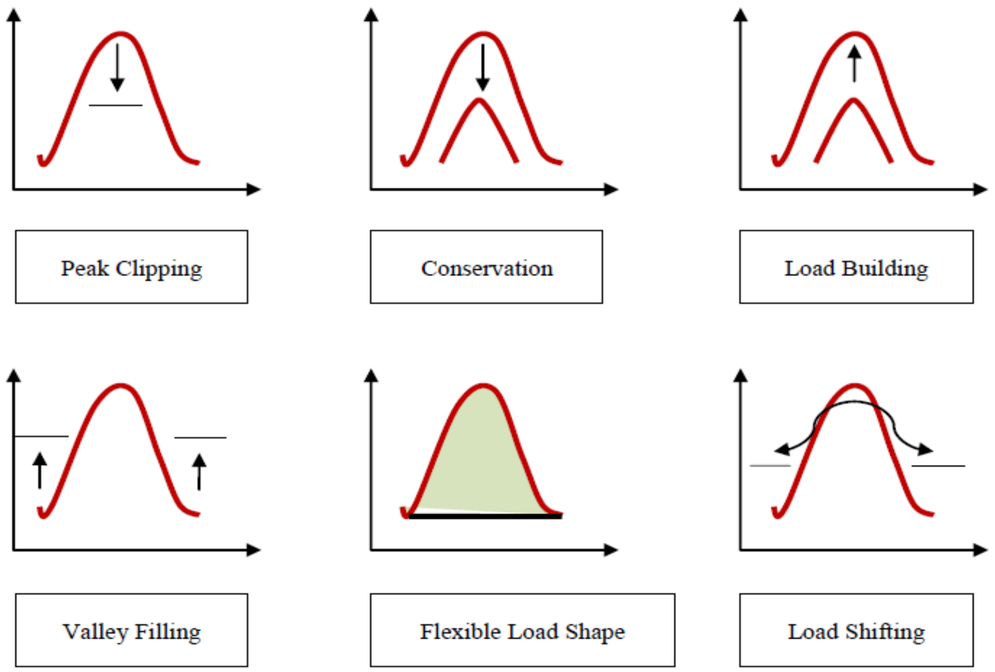


**Figure 3-4**: Basic load-shaping techniques.(Source: Electric Power Research Institute, Demand-side management: Utility options for the future, EPRI Reports, 2006).

### 3.6.3. Energy Efficiency (EE)

Energy efficiency means reducing energy use while providing the same level of service. Energy efficiency differs from the concept of energy conservation, as energy conservation aimed at reducing unnecessary energy use completely or partially [33].

Energy efficiency provides utility bill savings and environmental pollution reduction. In buildings, EE is typically implemented by using equipment that are more efficiently operating, which is reflected on the distribution by a reduction in energy consumption and peak demand.

### 3.6.4. Demand Response (DR)

Demand response is a specific program or tariff to motivate end-use customers respond to changes in price or availability of electricity over time by changing their normal schedule of energy use. It can also be defined as incentive payment program to encourage customers to reduce usage of electricity when grid reliability is jeopardized [34]- [35].

DR procedures classified as:

- Reliability programs.
- Price response programs.
- Peaking management programs.
- Auxiliary service programs.

During periods of peak demand, utility send electronic messages that instruct consumers to reduce their consumption by turning off non-essential loads. When using smart meters, signals will be sent automatically to equipment [36].

A customer may consider three actions in response. The first action is to reduce load only during critical peak time and maintain normal load pattern during off-peak time. This induces a decrease in customers comfort as they are forced to curtail electricity usage at certain times, which may not be desirable by customers, but reduces the overall consumption thus reducing electricity bill even further. The second action that could be taken in order to respond to high electricity prices or low availability is to shift their electric loads from peak to off-peak time. This method will decrease the peak load, fill low consumption valleys and at the end would flatten the load shape. This action increases the transmission and distribution efficiency as the system operates in more stable mode, without reducing the average amount of energy used by the end users. In the third action, customers can use on site generation to reduce demand seen by the utility. Such action would increase user autonomy, further decentralize generation and decrease average load on electric networks and transmission grids. On the other hand, it would increase system complexity.

### 3.6.5. Dynamic Pricing (DP)

The most popular method for managing peak demand is to modify the pattern of electricity consumption [37]. Electric utilities may use one or more of several pricing plans to reduce peak demand. These pricing plans include the following: [38] [39] [35]

- Time-Of-Use (TOU): Connect the pricing with time of consumption, to be high in the peak demand period, and be low in a period of low demand.

- Peak-Time Rebate (PTR): During peak period, the utility provides customers with rebates for reducing their usage of electricity.

- Critical Peak Pricing (CPP): Determine the peak demand period and increase the tariff to urge customers to reduce their loads.

- Real Time Pricing (RTP): a process of price change by fluctuations belong to amount of electricity, and inform consumers to reduce or convert consumption, or control smart appliances and equipment directly linked with utility through applications.

Figure 3-5 shows the difference in consumption using different plans in the dynamic pricing.

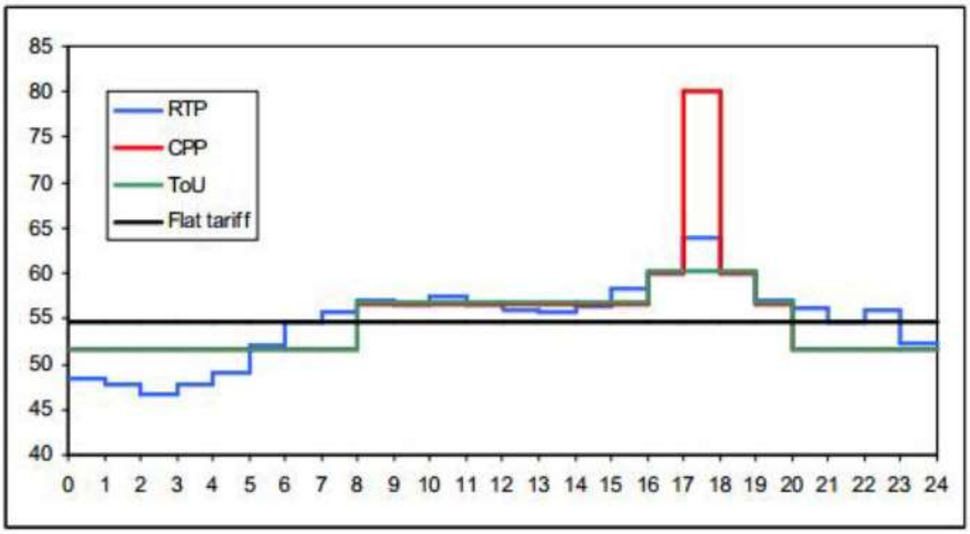


**Figure 3-5**: Examples of RTP, CPP and TOU. (Source: Pricing models and mechanisms for the promotion of demand side integration, Corentin Evens, Seppo Kärkkäinen, VTT Technical Research Centre of Finland,2009.)

From the above curve, it is clear that DR programs can be the express way for customers to reduce their loads.

## 3.7. Electric Vehicles (EV)

Electric cars is spreading rapidly around the world, over 20 million of EV will be on the roads by 2020 worldwide [40]. Electric vehicles have a strategic role in reducing greenhouse gas emissions from road transportation and are a key component of the transition to a green and low carbon economy. The electricity network operators are investing in their networks to ensure they can safely and reliably meet the increase in electricity demand required to support electric vehicle charging. It is therefore important for power grid operators to have full knowledge of where the EV charging equipment is connected, to better understand the increased demand, as well as ensure the network is fit for purpose.

With the increasing number of EVs and stations for charging them, there will be increasing demands on electricity, which will have effects on stability and reliability of electric network. Therefore, the high number of EV's electric chargers embarrasses new challenges for utilities in power flows, voltage profile, and grid losses [41]. Thus, the utility need smart strategies to cover the increased demand.

There are a number of process of charging scheduling such as vehicle to grid (V2G), and centralized management [42]. Smart grid as proposed method for smart charging can schedule the charging by smart forecasting the power grid loads and predicted EV loads, can integrate charging scheduling with the renewable energy systems [42]. Figure 3-6 shows smart home, through the methods of optimal use cleverly charging date is determined based on the data load and sources of electricity

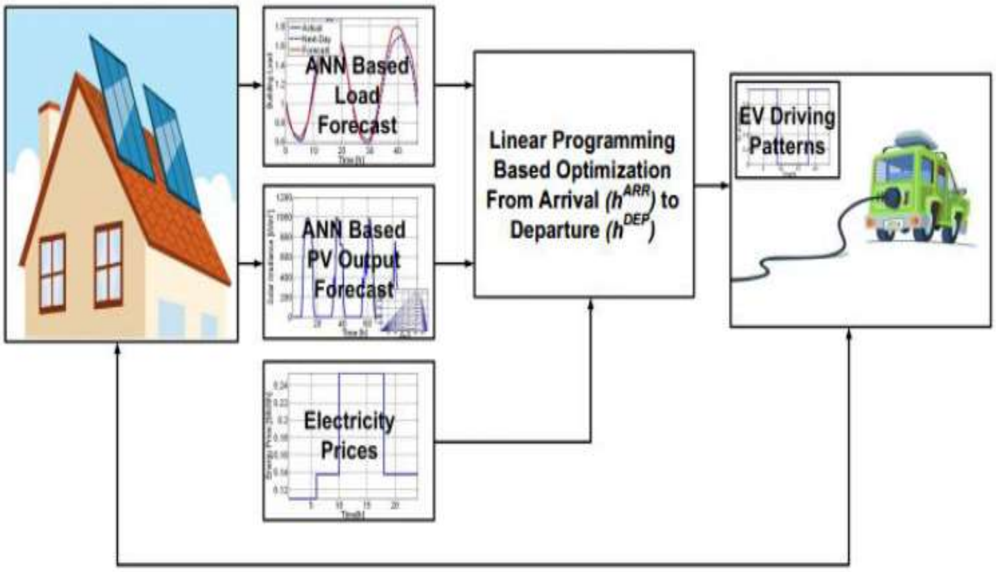


**Figure 3-6**: EV Charging System in smart Home. (Source: Optimal EV charge-discharge schedule in smart residential buildings, Power Engineering Society Conference and Exposition in Africa (Power Africa), 2012).

V2G technique using the battery in EV can act as storage units for the grid, according to charging schedule. The main element of V2G solution is the bi-directional converter. In case of peak demand, the vehicle feed the grid, and in under peak demand the grid will charge the battery of vehicle [43].

With the support of V2G technique, the EV's can play a more dynamic role in the grid such as engagement DR program. Figure 3-7 show a complete grid Environment contains all EV components, including individual home and charging stations.

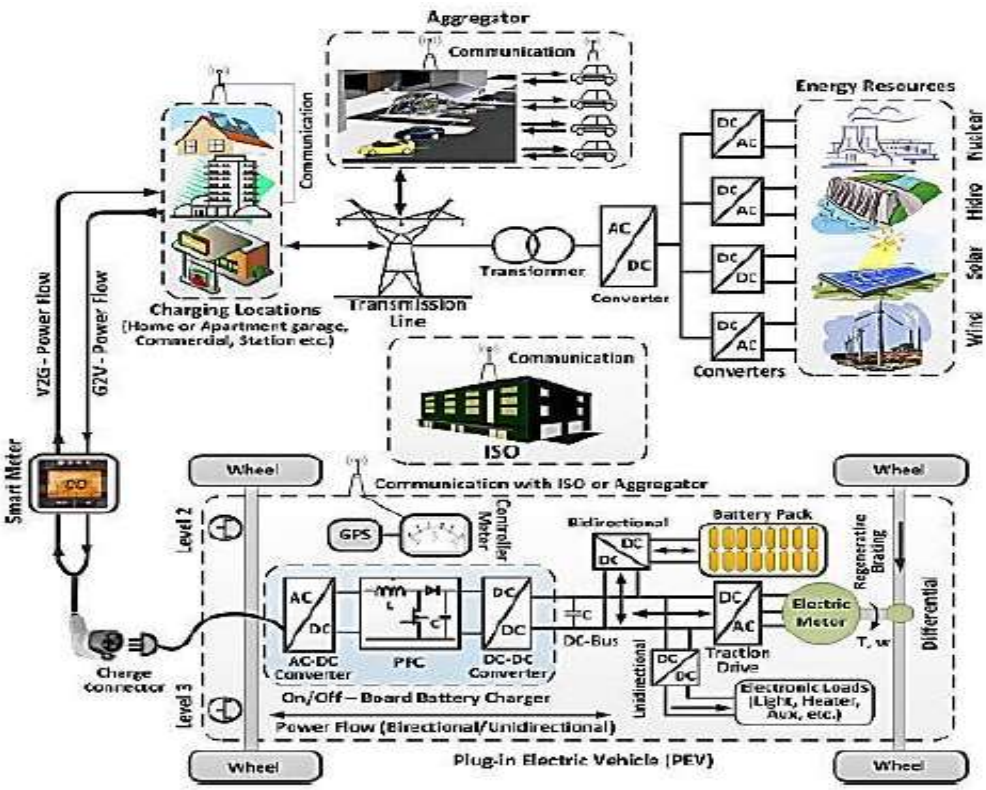


**Figure 3-7**: V2G Technique. (Source: Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Utility Interfaces, Murat Yilmaz, Philip T. Krein, IEEE Transactions on Power Electronics Volume: 28, Issue: 12, 2013 ).

# Chapter Four
# Tulkarm Electric Grid Analysis

## 4.1. Introduction

Tulkarem is a Palestinian city in the Tulkarem Governorate in the extreme northwestern of the West Bank. According to the Palestinian Central Bureau of Statistics, Tulkarem city and the adjacent refugee camps had a population of approximately (58,962 inhabitants) at mid-year 2006. Its land area consists of 13,793 dunums as figure 4-1 shows [44]. Despite the catastrophes and disruptions that affected the city in the last 100 years, it has not lost its distinctiveness. The physical plan covers an area of 13,790 dunums: the total city area is 18,000 dunums; the residential areas constitute 9,743 dunums, while the agricultural lands are estimated at 5,000 dunums, Industrial, commercial and transportation lands constitute 174, 6, 437 and 202 dunums, respectively [45].

**Table 4-1: General data of the City.**

| | |
|---|---|
| Governorate | Tulkarem |
| Government | Tulkarem City |
| Altitude | 162 m |
| Coordinates | 32.311528°N 35.0270389°E |
| Population | 56,334 (2011) |
| Jurisdiction | 13,793 dunums (13.793 km²) |
| (refugee camps) in the city | Tulkarem Camp and Nurshams Shams Camp (18,600 & 12,225 inhabitants) |

*(Source: Tulkarem City: technical Report, Tulkarem municipality, 2012)*

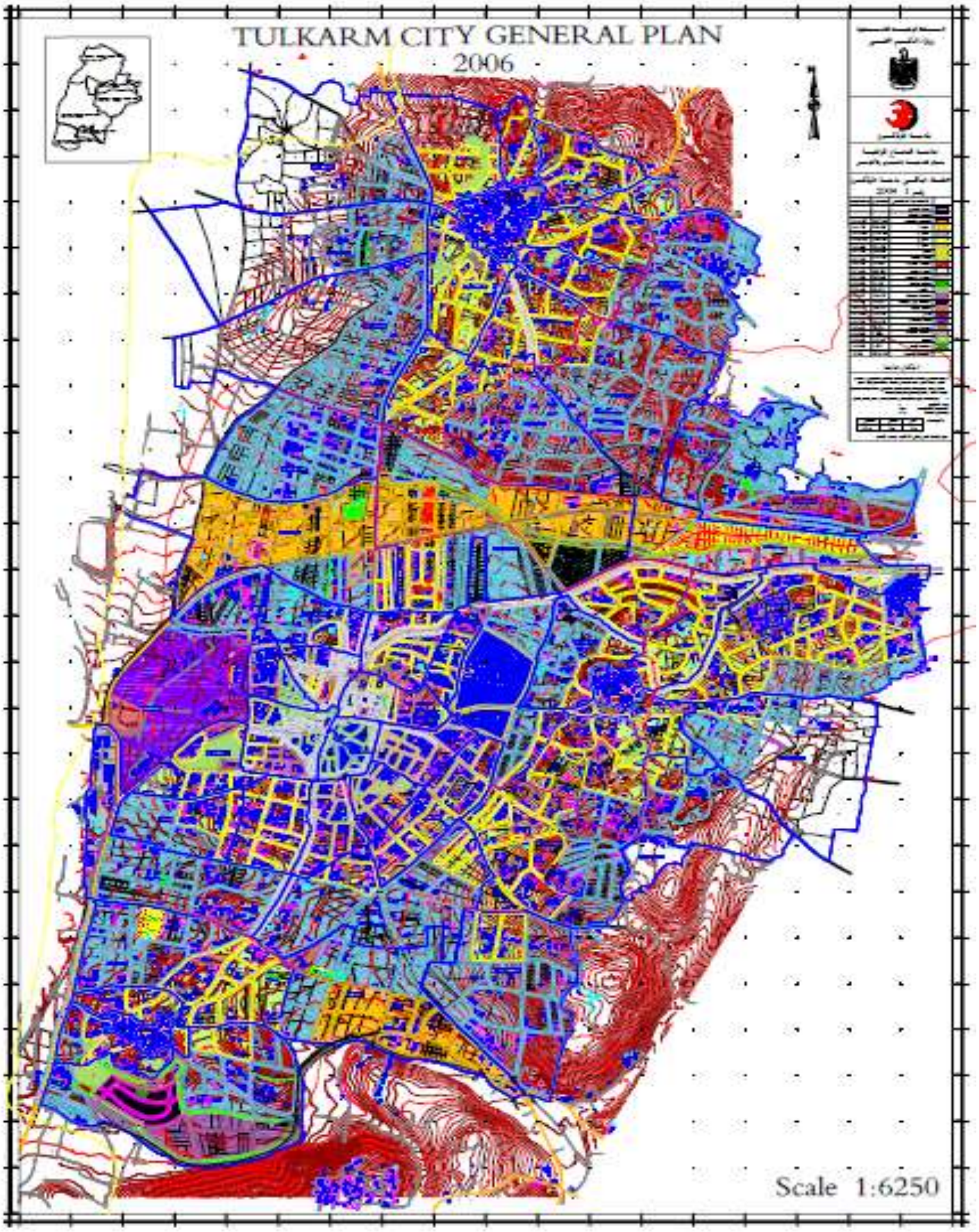


**Figure 4-1**:Tulkarem City general plane. (Source: urban planning department, Tulkarem municipality, 2016).

## 4.2. Climate of Tulkarem City

Tulkarem has a Mediterranean climate, warm, rainy in winter, hot, and dry in summer. Figure 4-2 shows the location of the city and its opening on the sea from the eastern side, and absence of natural barriers (mountains) help the accessibility of the marine effects, which acts on limiting the thermal effects on one hand, and on increasing the annual rainfall on the other. This made the city's climate almost coastal one, although it is located between the coast and mountains. Thus, the climate of Tulkarem falls within the Mediterranean climate [45].

The climate of Tulkarem is subtropical, with rainfall limited to the winter. The average temperature in winter ranges from 8 to 16 °C (46 to 61 °F), while the average temperature in summer ranges from 17 to 30 °C (63 to 86 °F). Tulkarem is distinguished by the moderating effect the sea breeze has on its climate. The average temperature does not exceed 27 °C (81 °F) in August, while February's average temperature does not fall below 13.5 °C (56 °F). Humidity is relatively high in summer, about 40- 70%, though it rises in winter to 70-85%. Tulkarem receives in excess of 550 millimeters (22 in) of rain yearly, which is dispersed and intermittent, characteristic of the Mediterranean Basin. Tulkarem city located at the top of one of the main water aquifer basin in the West Bank, which called (western basin). Tulkarem municipality depends on its own ground water wells which produce around (800 m3/hr.), and this is the main source for the drinking water, but for other purposes we can add the rainwater as part of the useable fresh water.

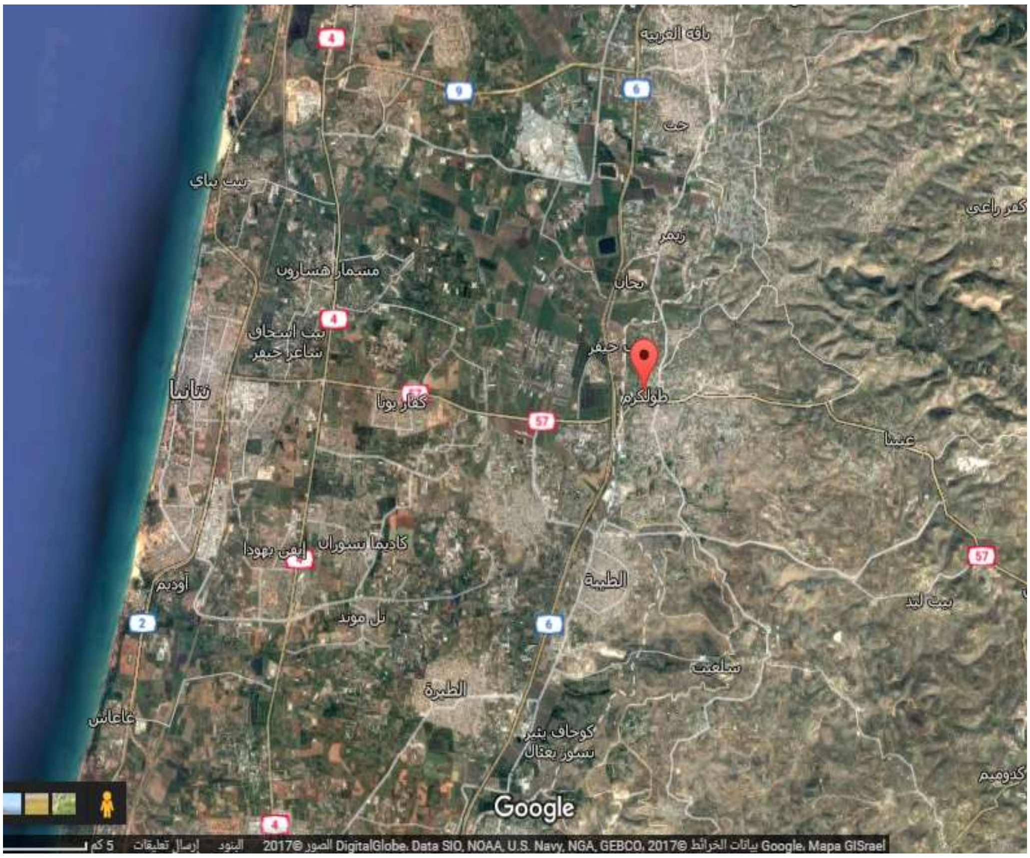


**Figure 4-2**: the location of Tulkarem city. (Source: Google Maps GIS real, 2017, https://www.google.com/maps).

## 4.3. Tulkarem Power Grid Description

Tulkarem Municipality purchases all of its electricity from the Israeli Electric Company (IEC) according to purchase contract signed in the year 1976. The total power supply quantity is (26 MW) (670 A), while the total need at this time is (37 MW) (950 A). Tulkarem power network is connected to the supplier with two medium voltage (22 kV) feeders; Tulkarem (1) and Tulkarem (2). Tulkarem (1) maximum current is 350 Amp meanwhile Tulkarem (2) maximum current is 320 Amps. [46] Figure

4-3 shows the single line diagram for connection points according to IEC. Figure 4-4 also shows the location of connection points in Tulkarem Near the separation wall.

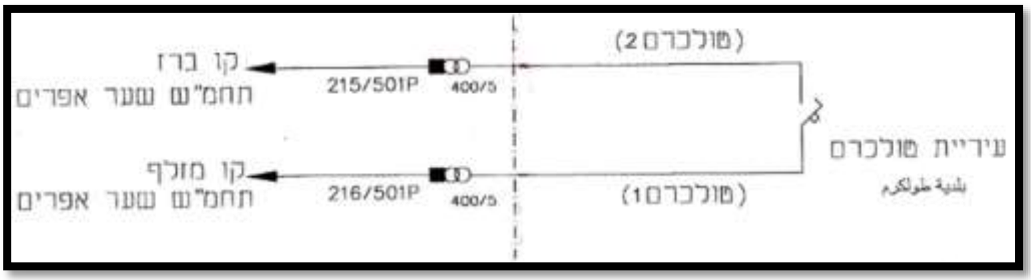


**Figure 4-3**: Single line diagram for connection points of Tulkarem. (Source: Israel electric company, 2008).


**Figure 4-4**: Location of connection points in Tulkarem.(Source: Tulkarem Municipality, Urban Plan Department, 2017).

Tulkarem electric network is owned and managed by the municipality through a special department (Electricity Dept.), consisting of 3 engineers and around 50 technicians. They carry all responsibilities for maintenance and development of the network according to the availability of financial resources.

Today, around 19000 commercial, industrial and residential customers are connected to the secondary distribution lines through service drops (380/220 volts). Customers demanding a much larger amount of power may be connected directly to the primary distribution level or the sub transmission level. The network stretches on a total length of around 250 Km, including different types of power capacity (Low Voltage & Medium Voltage) and around 124 Electrical transformer.

The main medium voltage transmission lines in the city and the neighborhoods are mostly overhead line. Distribution network consists of the following: [47]

- 124 substations 22/0.4KV
  - 54 transformers 630KVA/22/0.4KV
  - 39 transformers 400KVA/22/0.4KV
  - 25 transformers 250KVA/22/0.4KV
  - 6 transformers 160KVA/22/0.4KV
- 47Km ACSR (3 line and earth)
- 2Km Medium voltage U.G cable
- 300Km Low voltage network:
  - 4*95+2*25 ABC
  - 4*50+2*25 ABC

- 6*25 ABC
- 4*25
- AL Network
- Cu Network

* Steel poles:

- M.V lattice Poles
- M.V channels poles
- L.V tabular poles
- L.V channels poles

Tulkarem electric network serves 99% of the population and the region. The number of subscribers about 19000 customer divided in the following categories with the percentage of consumption as: residential 56.4%, commercial 18.9%, industrial 1.5%, governmental 7.5%, camps 15%, Agricultural 0.5%, air-condition for mosques 0.1%, and street lighting 0.1% as shown in Figure 4-5. [48]

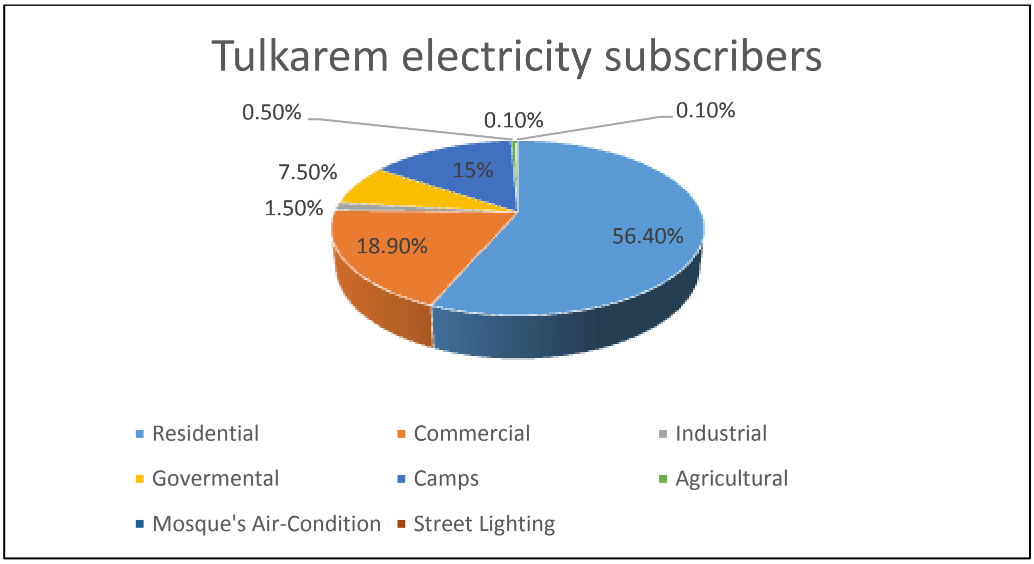


**Figure 4-5:** Categories of Electrical Customers in Tulkarem**.**

Municipality records show an average annual increase of 6.4% in consumption in all residential, commercial and industrial sectors. [46].

According to the financial department in Tulkarem municipality, the average monthly consumption of electricity for the last five years (2012-2016) is about 11.6 million kWh, and the annual average of consumption is about 139.4 million KWh. Technical and non-technical losses can be as high as 25% of purchased energy from IEC. [48]

### 4.4. Analysis of Tulkarem Power Grid

Through an interview with the director of electricity department in Tulkarem municipality, we got some information and reports on Tulkarem power grid. In order to achieve the objectives of the study and analysis the author drew the power grid for Tulkarem using AutoCAD software as shown in figure4-6, and the single line diagram for same grid using ETAP software as shown in figure 4-7, because there is no any drawing in the municipality.

According to the IEC bills of Tulkarem municipality the consumption of power energy in the last 5 years is shown in Table 4-2 and is illustrated in figure 4-8. Furthermore, we note that the annual growth in demand increasing after 2013 to several factors, including political stability of the security situation a fairly, and social include those refugee camps do not commit to paying and there is no control on consumption.

**Table 4-2: Annual Power Energy Consumption**

| Year | total consumption (KWh/y) | average consumption (KWh/m) | annual increasing |
|---|---|---|---|
| 2012 | 123,972,160.00 | 10,305,550.77 | |
| 2013 | 129,048,640.00 | 10,754,053.33 | 4% |
| 2014 | 138,018,360.00 | 11,501,530.00 | 6% |
| 2015 | 144,477,440.00 | 12,039,786.67 | 4% |
| 2016 | 161,798,720.00 | 13,483,226.67 | 11% |

(Source: Tulkarem Municipality, Financial Department, 2016)

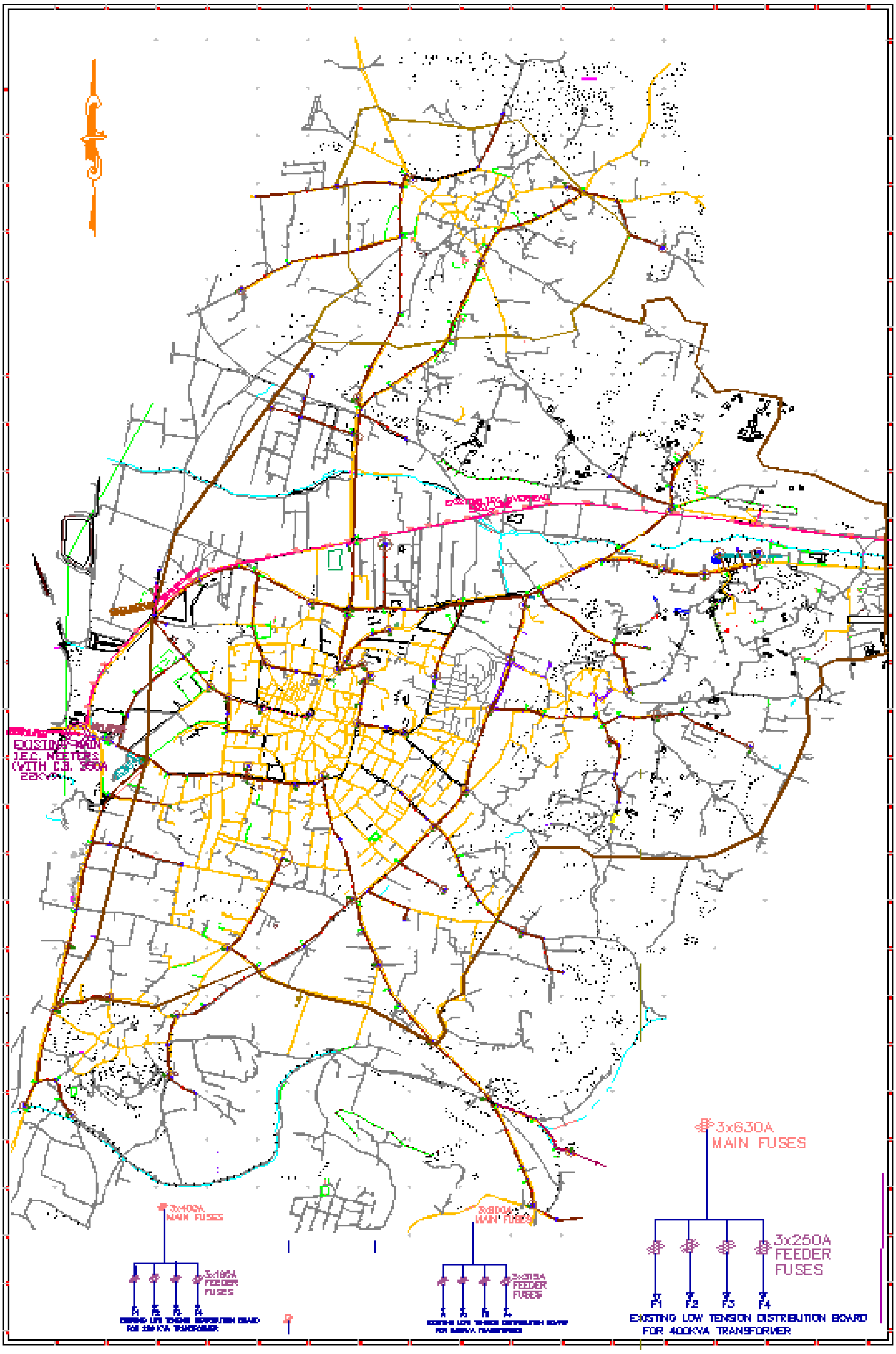


**Figure 4-6**: Power Grid for Tulkarem. (Source: drawn by author using AutoCAD software, 2016).

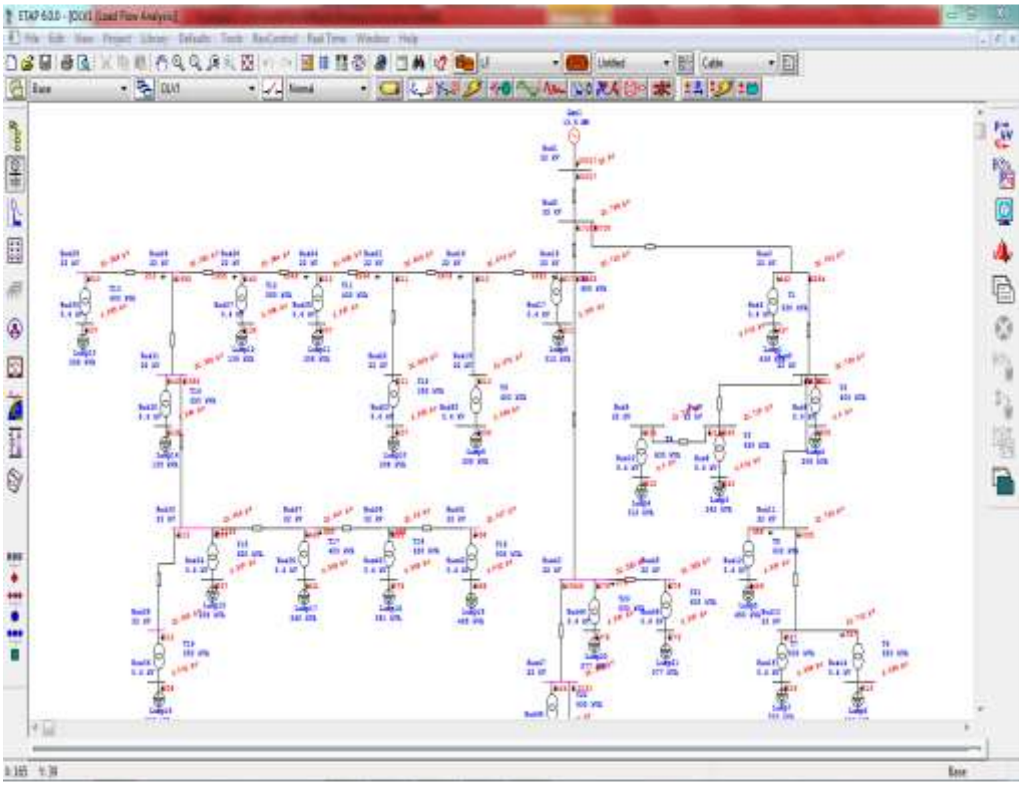

**Figure 4-7**: Power Grid for Tulkarem. (Source: drawn by author using ETAP software, 2016).

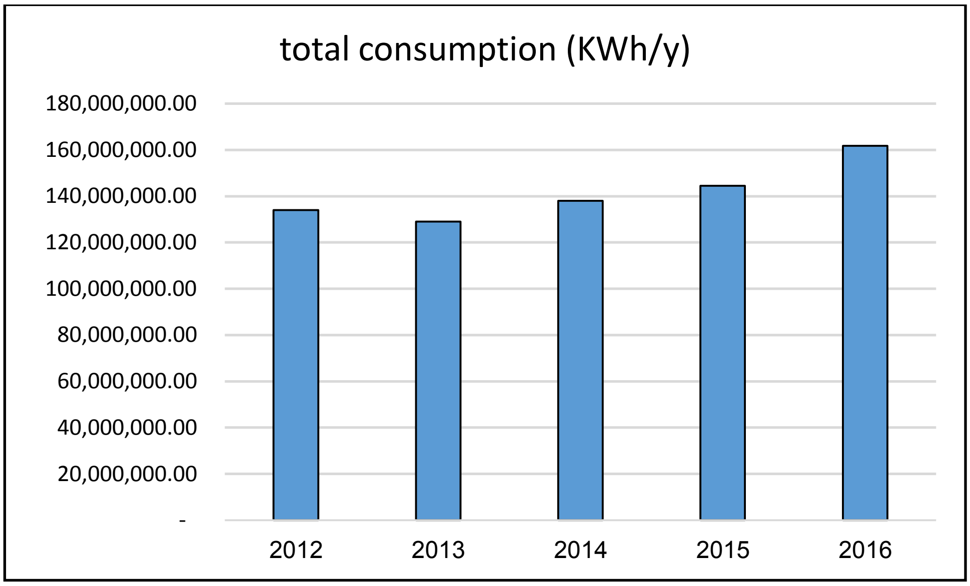


**Figure 4-8**: Annual Power Energy Consumption.(Source: Tulkarem Municipality, Financial Department, 2016).

The monthly consumption of electric power in 2016 is shown in the table 4-3 and is illustrated in figure 4-9. From the graph, it is clear that the highest consumption occurs in the summer months (July to October). Peak demand on electric power exceeds the maximum allowable rate as specified by the IEC. In such case, the managers at electricity department in Tulkarem municipality are forced to put a plan for disconnecting some customers on a rotating schedule. This is done by disconnecting some distribution transformers scattered in the city of Tulkarem and its neighborhoods manually [46]. This technique is a type of peak clipping as mentioned in load management in the previous chapter. In winter season, the demand increases, starting from December until end of February. The peak demand may exceed the maximum allowable levels. In this case, managers of electricity department usually take other measures such as turning off a specified number of pumps in water wells [46], or may reduce number of street lamps, which will be “ON” at nighttime.

**Table 4-3: Monthly energy purchased from IEC at year 2016.**

| month | total consumption (kWh/month) | consumption Tulkarem-1 (kWh/month) | consumption Tulkarem-2 (kWh/month) |
|---|---|---|---|
| Jan-16 | 13,710,240.00 | 7,680,000.00 | 6,030,240.00 |
| Feb-16 | 12,787,840.00 | 7,132,640.00 | 5,655,200.00 |
| Mar-16 | 9,680,000.00 | 5,489,440.00 | 4,190,560.00 |
| Apr-16 | 9,666,720.00 | 5,448,640.00 | 4,218,080.00 |
| May-16 | 13,064,160.00 | 7,293,120.00 | 5,771,040.00 |
| Jun-16 | 13,948,640.00 | 7,774,400.00 | 6,174,240.00 |
| Jul-16 | 17,059,520.00 | 9,127,040.00 | 7,932,480.00 |
| Aug-16 | 16,359,200.00 | 8,668,640.00 | 7,690,560.00 |
| Sep-16 | 16,091,680.00 | 8,368,960.00 | 7,722,720.00 |
| Oct-16 | 17,516,960.00 | 9,566,720.00 | 7,950,240.00 |
| Nov-16 | 9,483,200.00 | 5,269,920.00 | 4,213,280.00 |
| Dec-16 | 12,430,560.00 | 6,828,160.00 | 5,602,400.00 |

*(Source: Tulkarem Municipality, Financial Department, 2016)*

According to the above table, the total energy purchased from the IEC in year 2016 is (161,798,720 Kwh). In addition, according to report from finance department in Tulkarem municipality [48] the total sales invoices to all customers are (116,257,001Kwh). This shows that energy losses in 2016 were 28.1% of total energy purchased in that year. These losses include technical loss, and non-technical. Technical losses are naturally occurring losses, and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads.

Non-technical losses (NTL), on the other hand, are caused by actions external to the power system, or are caused by loads and conditions that the technical losses computation failed to take into account. NTL are more difficult to measure because these losses are often unaccounted for by the system operators and thus have no recorded information. The most probable causes of NTL are:

- Electricity theft
- Non-payment by customers
- Errors in technical losses computation
- Errors in accounting and record keeping that distort technical information

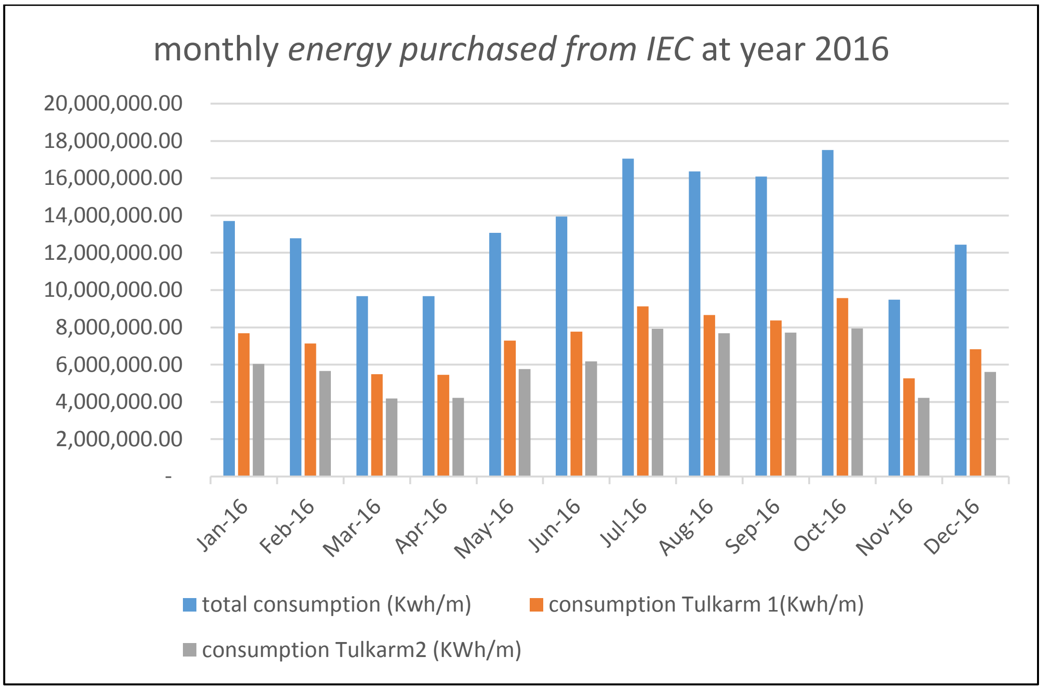


**Figure 4-9**: Monthly consumption of power energy at year 2016. (Source: Tulkarem Municipality, Financial Department, 2016).

Tulkarem power grid suffers from control less, and Lack of information. There is just one meter at the connection point in the Israeli side to calculate the energy bill. In addition, the municipality in the beginning of year 2015 installed another meter in their side to compare the consumption but this meter is not used. Moreover, there is no readings to confirm the validity of their work or whether or not. Nevertheless, the author was able to get some historical data for hourly demand of some days in 2015.

The following figure 4-10(a-d) show the first connection point (Tulkarem 1) daily load curve for some days, which cover a holiday day in summer and winter and a workday in summer and winter. In addition, figure 4-11(a-d) show the second connection point (Tulkarem 2) daily load curve for the same days.

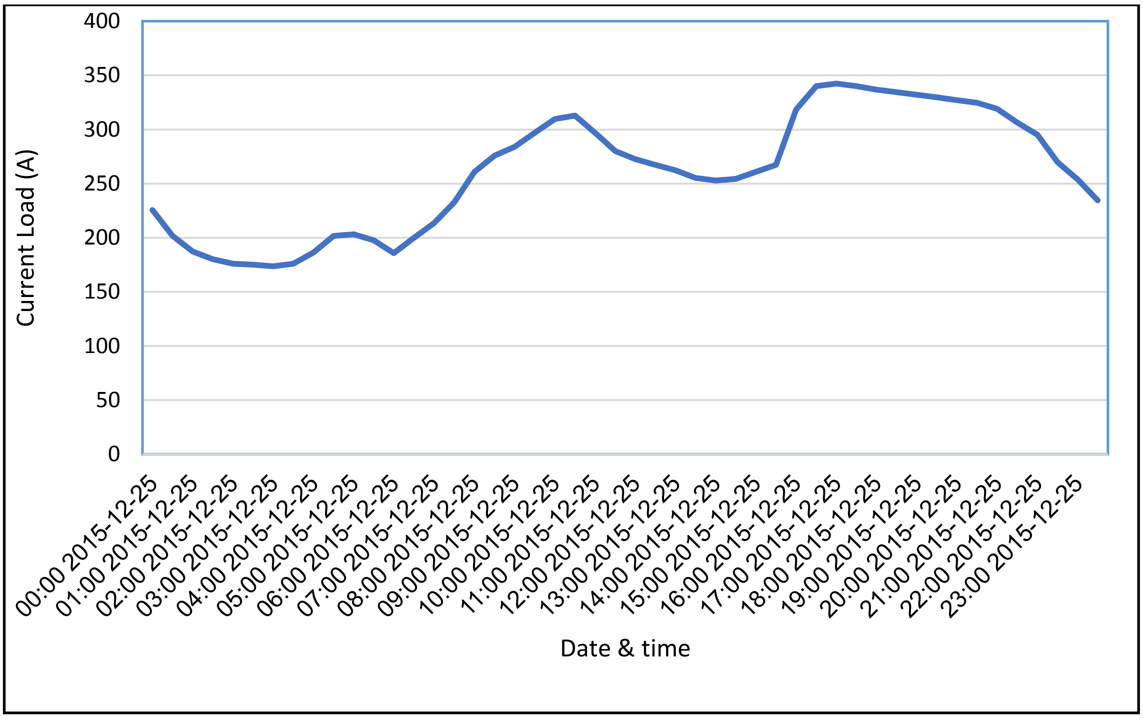


**Figure 4-10(a):** connection point Tulkarem 1 daily load curve for holiday in winter.

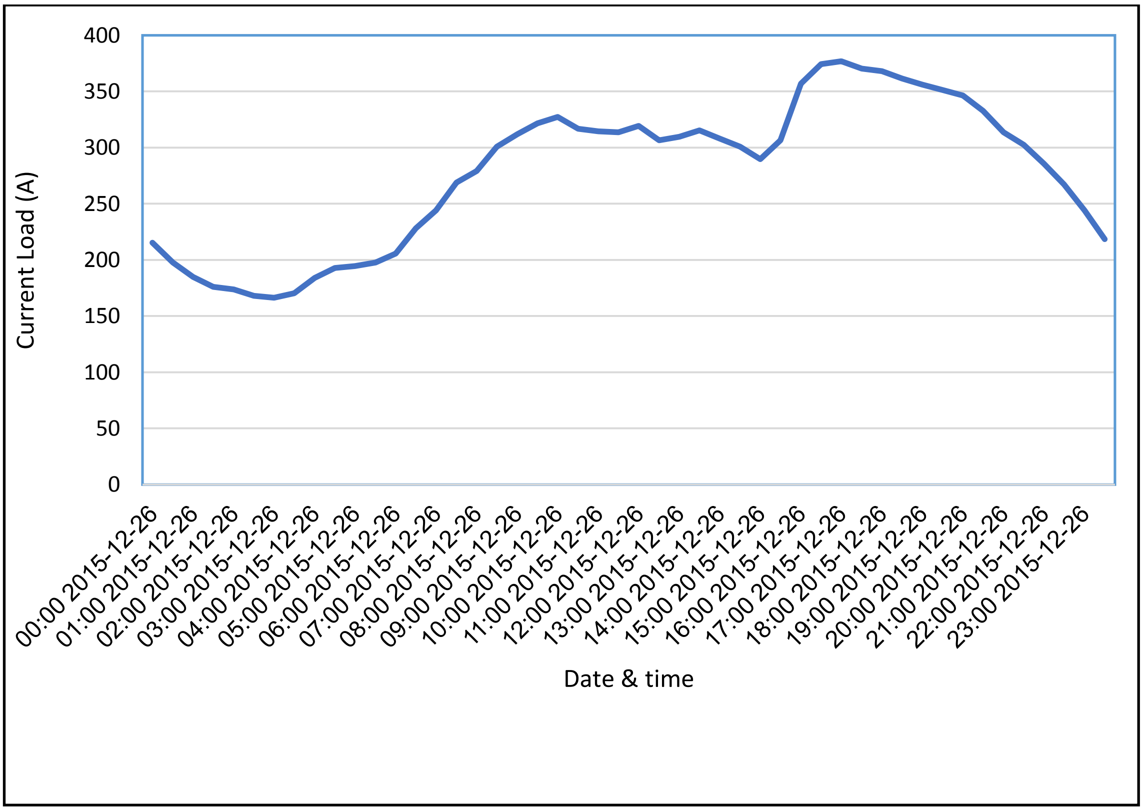


**Figure 4-10(b):** connection point Tulkarem 1 daily load curve for a  work day winter.

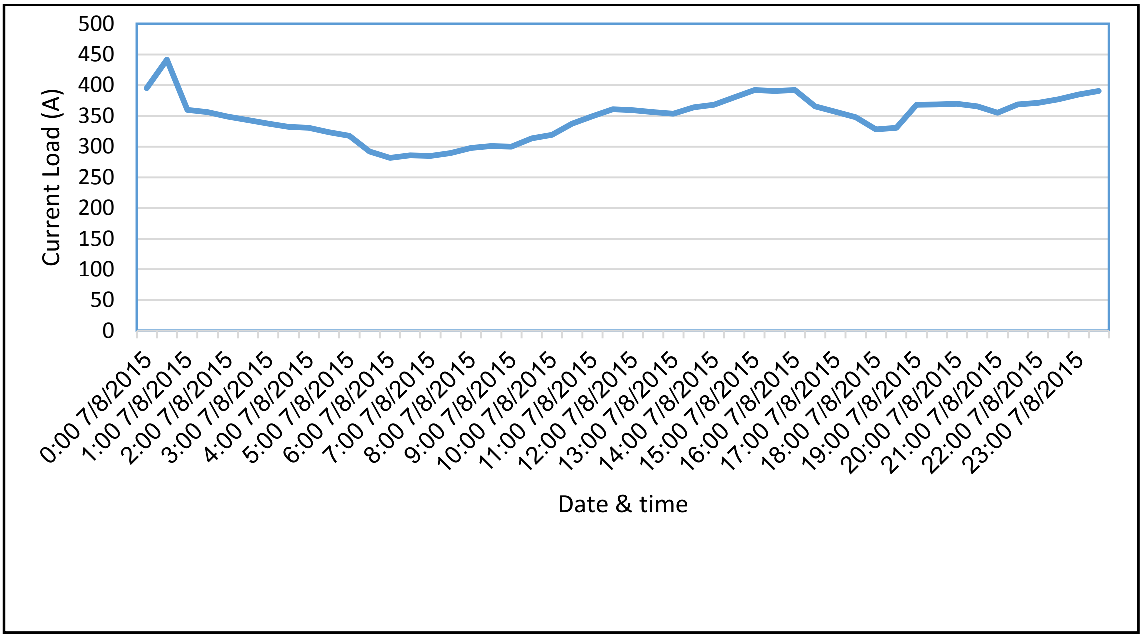


**Figure 4-10(c):** connection point Tulkarem 1 daily load curve for holiday in summer.

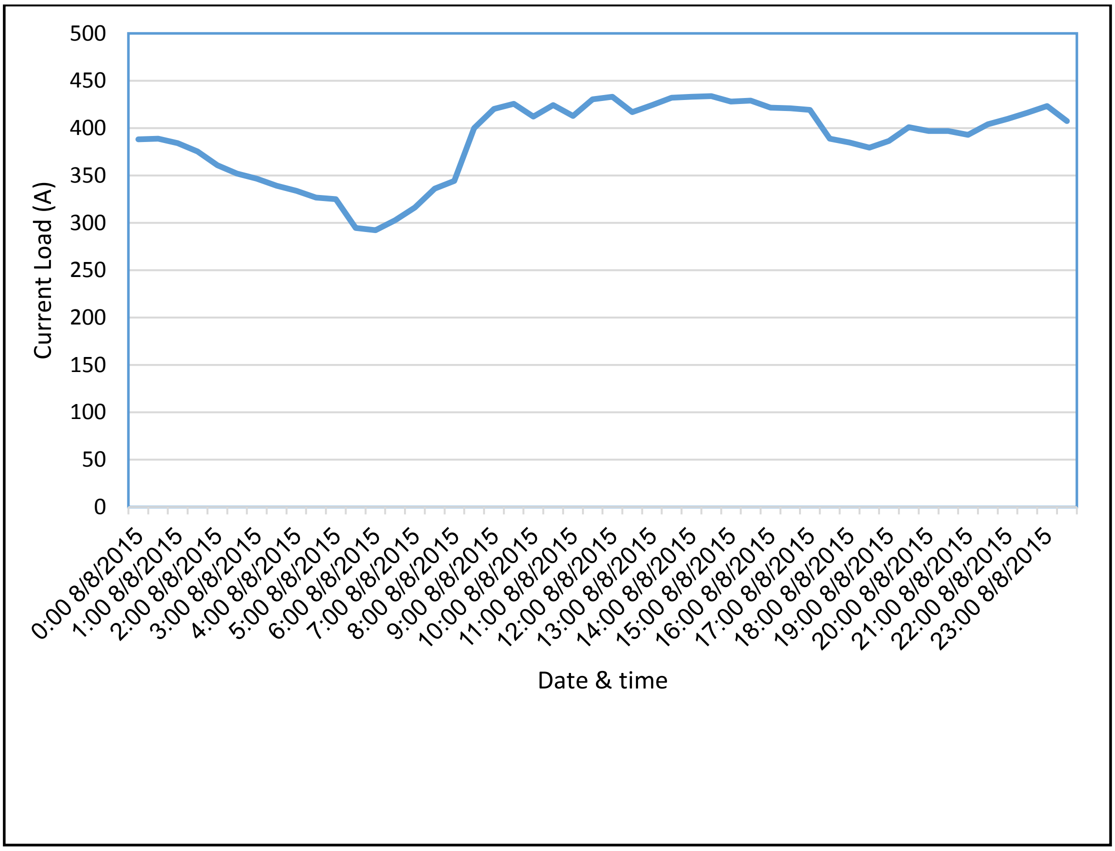


**Figure 4-10(d)**: connection point Tulkarem 1 daily load curve for awork day in winter.

**Figure 4-10 (a-d)**: Connection point (Tulkarem 1) daily load curve.

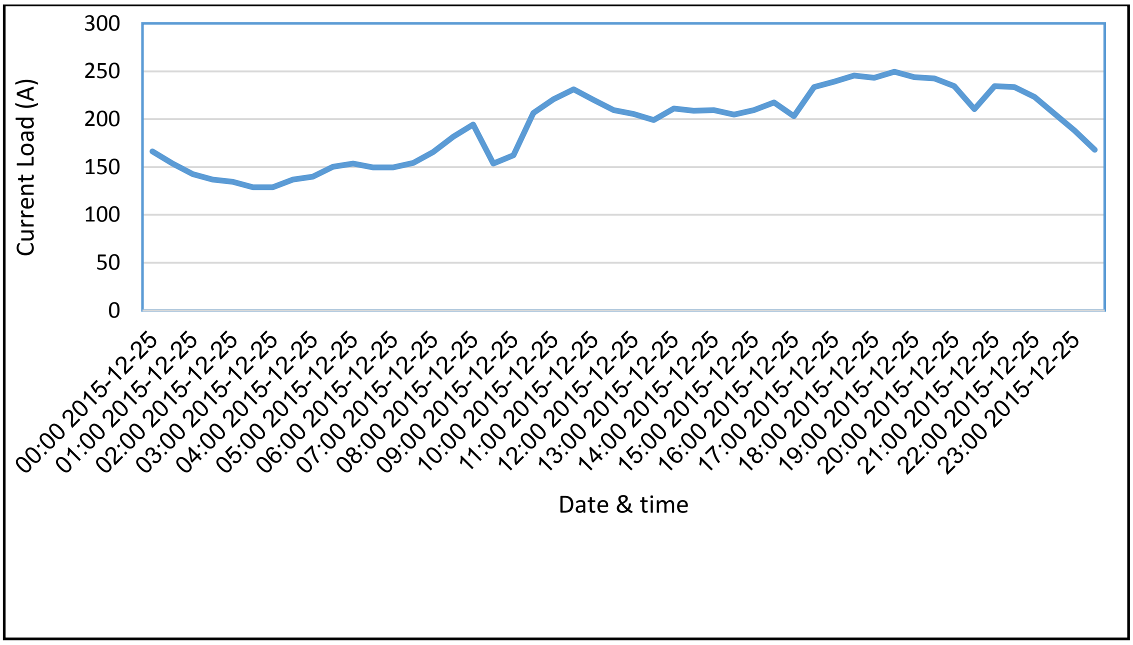


**Figure 4-11(a)**: Connection point Tulkarem 2 daily load curve for holiday in winter.

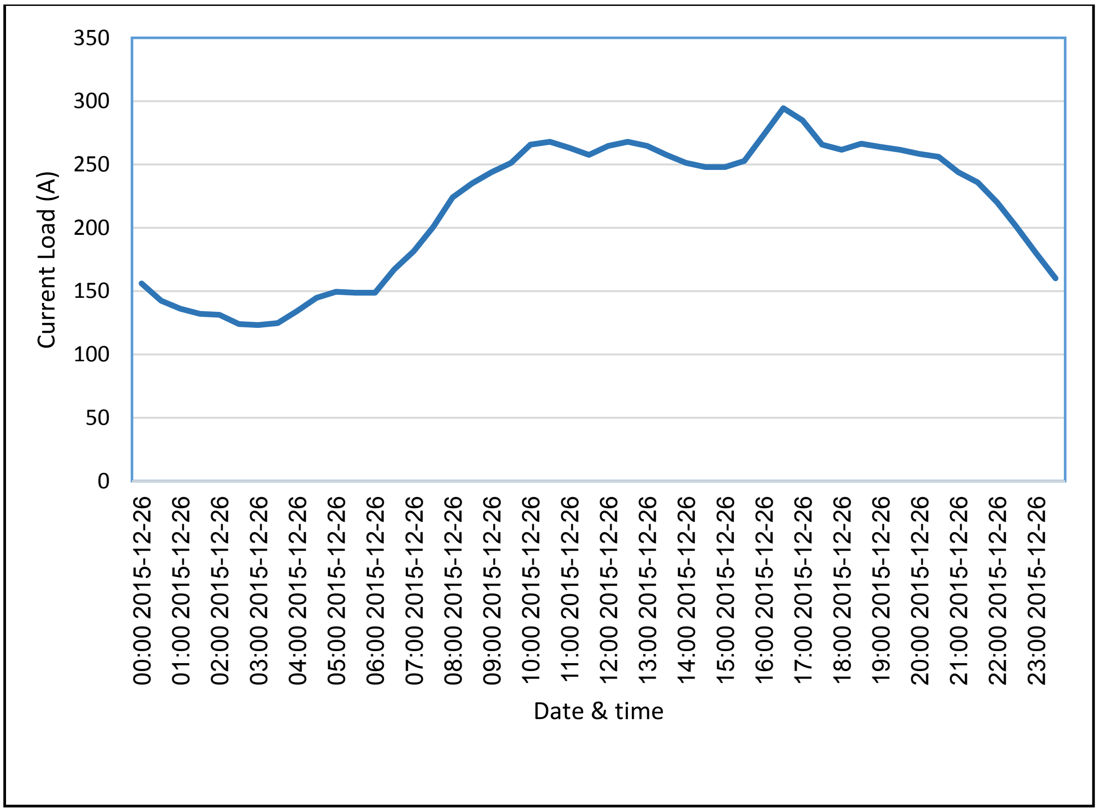


**Figure 4-11(b)**: Connection point Tulkarem 2 daily load curve for work in winter.

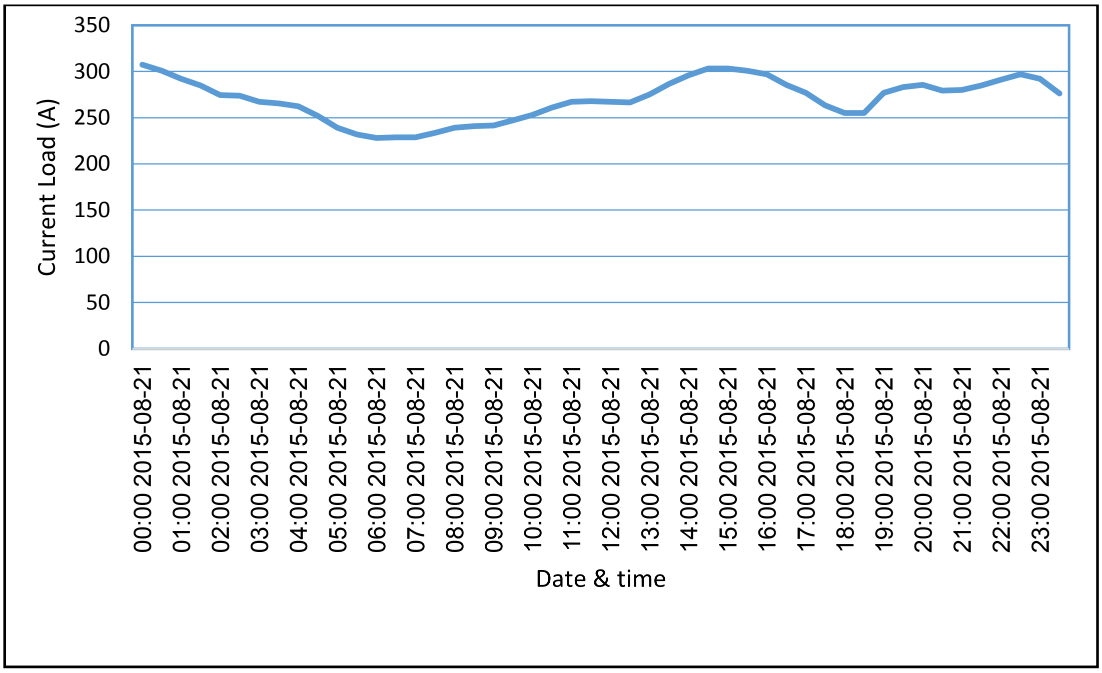


**Figure 4-11(c)**: Connection point Tulkarem 2 daily load curve for holiday in Summer.

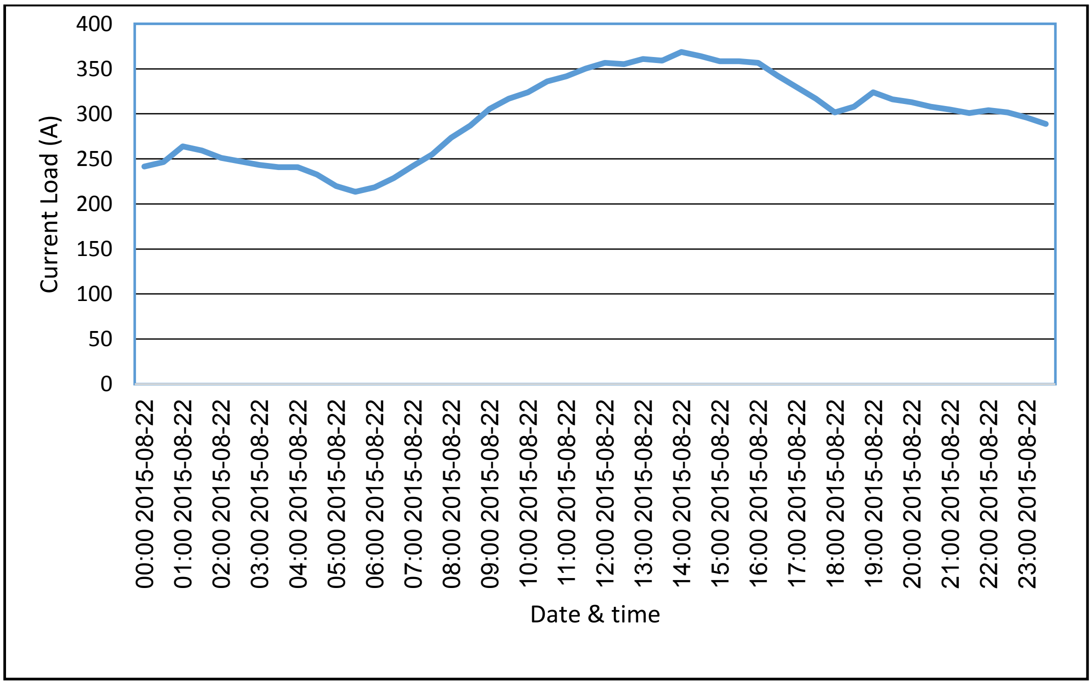


**Figure 4-11(d)**: Connection point Tulkarem 2 daily load curve for a work day in Summer.

**Figure 4-11 (a-d):** Connection point (Tulkarem 2) daily load curve.

The data of above figures can be summarized to describe the behavior of customers’ loads in different days of the year. Table 4-4 includes these summaries and analysis results for daily load curves in winter and summer.

## 4.5. Tulkarem Grid and Distribution Generation

Tulkarem municipality decided to approve connection of a renewable system (PV Solar Panels) with the grid by the end of year 2016. According to the law of net metering issued by the Palestinian National Authority. Until the beginning of 2017, only one customer has installed a rooftop PV panels with peak output of 5 kW. It is expected that the total generation capacity will increase sharply in the nearest future after the municipality approval and the decision of Ministry of Education to install PV panels on all schools in Palestine.

**Table 4-4: Summaries and analysis results for daily load curves in winter and summer**.

| | a holiday in winter | | a holiday in summer | |
|---|---|---|---|---|
| | Tulkarm 1 | Tulkarm 2 | Tulkarm 1 | Tulkarm 2 |
| Ratio of the maximum load % | 102.8 | 92.6 | 111.5 | 96 |
| Ratio of the minimum load % | 47.7 | 40.25 | 79.4 | 71.25 |
| Time interval of maximum | 16:00-20:00 | 16:30-22:30 | 12:00-17:00 | |
| Time interval of minimum | 1:00-6:00 | 23:00-9:00 | 5:00-8:00 | |
| Time interval of overloaded | 18:00-20:00 | | 12:00-15:00 | |
| | a work day in winter | | a work day in summer | |
| | Tulkarm 1 | Tulkarm 2 | Tulkarm 1 | Tulkarm 2 |
| Ratio of the maximum load % | 104.3 | 92 | 118.6 | 115 |
| Ratio of the minimum load % | 45.1 | 38.5 | 81.7 | 70 |
| Time interval of maximum | 15:00-21:00 | 9:00-22:00 | 9:00-17:00 | 9:00-22:00 |
| Time interval of minimum | 1:00-5:30 | 23:00-7:00 | 5:00-7:00 | 5:00-6:30 |
| Time interval of overloaded | 18:00-20:00 | | 11:00-17:00 | 11:00-17:00 |

# Chapter Five
# Proposed Tulkarem Electric Grid

## 5.1. Introduction

Planning for future electrical system must consider the ability to meet demand for electricity without harming the environment. These power systems will have to integrate different types of generation characteristics including; bulk, remote, distributed and volatile, as well as integrate storage and adapt to new types of consumer demand, including the need to power electric vehicles.

Smart grids will use modern communication and information systems to make use of new design concepts and advanced materials in system components like transformers and circuit breakers to improve efficiency, reliability and operational performance. Newly developed power electronic devices will help maximize performance of existing assets and make the grid more resilient in the event of distortion and disruptions.

Demand peaks can be mitigated with the integration of energy storage technologies that will help and allow the grid to integrate more renewable energy power sources such as solar PV systems. Use of more controllable transmission and distribution systems can accommodate fluctuations in supply, increase system efficiency and optimize operations. On-line monitoring and control systems will help prevent interruptions in power supply before they occur. A smart grid combines all of these features, linked by suitable communication technologies.

With advancements in communication systems and power electronic devices, the establishment of such modern power systems is possible even for simple and undeveloped grids. Any researcher can reach a conclusion that developing countries now own modern communication systems that can put them in an excellent position to take the lead in providing tailor-made solutions for the further development of smart electrical systems.

Smart grid can have the way for the future of electric power in the 21 century. The existing power grid infrastructure, such as relying on traditional sources, must be overcome through better deployment of renewable energy sources and the addition of an Information and communication layer. Smart grid is to be self-healing and allow for remote routing, better monitoring and control.

In this chapter, the researcher will study the possible strategies for converting the existing grid in Tulkarem to a smart grid. Some demonstrated technologies will have a part pretty in pushing ahead. This incorporates advanced digital meters (Smart meter), low-cost communication systems, distribution automation, and distributed energy resources. At the end, the researcher will investigate the possibility to solve the chronic problems of existing power grid.

## 5.2. Main Features of Tulkarem Smart Grid

The proposed Smart grid for Tulkarem will have four main features and applications:

1- Implementing advanced metering infrastructures

2- Identification and reduction of all losses, technical and non-technical.

3- Conducting load control and demand side management.

4- Monitoring and managing Distributed Generation, mainly from PV systems.

## 5.3. Implementing Advanced Metering Infrastructures

Significant elements of the system to change the present system down to smart grid, contains advanced metering infrastructure, which incorporate smart meters.

In Smart Grid, the smart meter is a flexible part with intelligent capacities to meet the customer's requests, and their every goal. Smart metering is an essential requirement to better management of peak demand. It allows measure and communicate real time power usage, encourage remote monitoring and control utilizations, and consumers are given real time pricing and evaluating utilization data. Smart metering likewise gives highly accurate and secure information to distribution utility to screen their systems, manage distribution instantly, and making plans. It will permit direct load control of heavy load instrument, such as air condition systems, and water pumps, so that in times of power shortage, electricity distributor can proportion supply to such machines, without noticeably influencing their performance.

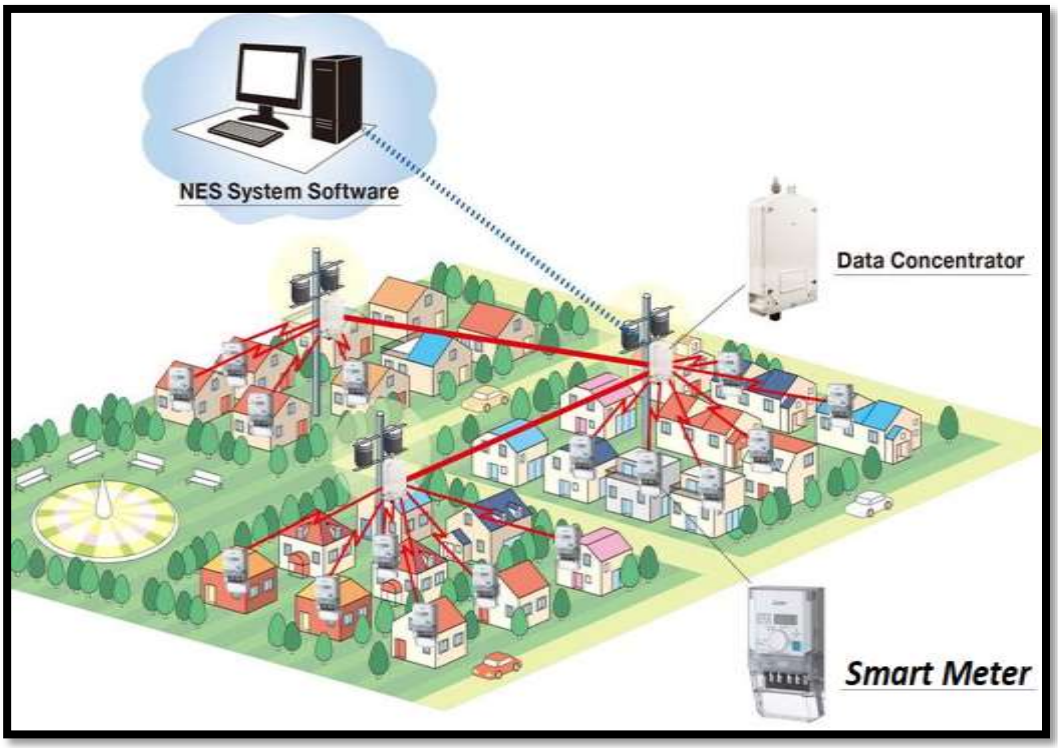


***Figure* 5-1**: *Smart meter network* (Source: Energy Services Network Association (ESNA)-2014).

Direct communications between utility centers and remote smart meters will minimize the cost of meter reading, and eliminate estimated reads, so providing customers with exact energy bills. Furthermore, it permits remote connect/disconnect of power to customer buildings, fundamentally enhancing client administration and cost when beneficiary residents change. Direct transfer of payments from customer bank account will be possible without any need for him to go to “One Stop Shop Center- Public Services” for charging their prepaid smart cards.

Domestic, commercial and industrial clients waste energy using too much energy and over limit. Smart metering can control this abuse of energy. Since if the power flow surpasses for a specific time then smart meter will cut off the power supply and it will be reestablished when the power goes to its endorsed limits. This element will significantly fulfill the utility objectives regarding energy.

### 5.3.1. Tulkarem Smart Meters Feasibility Study

The great challenge facing the proposed system is how to replace all old electromechanical and prepaid electronic meters by smart meters. In Tulkarem city, there are around 19000 meters some of them are single phase and the others are three phase low voltage meters. Worldwide, the average cost for the replacement ranges between $80 to $120 for a single-phase meter, and $200 to $240 for three-phase meters. If we consider the average cost for replacing any meter is $160, then the estimated cost for all meters in Tulkarem is three million US dollars.

This relatively huge investment can be justified by the economic benefits of smart meters in addition to other technical benefits. Installing smart meters will reduce running costs of the electric utility by:

1- Minimizing the cost of meter reading

2- Ability to control the energy consumption of customers

3- A reduction in ‘costs to serve’ by reducing number of data readers and employees for charging CARDs for prepaid meters.

4- Ability to switch substations from one feeder to another depending on loads for each feeder

5- Reduction in technical and non-technical losses by direct monitoring of energy flow in the network.

6- Ability to classify each customer as “essential” or “nonessential” in the database. Load control will be done with care for essential loads such as hospitals.

7- Ability to read Power Factor (PF) for each customer and make right decisions for those with low PF including fines.

8- Same network can be expanded later to include smart metering of water consumption.

Therefore, we can conclude that the smart meter project will provide tangible as well as intangible benefits to justify the high capital cost and operations cost. As a relatively high capital cost investment, decision makers in electric utilities have hesitated because the break-even calculation is too hard to quantify and substantiate. Figure 5.2 shows an example of the current investment and benefit calculation to justify smart meters. For the case of Tulkarem, will consumer driven savings, reduction in losses, utility automation, demand response and avoided costs really result in payback? It is hard to tell if we are going to be above break-even. If the same calculation is done using the new generation of low cost smart meters, coupled with their use of free existing communication network infrastructure and service fee-based cloud computing, the break-even is lower and easier to see, as shown in Figure 5.2-b.

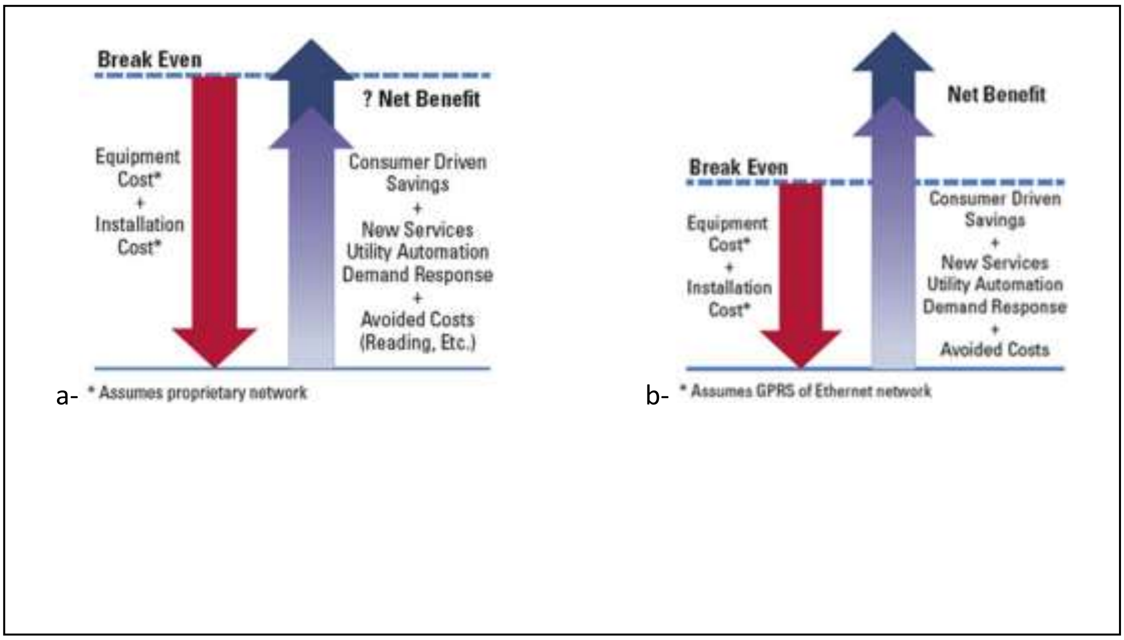


**Figure 5-2***:* a- Current cost benefit model for smart meters b- New generation smart meter cost benefit using low cost meters

*(Source:http://www.utilityproducts.com/search.html?q=smart+meter)*

Because the smart meters are the basic chords in the smart grid, and a link between all the elements of the electrical installation, must begin to transition to the smart grid. In Tulkarem as mentioned earlier almost 19000 subscribers, distributed to all categories, assuming that the average cost of the smart meter and installation is around $160 in average for single phase and 3-phase meter, then the total cost will be $3.0 million. Other costs for data communications, controllers and data recording and analysis are estimated at 6 Million US dollars. In this case, the total cost for smart metering system and required communication infrastructure is US $ 9 million. Here, the researcher proposes a 3-stages plan spread over 6-years period to cover this cost subjectively by starting investment by monitor $1 million. Then buy subsequent quantity of financial saving resulting from the installation of the system, it is called Revolving Fund as shown in figure 5-3.

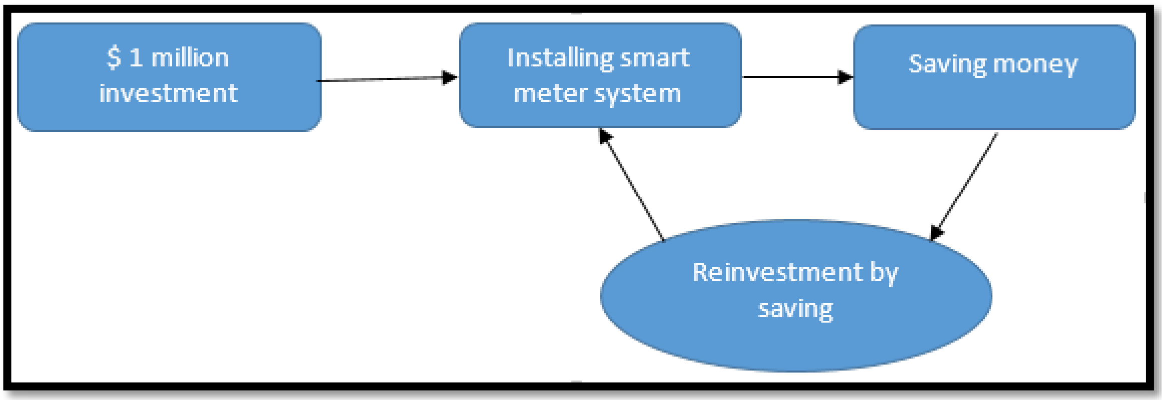


**Figure 5-3:** Revolving fund flow chart.

Currently there are 16 data readers and 8 employees for card charging. The average monthly salary with other benefits for each person is 3000 NIS.

Total Savings of Salaries = 24 x 12(months) x 3000 (NIS) = 864,000 NIS/yr

= 864,000/3.5 (NIS/$) = 246,850 US $/year

Minimizing technical and non-technical losses from 22% (currently) to 12% in 5 years, and average annual losses cost total is US $4,095,000 (2016), then

Savings by reduction of losses =

4.095 x (22-12)/22 = 1.8613 Million US $/year

Total Savings = 246,850 + 1,861,360 = US $ 2.1 million

If total cost of smart metering with related communication system will cost 9 million US dollars, then:

Payback period = 9/2.1 = 4.28 years

Notes:

- System costs do not include devices for load control
- Savings by improvements for technical losses or load control are not included

The cost of the system to include load control on substation level and customer level will add 70% to system cost, and will total to around $M 15.5. The benefits of installing smart meters must be integrated with load control and energy management system.

### 5.3.2. Smart Meter Benefits for Tulkarem Electric Network

Smart Metering allows to:

- Gain real and instant data on energy consumption of customers
- Minimize the cost of meter reading
- Ability to minimize technical and non-technical losses
- A reduction in ‘costs to serve’ by reducing number of data readers
- Ability to switch users from one feeder to another depending on loads for each feeder

- Help for revenue protection by comparing purchased and sold energy
- Monitoring of the distributed generation from building renewables
- Support in demand response techniques.
- More effective grid management.
- Provide a new communication channel to customers for instructions.

### 5.3.3. Benefits for Consumers

- Direct payment of electric bills from customer bank account without need for in-person visits to "One Stop Shops of municipality"
- Consumers can be informed remotely (historical data) or locally (real-time data) on:

  - Dynamic tariff and Energy costs.
  - Related carbon emission data.

- Energy consumption of household electrical can be displayed on meter display.
- Multi tariff functions can be added to allow demand response techniques.
- Allowing electrical appliances to be automatically controlled.
- Allowing the consumer to reduce costs by shifting energy consumption to off-peak cheaper tariff periods.

### 5.3.4. Benefits for Palestinian National government

Smart Metering will:

- Reduce energy imports on national level,
- Be a national strategy in the fight on climate change.
- Help government implement liberalization of energy markets, so each distribution company can develop its strategies and tariff system.
- Allow interconnection between distribution companies and other companies in the area.

## 5.4. Losses in Tulkarem Grid

Power losses is a very important challenge for any power network, which require effective solution. Power losses, which can be defined as the difference between the amounts of energy delivered and the amounts of energy customers is billed for. This difference in the generated and distributed units is known as Transmission and Distribution loss. Transmission and Distribution (T&D) loss are the amounts that are not paid for by users.

$$\text{T\&D Losses} = \frac{\text{Energy Input to feeder(Kwh)} - \text{Billed Energy to Consumer(Kwh)}}{\text{Energy Input (kwh)}} \times 100\%$$

There are two types of Transmission and Distribution Losses:

- Technical Losses

- Non-Technical Losses (Commercial Losses).

Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record keeping. These three categories of losses are respectively sometimes referred to as commercial, non-payment and administrative losses, although their definitions vary in the literature.

These energy losses and the percentage losses are defined in terms of the following equation:

$$Total\ Energy\ Losses = Energy\ Received - Energy\ Sold \quad (1)$$

$$Total\ Energy\ Losses = NonTechnical\ (NTL) + Technical\ (TL) \quad (2)$$

$$NTL = Energy\ Received - Energy\ Sold - TL \quad (3)$$

$$Percentage\ Loss = \left(\frac{Received\ Value - Sold\ Value}{Received\ Value}\right)\% \quad (4)$$

The better detection and controlling of losses is one reason for trade to smart meters. The usage of smart meters presents powerful and real measurements. It can be arranged to measure the consumption of energy every short interval of time picked by the utilities. Also, these meters must be fixed at the MV active feeder and at the end of each transformation point. What's more, they must be introduced at each LV customer as an initial step of distribution network advancement as appeared in the figure 5-4.

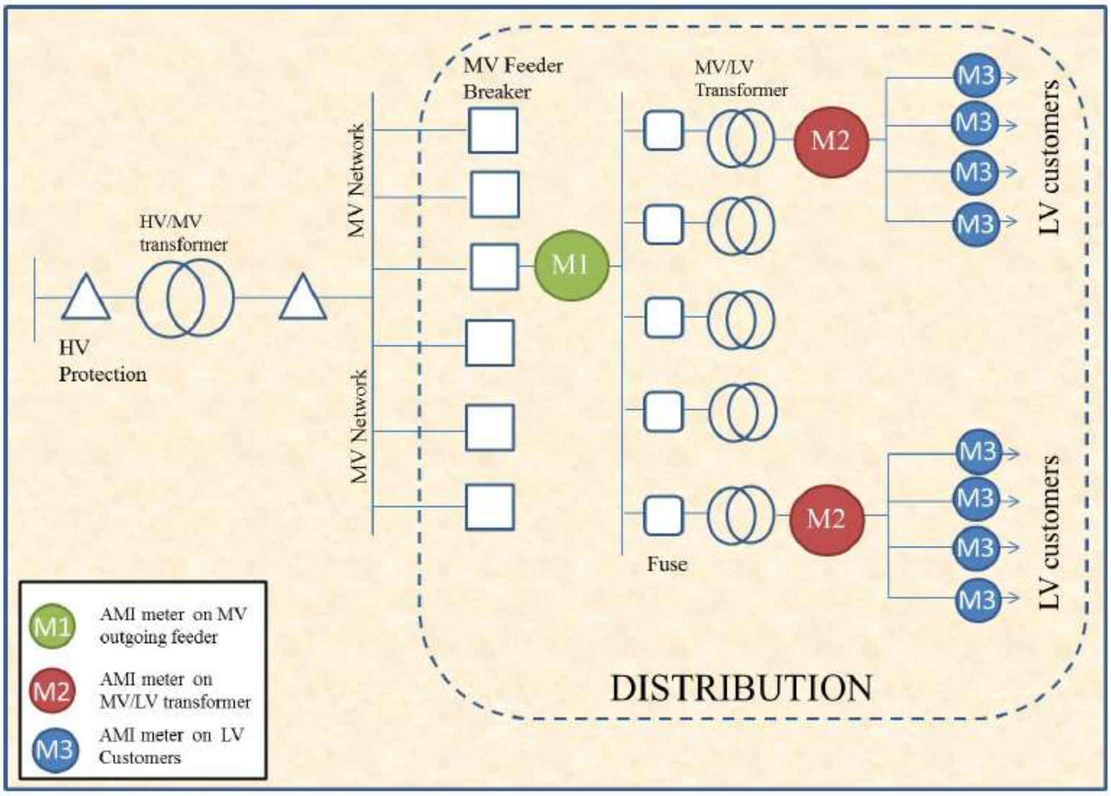


**Figure 5-4**: Advancement distribution network

Besides, the use of these meters helps the utilities to develop the required load profile for every client type.

What's more, the establishment of a master station that controls and screens from a separation all the executed meters is an indeed issue even if it is costly. Besides, it can detect the deceitful clients during a short time with less number of assets and reviews and it monitors all power flowing in the framework.

Tulkarem Municipality must spend more money and time for detection of non-technical losses and concentrate on non-technical loss reduction as their first priority. By diminishing the losses there is a decrease of the cost of electricity to clients and change of the efficiency, reliability, and quality of distribution network. Where is studying losses in Tulkarem for the years 2013 to 2015 shows that the average technical and non-technical losses around 3.5 million dollars per year. Table 5-1 shows the energy quantity

**Table 5-1: Tulkarem energy data 2013- 2014.**

| Year | received KWh | sold KWh | percentage losses | yearly losses NIS | yearly losses $ |
|---|---|---|---|---|---|
| **2013** | 129,248,640.00 | 100,173,486.00 | 22% | 12,502,316.22 | 3,379,004.38 |
| **2014** | 137,350,520.00 | 103,741,348.00 | 24% | 14,451,943.96 | 3,905,930.80 |
| **2015** | 146,969,120.00 | 124,157,695.00 | 16% | 9,808,912.75 | 2,651,057.50 |
| **2016** | 161,747,106.00 | 126,500,455.48 | 22% | 15,156,059.72 | 4,096,232.36 |

*(Source: Tulkarem Municipality, Financial department 2017)*

Figure 5-6 illustrate the percentage of losses from year 2013 to 2016, showing that in 2015 the percentage of losses is decreased. Inquire from Director of municipal electricity about the cause of this descending, he reported that the municipality had in that period implement search operation about thefts and illegal consumption, and arrested a large number of commercial consumers. However, in this period we can reach a reduction in losses by 12 million KWh which cost around $1.58 million.

This reinforces the importance of working to reduce losses especially non-technical losses. In smart ways, less costs and permanently not restricted to sporadic inspections.

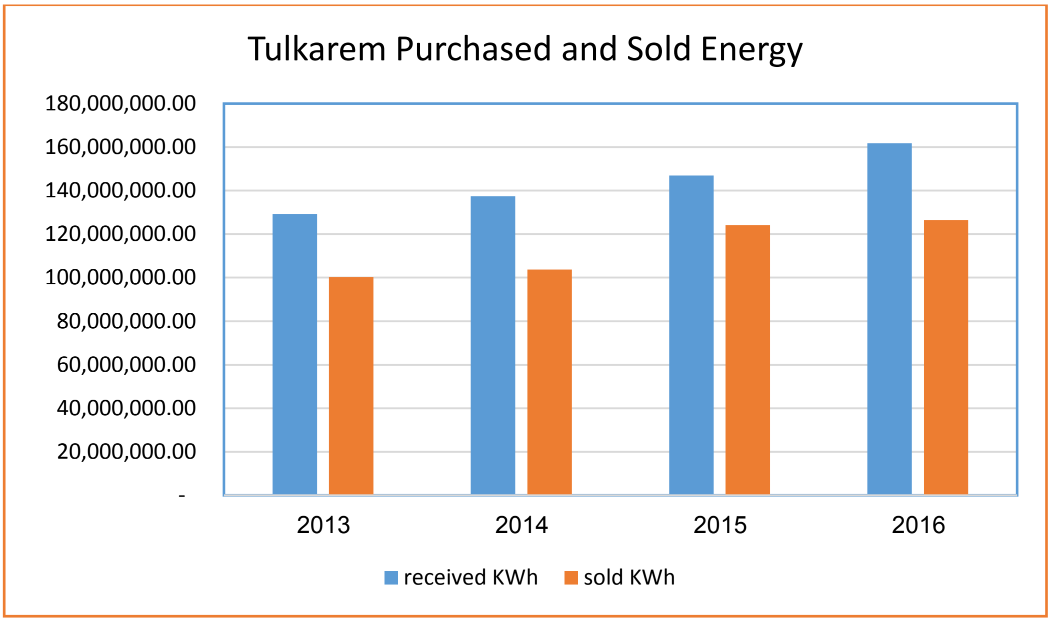


**Figure 5-5:** Tulkarem Purchased and Sold Energy.

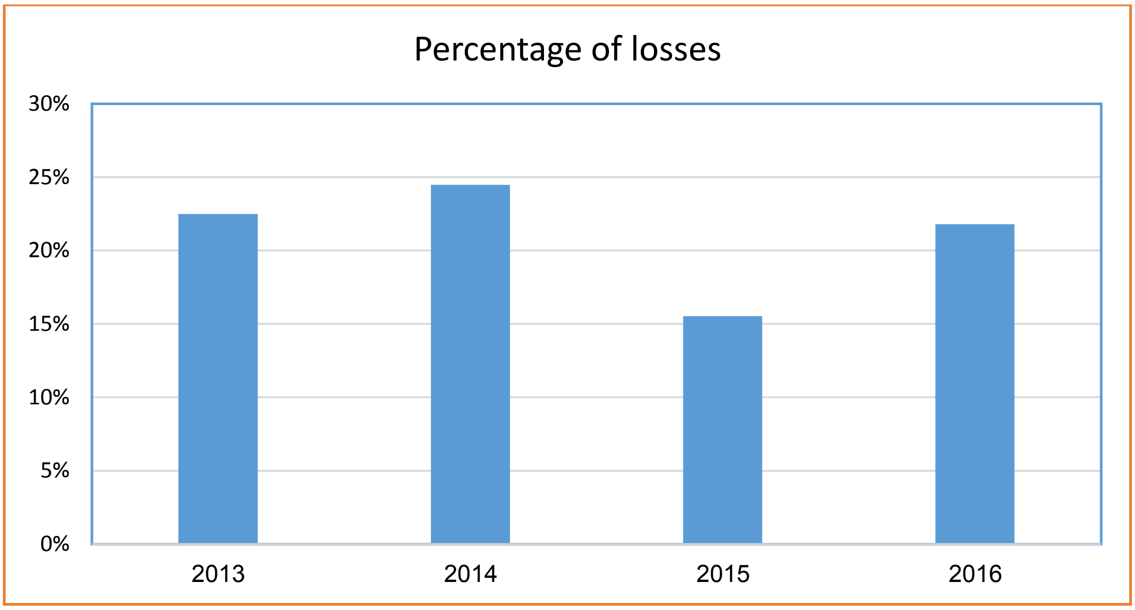


**Figure 5-6**: Percentage of losses.

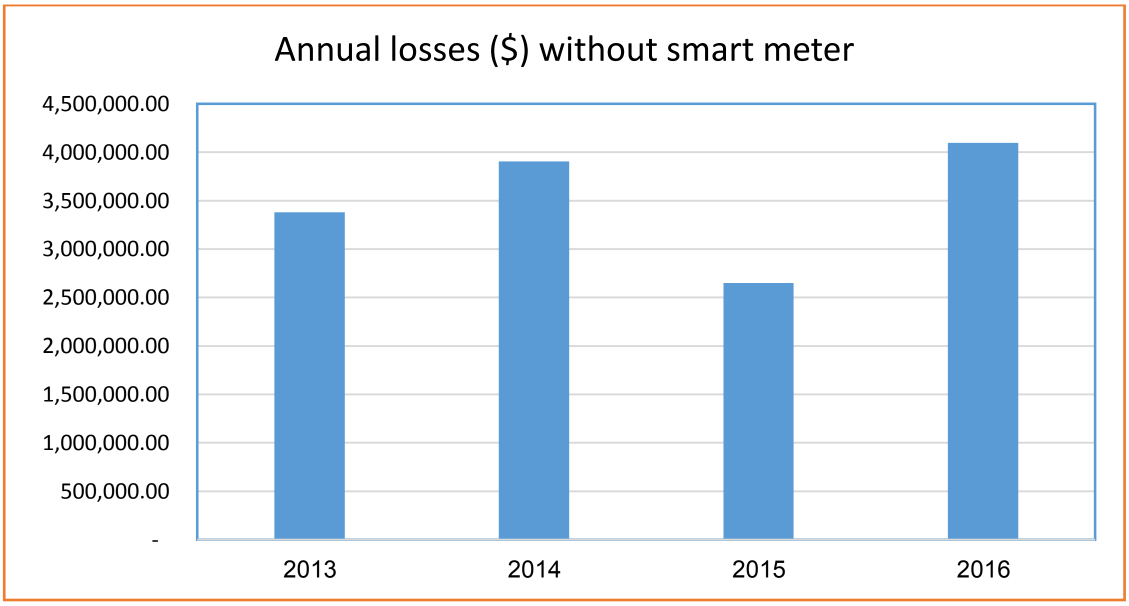


**Figure 5-7**: Annual losses in US $.

Smart meter depends on various communication technique for exchanging information to long distance. Wireless and power line carrier communication are two efficient solutions for automatic meter reading, however power line carrier communication is more practical and economical solution compared to wireless system [49]. Power line carrier communication (PLC) is a sort of procedure to transmit information over electrical cable in low voltage side. Due to intense capacity that such smart metering, gives greater capacity in supplies network, for example, exchanging of charge and more information.

### 5.4.1. Detection of Non-Technical Losses Using Smart Meter

Non-technical losses are estimated at 10% and related to thefts, defective meter and error in meter reading, billing of customer energy consumption, lack of administration, financial constraints, and estimating unmetered supply of energy.

Illegal use of power is a major issue in Palestine. In such usage client make an illegal connection with power grid and this connection does not pass a meter, so with no payment is made for consumed energy.

H. Cavdar [49] accepted that power could be used illegally in the four methods appeared in Figure 5-8 exchanging of energy cables at the meter box (Case 1), use of outside phase before the meter terminals (Case 2), use of fixed magnet (Case 3) and use of mechanical items (Case 4). Take note of that Cases 3 and 4 happen for electromechanical energy meters, and do not happen for digital meters.

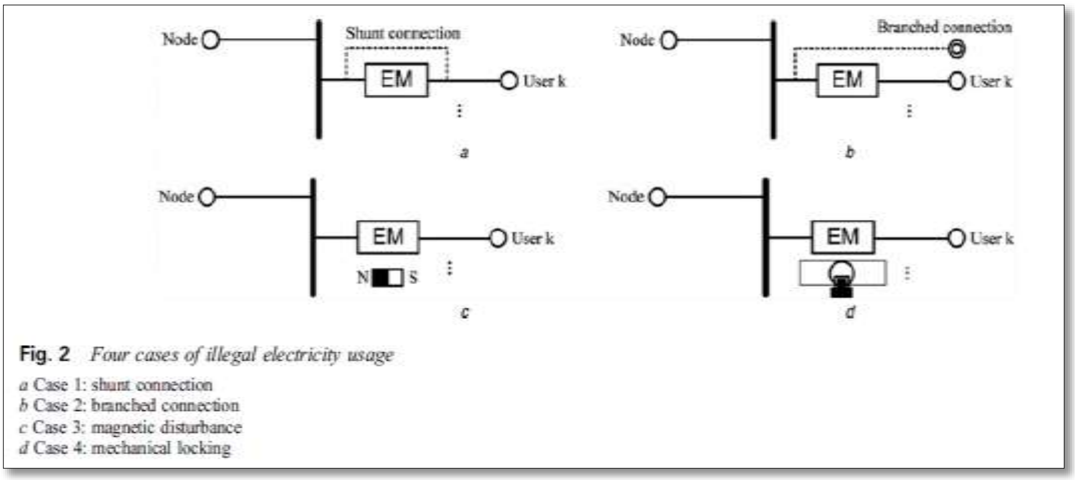


***Figure* 5-8*: Illegal electrical connection methods*** (Source: Cavdar I.H., A solution to remote detection of illegal electricity usage via power line communications, Power Engineering Society General Meeting, 2004. IEEE).

Many researchers suggested several ways to detect the illegal use of energy which can be applied in smart grids:

− H. Cavdar's [49] recommended fundamental technique to use two electrical meters: one on the client side and the other put outside. This means we have to double the amount of meters.

− Byambasuren Bat-Erdene, et al [2] proposed two developed smart meters, terminal smart meter (TSM) and gateway smart meter (GSM). TSM is installed at client side, where GSM is installed on the grid node.

− A. Pasdar and S. Mirzakuchaki [50]recommended a technique to use smart meters to disconnect all clients and transmit a low-voltage signal with a high frequency through the main line. The impedance of the concerned line will be measured and the result will be compared to the value of an ordinary line without illegal connections. Nonetheless, the main drawback of this technique is that the power delivery system of all clients must be disconnected. However, we think this technique is a suitable technique for Tulkarem grid. The steps are shown in flowchart in figure 5-9 below.

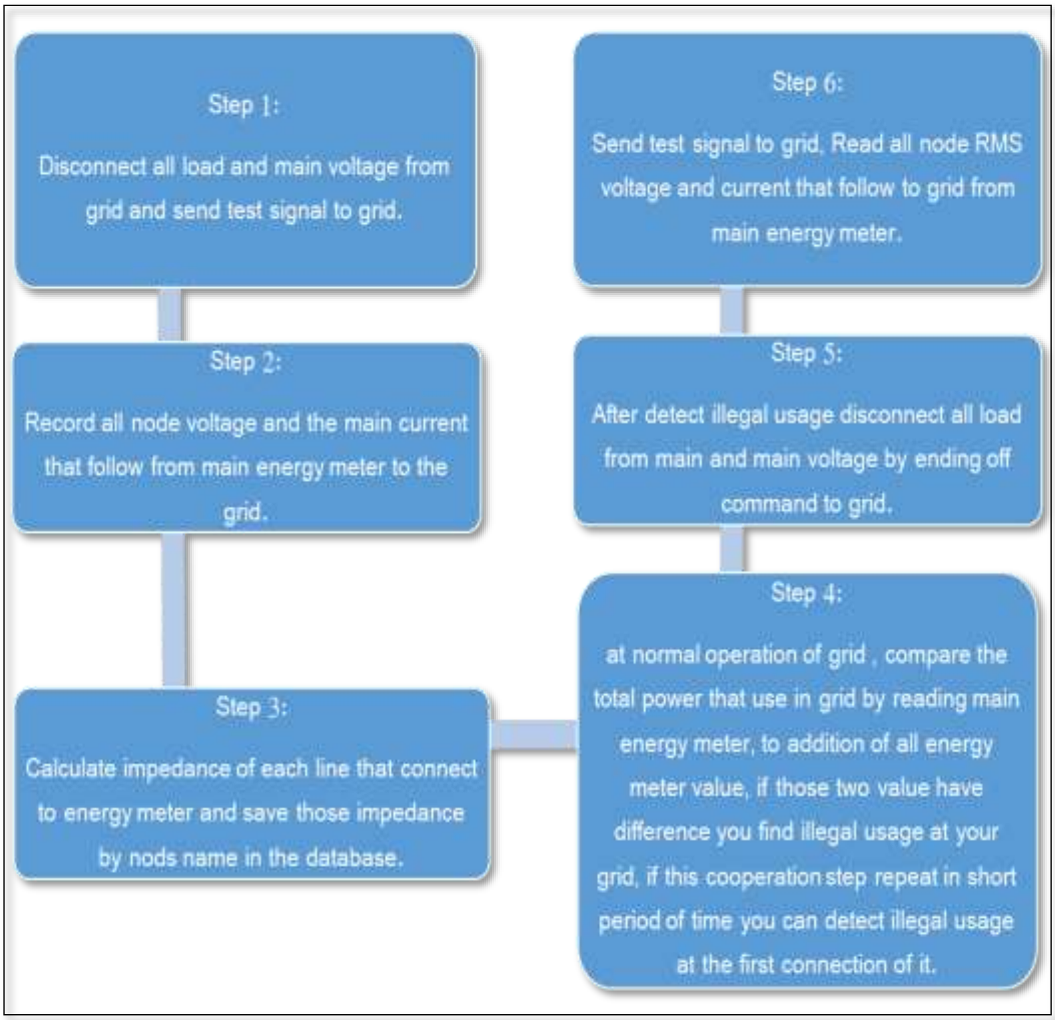


**Figure 5-9:** Technique steps to detect non-technical losses using smart meter.

### 5.4.2. Technical Losses Calculation

It is extremely difficult to estimate non-technical without the exact count of technical losses. Technical losses are the segment of distribution network losses that is natural in the physical delivery of electric energy. It incorporates conductor losses, transformer losses and losses because of potential/current coils in metering hardware. In this way, technical losses are engineering problems, they are well knew and conceivable to figure and control in view of their known quantities, for example, resistance, reactance, capacitance, voltage, current and energy.

Technical losses are figured by using load flow examination. With a specific end goal to perform flow analysis, different strategies have been arranged, for example, Gauss Siedel, Newton Raphson and so forth. These strategies were basically created to take care of issues postured at the transmission network level. However, they don't join for the distribution networks. The main reason that these strategies are more appropriate for a transmission framework as opposed to a distribution network, it is that both have various topology and R/X ratio of the distribution system is significantly higher than that of the transmission system.

The distribution system in Tulkarem has a radial or weakly meshed structure, unbalanced operation, unbalanced distributed loads, extensive number of transports and branches, and it has extensive variety of resistance and reactance values. In light of the Tulkarem is outspread system we use calculation in view of the strategy "forward clearing technique" as will be discussed in following sections.

### 5.4.3. Electric energy Losses Case Study

In Tulkarem grid, the percentage of losses average is around 22% as indicated in the table above for the last four years. In addition, by using load flow program ETAP we found that estimated technical losses for existing grid in Tulkarem is 12%, which means that non-technical losses present around 10%. If we assume that in the event of installing smart meters, applying the methods of detecting illegal uses and direct control of load flow to avoid losses, we will get a total loss reduction by 10% and total losses in the network becomes 12%. Therefore, consumption will be less, which means lower demand is expected and more savings will be achieved. In addition, this will improve network efficiency and solve power quality' voltage problems. Economically, it will save approximately $ 2 million annually. As shown in figure 5-10.

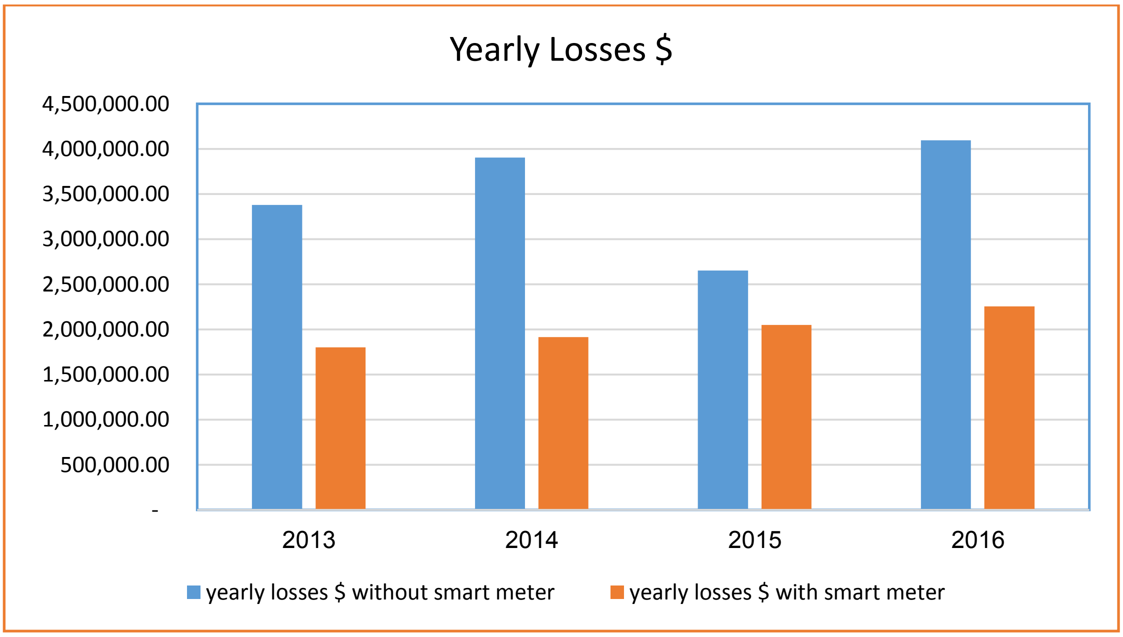


**Figure 5-10:** Estimated cost of losses ($) before and after smart grid.

## 5.5. Energy Management System Scheme for Proposed Design

The Demand-side Management is a leading program in the Smart Grid. The objective of the program is to outline foundational smart grid components and technologies to empower demand response, i.e., the scheduling and control of client load.

Smart Meter is the center wise unit that assumes the hugest part in proposed project. Firstly, it keeps up an intelligent association between households units of end customers and distribution grid as mentioned before. Through a two-way communication, customers can get ongoing data about power cost and grid load from their energy providers. Electrical department will be informed with instant power usage of each customer. After all, these data being gathered and organized, electric department will get an exact grid load for some specific regions of its scope. This data will be useful in each part of grid management and price determination.

The objective of this proposed system is to make demand response, through either direct load control or dynamic electricity pricing successful for the aggregators.

### 5.5.1. Dynamic Pricing

Dynamic pricing can help free market activity cooperate, to lower operating costs and improve reliability. We will likely outline dynamic pricing plans that are powerful and people-centric. That is, customer ought to have the incentive to lessen usage when supply costs are high especially at times of high demand.

Maybe the most proficient dynamic pricing model is real-time pricing (RTP), where retail costs change on an hourly or sub-hourly premise to reflect the true cost of supply. Nonetheless, these real-time prices are regularly unpredictable, which can hurt costumers and may discourage participation in willful element valuing programs. Alternative pricing options, for example, time-of-use (TOU) or critical peak pricing, are less alluring from a system standpoint, since cost is no longer specifically connected with system standpoint. There is a requirement for new dynamic pricing structures, which can mitigate volatility, while permitting prices to change ceaselessly in response to system.

We propose to implement a “dynamic pricing plan” that gives motivating forces to demand response alongside price certainty for customers who are as of now using power. Figure 5-11 illustrates the proposed flow chart. Like real-time pricing, empowering demand response during peak hours.

One of the most important challenges in Tulkarem is posting this project, and the number of subscribers who are committed to this program. Therefore, we have implemented an oral questionnaire fields for different community groups. From this survey, we concluded that 20% of customers are interested in knowing the value of instant tariff and their electric bill, and will change the nature of consumption in case of implementing dynamic pricing. Meanwhile, 40% are interested in knowing the instant tariff, but find it is difficult to cope with such a system and prefer that direct intervention to be implemented by the centralized controller of the system. The remainder customers rejected the idea of increasing cost of energy at critical demand periods, and they may not be able to change their consumption nature.

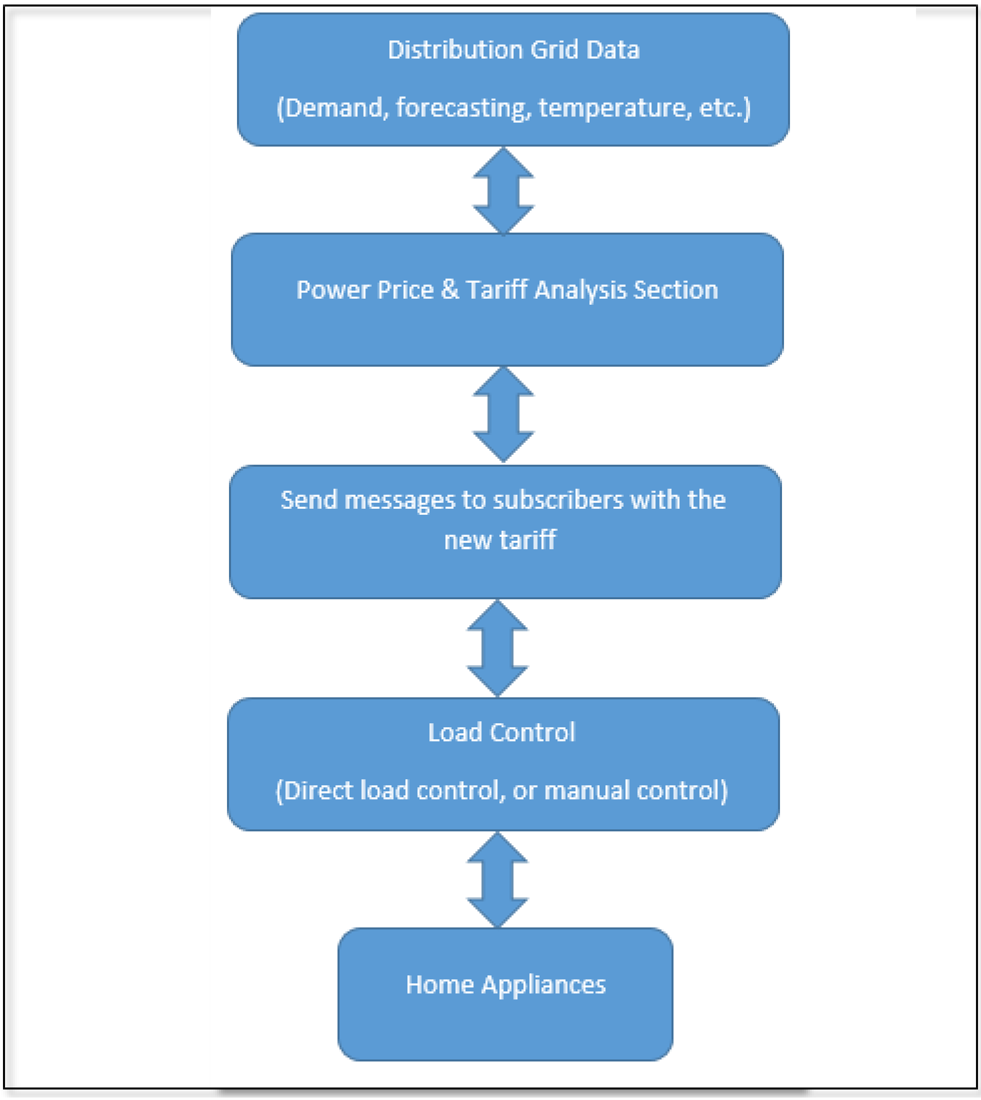


**Figure 5-11**: Flow chart for time-of-use (TOU) or critical peak pricing.

However, we expect that the not less than 50% of customers will interact positively with dynamic pricing when it is implemented and when they discover the benefits for those who acted accordingly to reduce demand at peak hours. These customers will find that.

### 5.5.2. Direct Demand Response

Distribution systems are prepared to meet the power demand while guaranteeing security and quality requirements. Numerous logical productions have proposed techniques concerning optimal direct load control methodologies. These plans to reduce the operational costs of the electric system, or concentrate on limiting the peak demand.

The estimation of the consumers' adaptability potential in direct load control relies on upon the:

- Amount of energy that is consumed by loads that could possibly be controlled (air-conditioning systems, heating systems and domestic hot water)
- Deployment of the devices that empowers the control of distribute of loads.

The procedure of a direct control of any individual load might be partitioned into three sequential stages:

stage1: load cut-off.

stage2: power bounce back.

stage3: energy shift.

The change of the electric demand is a consequence of the addition of all the issued load controls. Thus, the power demand of a MV substation might be expressed by the following equation:

$$Ptotal\ (t) = P.(t) + \sum_{type\ of\ load} [\,-Pco(t) + Pb(t) + \Pr(t)] \qquad (5)$$

Where:

- P total (t): Is the power demand of the considered MV substation at time that incorporates the effects of direct load control [KW].
- P. (t): Is the power demand of the considered MV substation at time t that does exclude coordinate load control [KW].
- Pco (t): Is the power that is cut-off at time t because of the direct load control of a considered type of load (air-conditioning systems, heating systems and domestic hot water) [KW].
- Pb (t): Is the extra power because of the power bounce back at time t that happens subsequent to shedding a specific type of controlled load (air-conditioning systems, heating systems and domestic hot water) [KW].
- Pr (t): Is the additional power because of the energy shift at time t. It relies on upon the type of load (air-conditioning systems, heating systems and domestic hot water) [KW].

Direct load control process relies on upon several parameters, the measure of controlled loads decides the greatness of the adjustments in power demand, the quantity of consumers that have been included in the technology deployment decides powers that can be controlled, and it is constrained by contractual responsibilities as assurance consumer comfort. To the case of Tulkarem, air conditioning systems (mainly Slit Units) are the only possible controllable loads. Electric space heating and water heaters are used at in a very small scale and decentralized configuration which are very difficult to control.

Flow chart in Figure 5-12 illustrates the proposed direct load control systems.

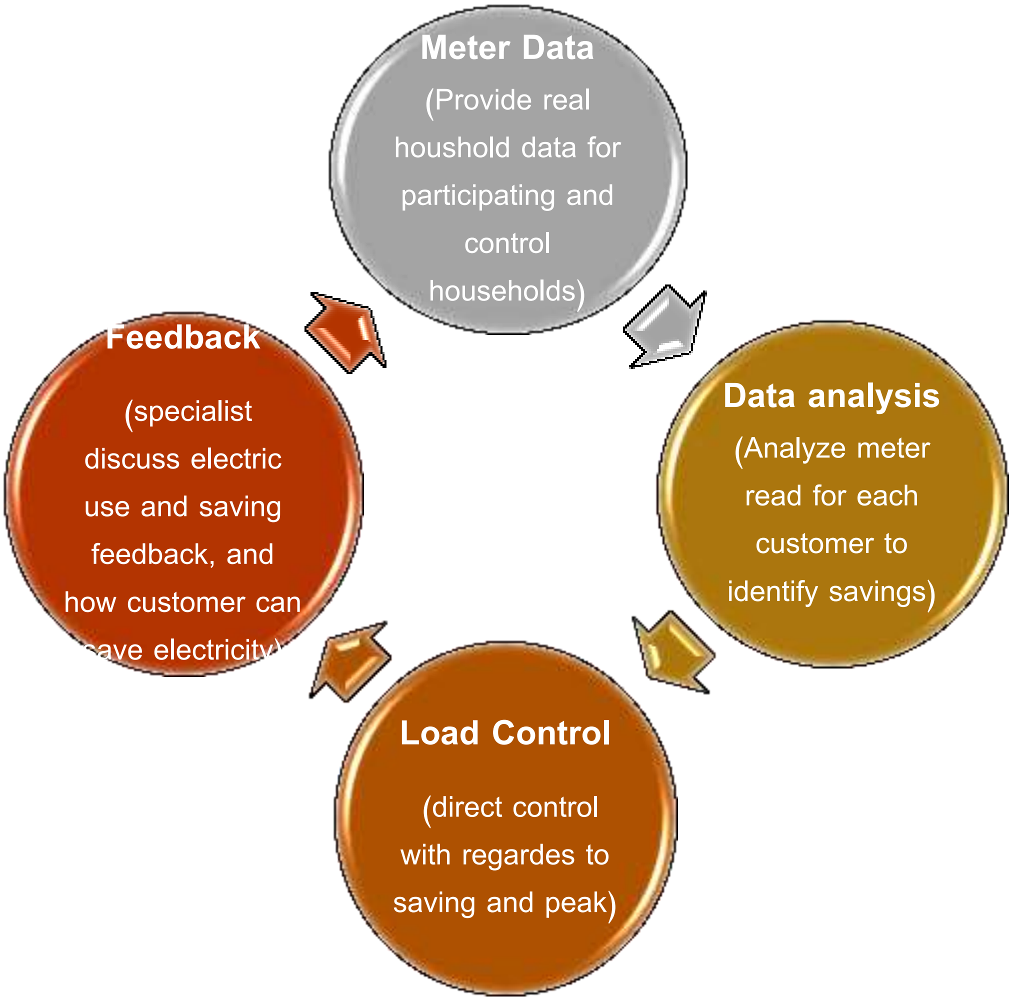


**Figure 5-12**: Flowchart for direct load control in smart grids.

Direct load control is completed for decide time during the peak load in which the peak load reduced diminished by more than 15% from the base case. The objective of up to 15% peak diminishment is effortlessly achievable with the direct control of air-condition systems alone in residential, governmental and commercial sectors.

Although the data on type of load in residential, governmental and commercial sectors during the peak hours is not available but one can safely assumed the percentage of residential, governmental and commercial sectors load is 85%, The air-conditioning load in government and commercial is over 80% during the peak hours. In residential sector in Tulkarem, during the peak hours between 1 and 5 pm in the hot summer days, the air-conditioning load that participate to the peak may reach over 80%. Proposed methodology to assuming 25% air-conditioning load is cut for 15 min every hour on revolution premise in the three sectors, then a straightforward estimation that the peak reduction will be:

$$peak\ reduction = 80\% * 85\% * 25\% = 17\% \qquad (6)$$

By integrating smart meters with smart control software, it will be possible to implement a smart strategy for controlling unessential loads for reducing the loads at critical times.

## 5.6. Integrated Distributions Generation

By the end of 2016, Municipality of Tulkarem approved installation of rooftop PV systems and connecting them to the local grid. The Ministry of Education and Higher education decided to install PV-systems at rooftop of all schools in the West Bank and Gaza, and this includes Tulkarem city' schools. This means that in the nearest future there will be a large number of these systems in the city and connected to the local grid. PV-system generates electricity that is fed into the grid, and they can be considered as distributed generation. Distributed generation may supply few watts (W) to ten megawatts (MW) and offers different advantages compared to conventional power generation.

The significant advantages of distributed generation can be classified into two advantages: economic and operational. From an economic perspective, distributed generation gives support and load control during peak demand periods, in this way diminishing interference that may prompt to system blackouts. It likewise decreases the risk of investment, because of the adaptability of its ability and installation placement. Distributed generation operational costs are reduced since PV-systems are installed near the client load, therefore abstains from overhauling or setting up another transmission and distribution network. From the operational perspective, distributed generation guarantees the reliability, stability of supply, and reduces power losses. Likewise, this technology additionally assumes a basic part in decreasing emissions of greenhouse gases, given that renewable energy is its main source and no gasses are emitted amid its operation, compared with conventional power generation.

From a technical perspective, we expect that distributed generation in power systems will cause changes in power flow. It must be clear that the present power systems topology in Tulkarem is radial. Therefore, before solving load flow issues, there are four constraint factors in power flow that ought to be known:

(1) Voltage angle, (2) Voltage magnitude,

(3) The real power (P) and (4) The reactive power (Q).

These factors can decide the characteristic of buses whether as PQ or PV bus. In PQ bus there is no power generation source and these commonly are load buses where the net P and Q powers are determined, with the obscure being the angle and voltage magnitudes. PV’s are generator buses, where the active power P output and the voltage magnitude are known, while the reactive power Q and the angles are obscure. The auto voltage controller (AVR), which keeps the voltage magnitude at a steady level by changing the field current of the generator and its reactive power output normally, controls these buses. A distributed generation can be demonstrated as a PQ or PV bus. It can also be demonstrated as a negative load, where the P and Q are injected in power network.

In order to evaluate the effect of distributed generation on our Smart Grid, it is essential to build up a suitable applied model, and a test setup is required. The researcher proposes to integrate distributed generation with the network and control the production, stockpiling part of the production in batteries as shown in figure 5-13.  This can happen only through a smart network with future prospects.

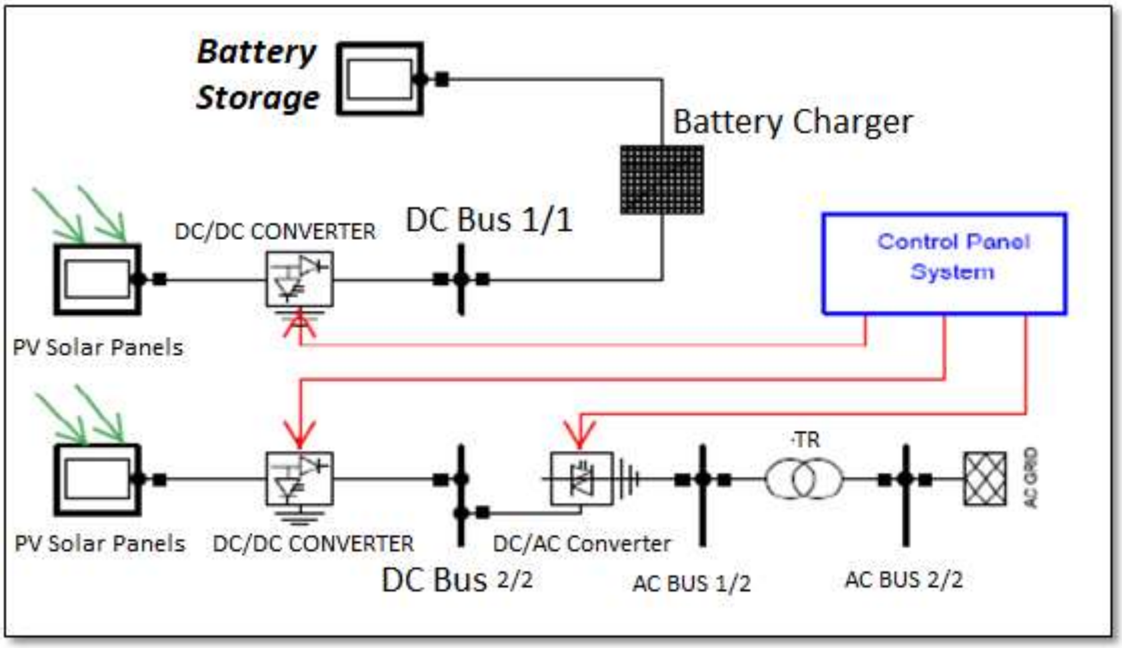


**Figure 5-13**: PV operation and grid connection.

Through the projected increase in the number of participants of the rooftop PV systems with 5KWp connected to the grid, a change in the shape of daily load curve of the network is expected. A reduction in load curve will occur at the times of high solar radiation as shown in figure 5-14.This figure is made on the assumption that 1000 PV units of 5 KWp are installed.

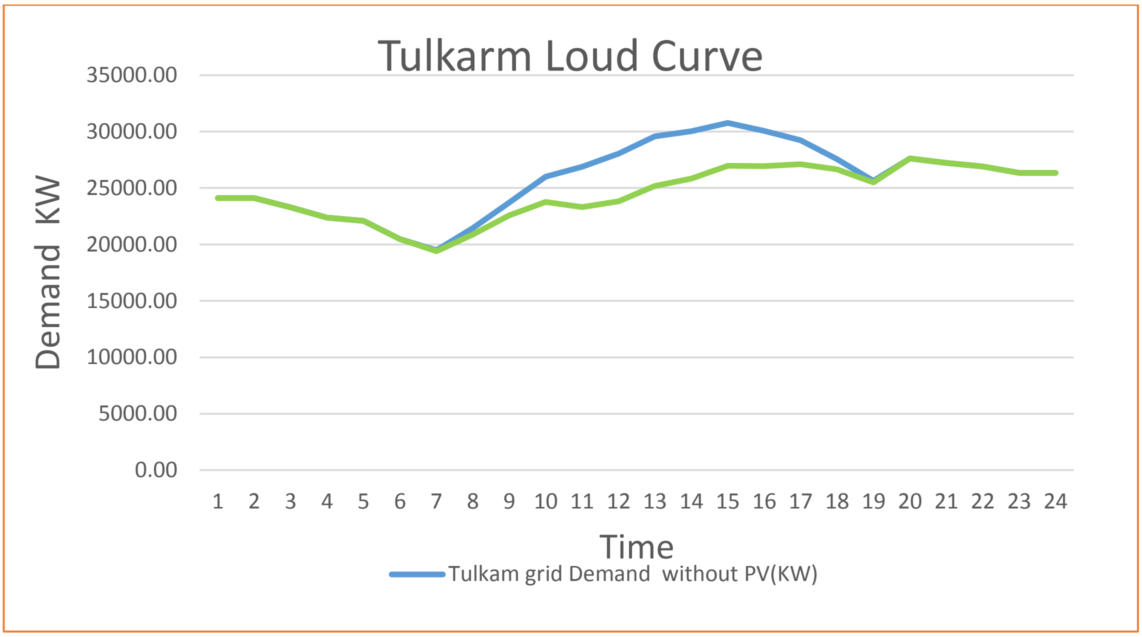


**Figure 5-14**: Typical change in daily load curve in Tulkarem with 1000 rooftop PV system installed.

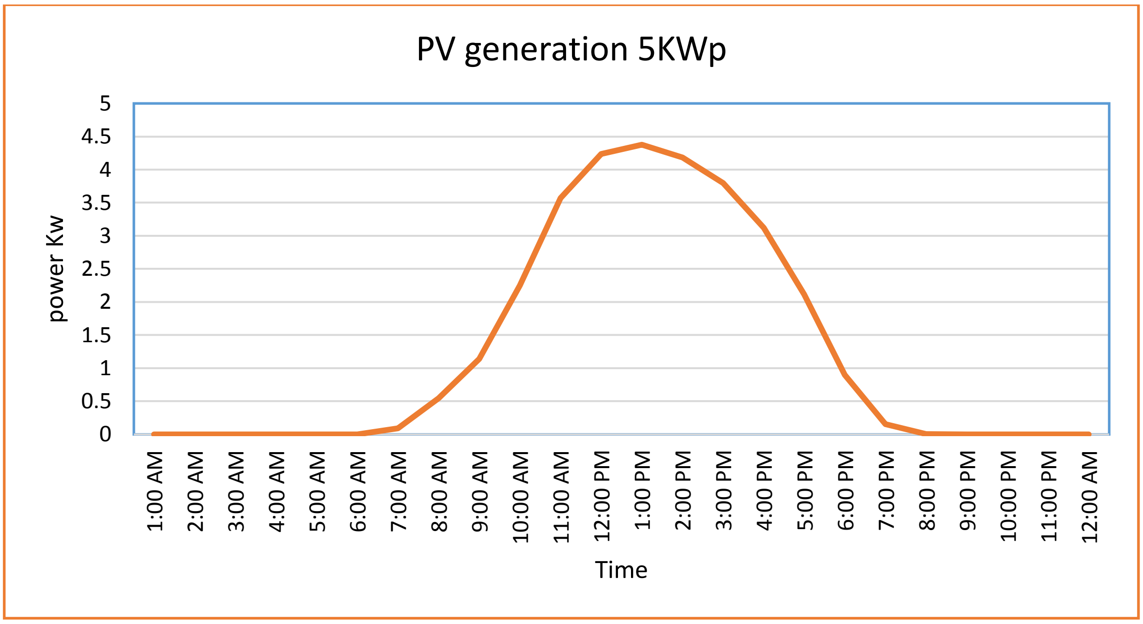


**Figure 5-15**: Typical daily generation curve of 5 KWp PV panels.

The hours of sun radiation differ from season to season as indicated by the Julian day of the year, and can be calculated according to the following equations.

$$\delta = 23.45\ \sin\left(\frac{360\ (284 + N)}{365}\right) \tag{7}$$

Where:

$\delta$ = declination angle.

N = the Julian day number, such that N=1 on the 1st January and 365 for 31 of December

$$Hs = \mp\ \cos^{-1}(-\ \tan\delta *\ \tan L) \tag{8}$$

Where:

Hs = the hour angle.

L = the latitude.

$\delta$ = the declination angle.

$$t_D = \frac{2|Hs|}{15} \tag{9}$$

Where:

$t_D$ = the daylight time.

Through an intelligent network, it will be possible to control distributed generation and to know the exact amount of generation, the demand of customers for power and energy surplus quantity. In the case of stations with storage units such as batteries, we can monitor the state of charge of these batteries, and many other details about the whole system. All of these activities can be done simultaneously using different means of communication as discussed before.

### 5.6.1. Storage System (Battery Bank)

The maximum power output of DG depends on different factors such as sun oriented radiation, temperature, and demand. So we will be unable to meet the load demands at all circumstances. A battery may be considered as a power supply amid these circumstances.

The two principle types of batteries used are nickel cadmium and lead-acid. Lead-acid batteries is yet the most widely recognized type for renewable systems. Nickel-cadmium batteries are limited being used because of higher cost, restricted upper working temperature, and lower energy efficiency. The two types of lead-acid batteries accessible at high limits capacities are the regular type and the block type. The block type has long lifetime (>10 years), ability of standing very deep discharge, and high cycling stability rate, but it has a higher cost. The ampere-hour capacity ($C_{Ah}$) and watt-hour capacity ($C_{wh}$) of a battery bank desired to supply a load for a specific period (day) when energy from renewable systems unavailable can be given as follows:

$$C_{wh} = \frac{E_l * AD}{\eta_v * \eta_{wh} * DOD} \quad (10)$$

Where;

$C_{wh}$: watt-hour capacity.

$E_l$: is the load requirement during the time interval.

AD: is the daily autonomy.

$\eta_v$ and $\eta_{wh}$ : are the efficiency of inverter and battery bank respectively.

DOD:

From that, total capacity of the battery relies on daily autonomy that represents to number of hours or days, which battery will be fit to supply the load if there should be an occurrence of lack of the renewable sources.

### 5.6.2. The Proposed System with Storage

The strategy proposed by the researcher has been applied to the case study of the date 22/8/2015, owing to limited data and poor real information about electrical consumption. This date represents a typical harsh summer day in Tulkarem, and on this day most electrical network problems occurred especially demand increase, and the consequent increase in technical losses.

Figure 5-16 shows the daily load curve of the date 22/8/2015, as recorded by electrical department of Tulkarem municipality. Table 5-2 provides full analysis of the grid on that specific date.

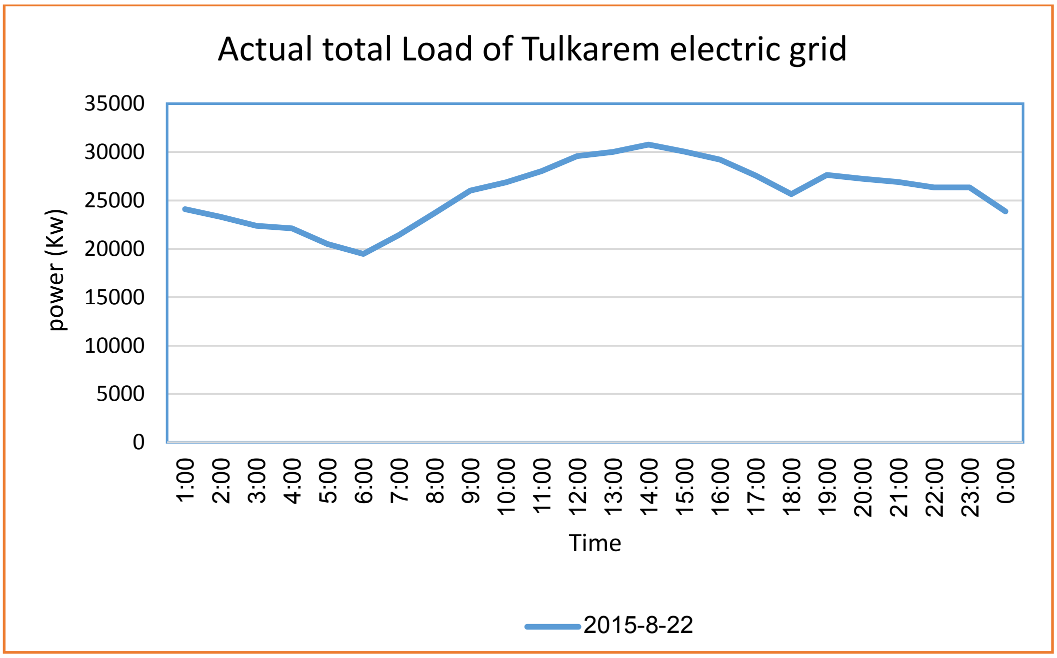


***Figure* 5-16**: *Actual Load Curve of Tulkarem electric grid on 22/8/2015* (Source: Tulkarem municipality historical data).

**Table 5-2: Analysis of a typical daily load curve in Tulkarem.**

| Date : 22Aug, 2015 | | |
|---|---|---|
| Without PV & battery | | |
| Grid capacity ($P_c$) | 25530.43 | KW |
| Max Demand ($P_{max}$) | 30758.45 | KW |
| Time of max demand | 15:00 | |
| Base demand ($P_b$) | 19479.34 | KW |
| Time of base demand | 7:00 | |
| Average Demand ($P_{avg}$) | 25804.79 | KW |
| Grid Load Factor ($P_{avg}$ /$P_{max}$) | 0.84 | |
| Grid capacity factor ($P_{avg}$/$P_c$) | 1.01 | |
| Grid Utilization factor ($P_{max}$/$P_c$) | 1.20 | |
| Grid Reserve capacity ($P_c - P_{max}$) | -5228.02 | KW |

In this specific day (22/8/2015), and according to equation 8, power generation is stretching between the hours of 6:00 to 19:00. Figure 5-17 shows the daily generation of rooftop PV panels with peak capacity of 5 kW.

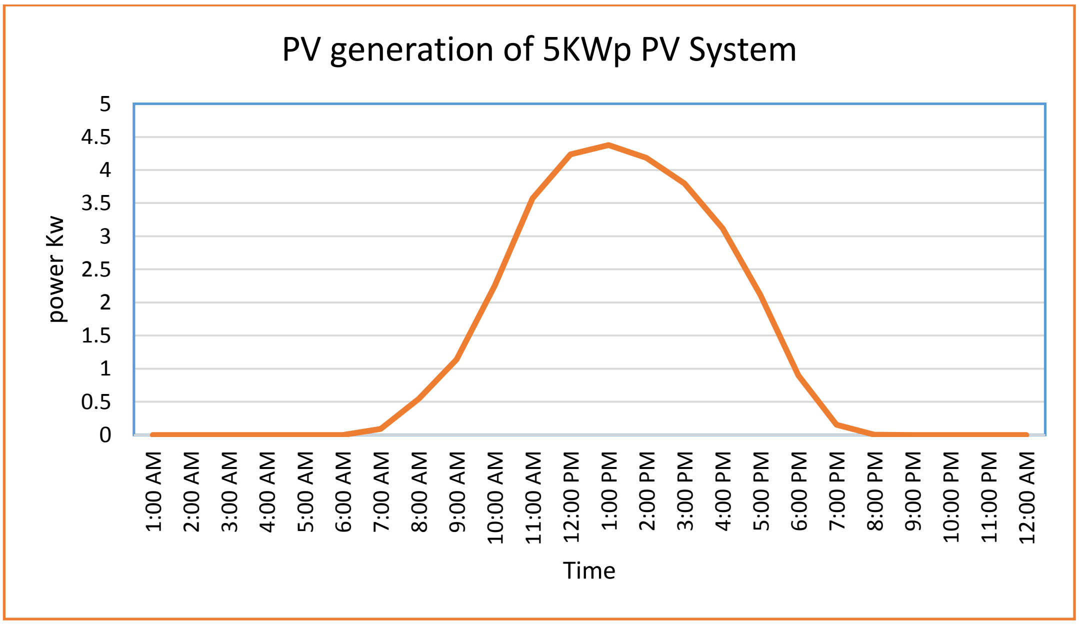


**Figure 5-17:** Simulated generation curve of 5KWp rooftop PV for 22/8/2015

**Proposed scenario 1:**

Connect new DG with smart grid to control and schedule the production quantity at daylight period, integrating with the grid status in real time and forecasting. Figure 5-18 shows proposed connection.

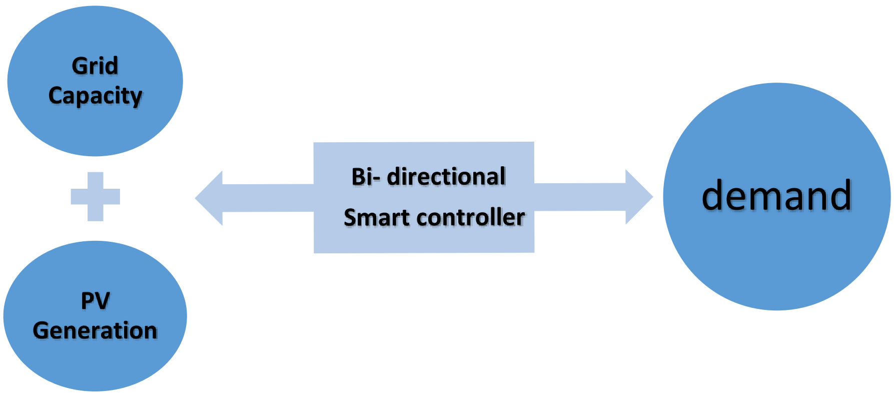


**Figure 5-18**: Scenario 1 proposed connection.

Applying this scenario to the situation on 22/8/2015, and the results were applied to table 5-3. This will produce a new load curve for the day which is illustrated in figure 5-20.

From this figure, it is clear that by increasing the number of DG the total amount of production increases, and energy demand in the period of daylight is decreases.The following regression equation describes the relationship between the amount of energy produced and the number of DG connected to the network.

$$energy\ produced\ per\ day\ (Y) = 30.53\ X - 49.54 \qquad (11)$$

Where;

X is the number of DG

In addition, increasing the number of DG decreases demand over grid capacity as shown in figure 5-19.

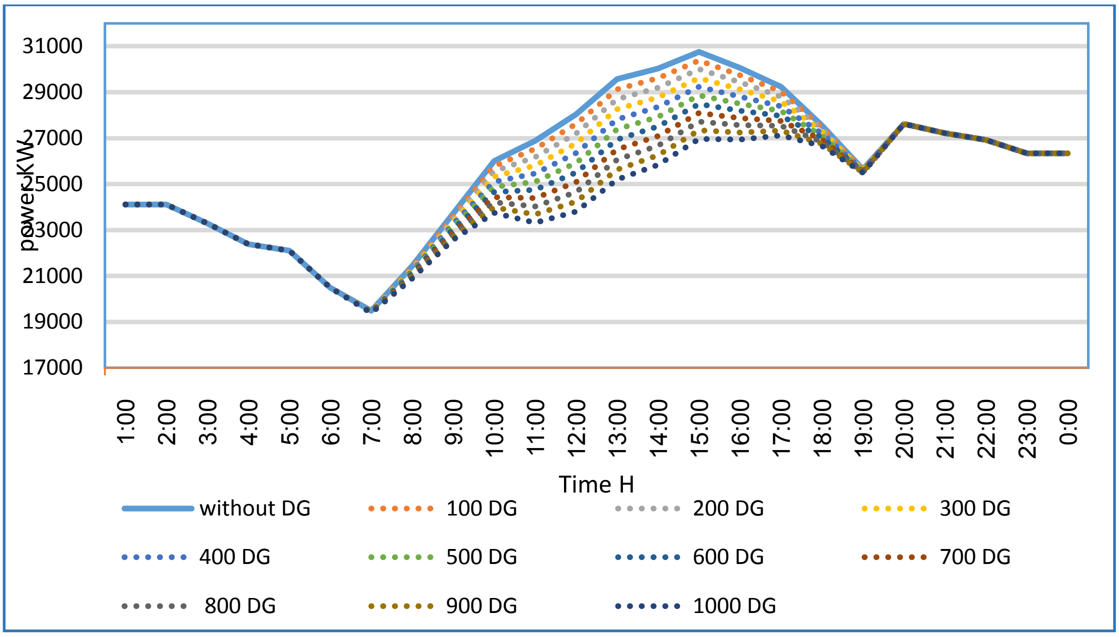


**Figure 5-19:** Load curve changes with increased number of PV systems.

Nevertheless, by studying the effect on the grid, it is obvious that by connecting 1000 DG to the grid, the quantity over grid capacity is stabilized. For the period without sun radiation, there is no effect on demand and load curve, which may result in a new maximum demand (new daily peak) and there is a need to minimize it or flatten it. The relationship under 1000 DG illustrated by the following regression equation.

$$\text{Grid reserve capacity (Y)} = 2.86\,X - 5055.5 \qquad (12)$$

**Table 5-3: Analysis of proposed scenario 1.**

| | With PV | |
|---|---|---|
| Grid capacity | 25530.43 | KW |
| Max Demand | 27615.59 | KW |
| Time of max demand | 20:00 | |
| Base demand | 19387.34 | KW |
| Time of base demand | 7:00 | |
| Average Demand | 24534.79 | KW |
| Grid Load Factor | 0.89 | |
| Grid capacity factor | 0.96 | |
| Grid Utilization factor | 1.08 | |
| Grid Reserve capacity | -2085.16 | KW |

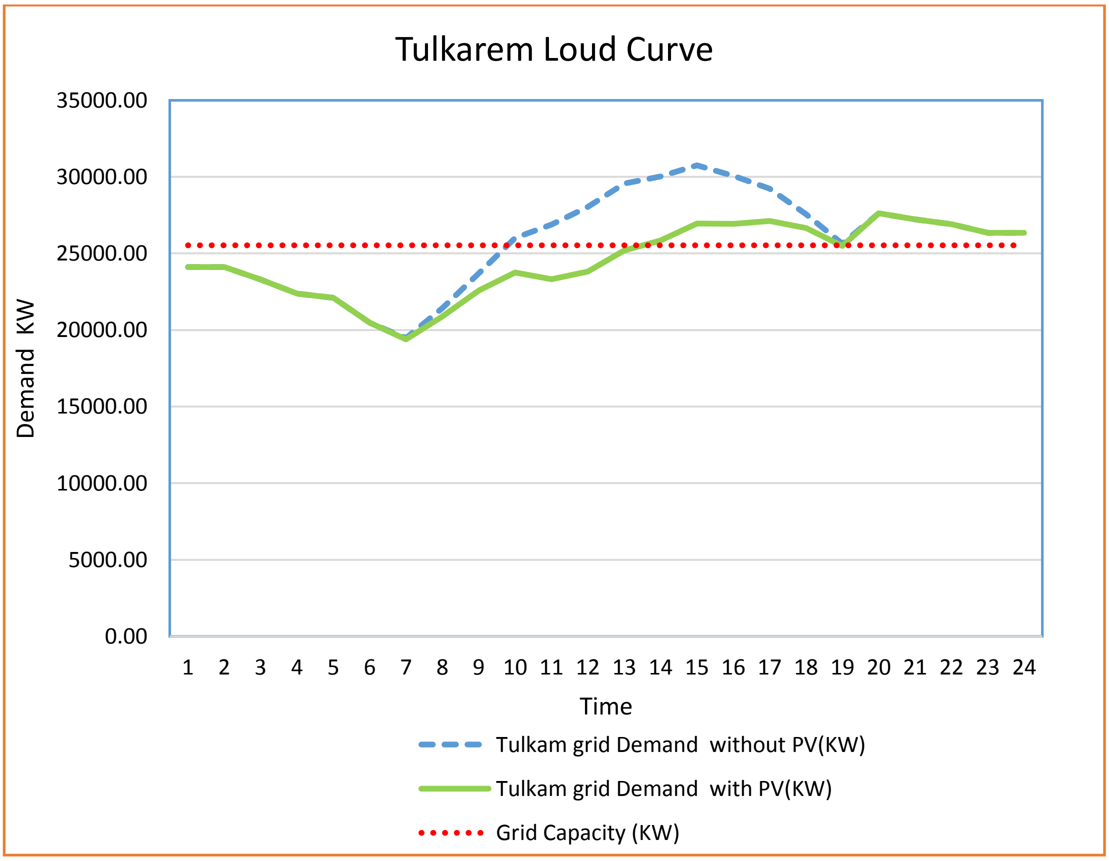


**Figure 5-20:** Analysis of scenario 1 load curve.

**Proposed scenario 2:**

In scenario #1, we succeeded to reduce purchased power from the Israeli company during sun radiation time. However, for evening hours after sunset, the demand is still over grid capacity and there is a new peak, which is needed to be reduced more.  For this problem, we propose the second scenario, which includes storing part of the electrical energy at low demand times in batteries. This is scenario is considered as a load shifting technique as explained before. Size of the storage battery banks will not be that huge in order to reduce the cost, but only to cover consumer needs at nighttime outside the period of daylight. The proposed size was estimated to cover 3000 kWh per day, so we need around 1100 lead-acid batteries of the type 115Ah/12V, which means 3 batteries for one third of the 1000 PV systems. Through the smart grid, the stored energy will be fed to the network using DC/AC inverters at specified times when the demand exceeds the new threshold value (27 MW) during daytime or at nighttime. The operation and control of the battery mode will be fully automated in real time, and smartly balancing the three sources (purchased power, PV generation and battery storage) to maintain the demand very close to grid capacity. Figure 5-21 illustrates proposed connection of scenario #2.

Applying this scenario to the situation on 22/8/2015, and the new results are listed table 5-4, and change the shape of the curve as shown in figure 5-23

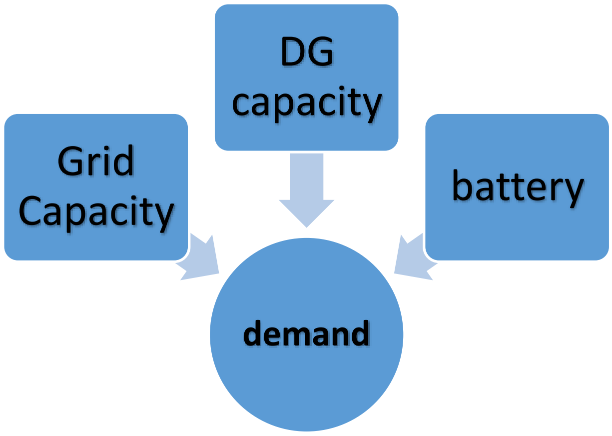


**Figure 5-21**: Scenario 2 proposed connection.

The control scenario in a smart way and the following flowchart illustrates the mechanism

.

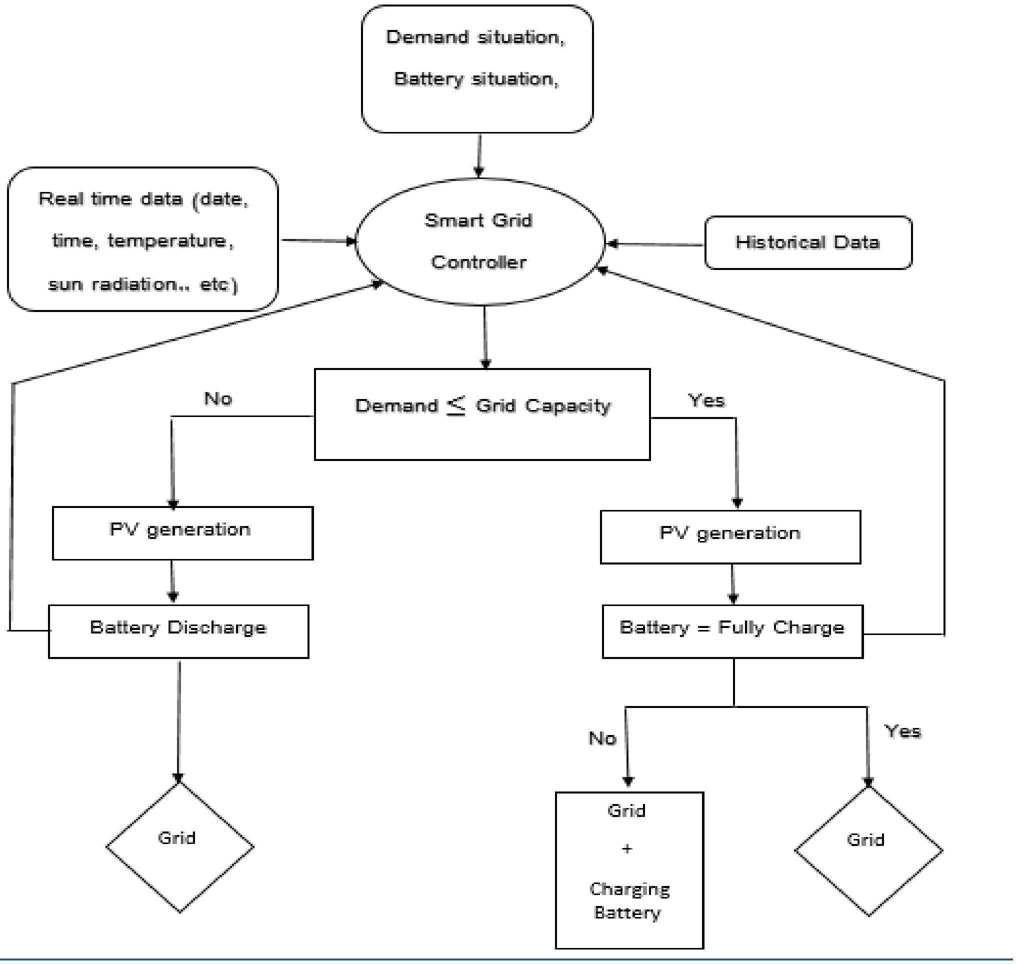


**Figure 5-22**: Flowchart for scenario #2.

In order to be clear result, Figure 5-23 illustrates the relationship between all the scenarios together.

**Table 5-4: Analysis of proposed scenario 2.**

| | With PV & battery | |
|---|---|---|
| Grid capacity | 25530.43 | KW |
| Max Demand | 27015.59 | KW |
| Time of max demand | 20:00 | |
| Base demand | 20985.31 | KW |
| Time of base demand | 6:00 | |
| Average Demand | 24777.14 | KW |
| Grid Load Factor | 0.92 | |
| Grid capacity factor | 0.97 | |
| Grid Utilization factor | 1.06 | |
| Grid Reserve capacity | -1485.16 | KW |

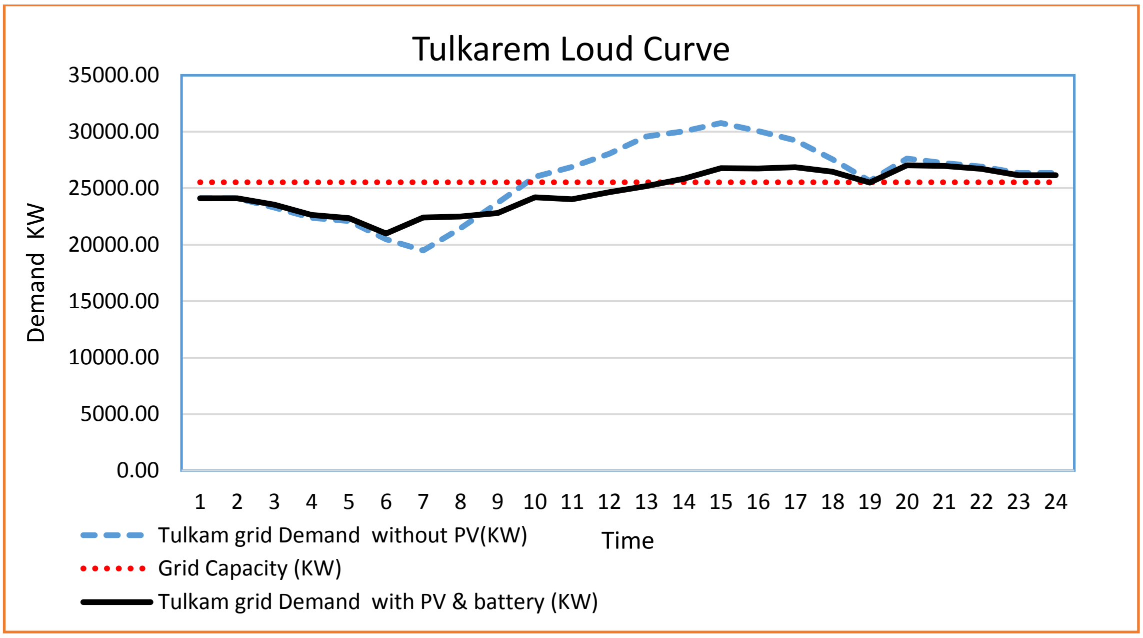


**Figure 5-23**: Analysis of scenario 2 load curve.

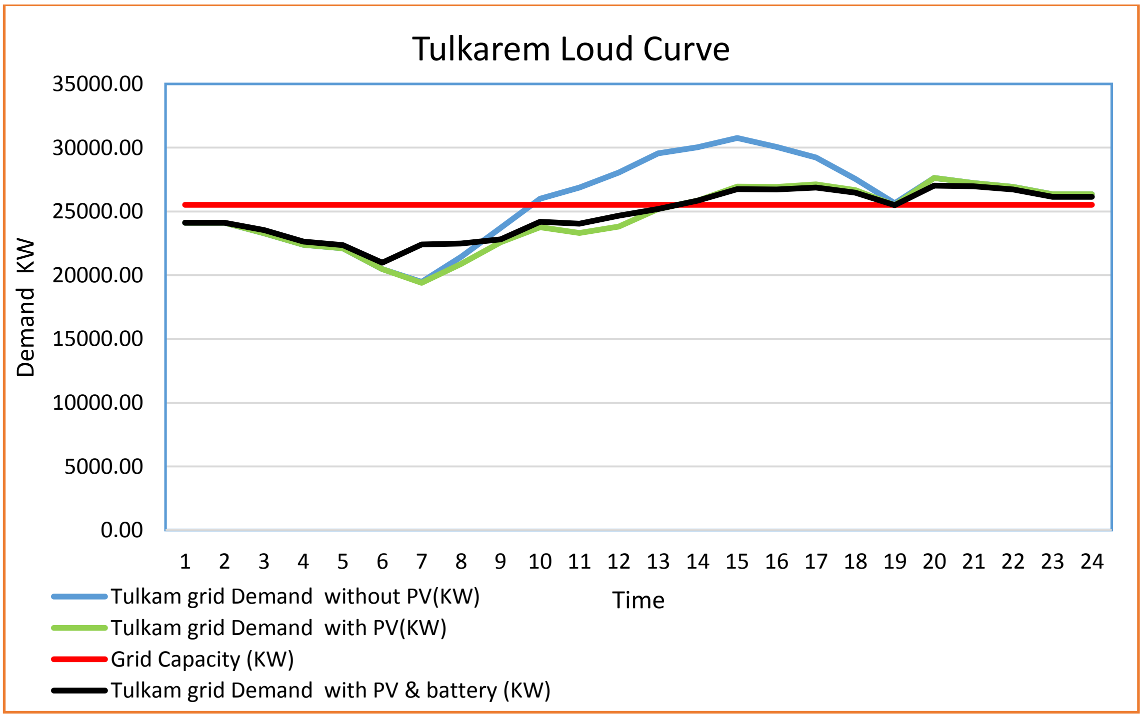


**Figure 5-24**: Tulkarem Load Curve before and after integrated DG.

### 5.6.3. Simple Cost Analysis of Integrated Rooftop PV

The cost of the proposed system depends on different components. The first component is the central control unit which will cost no more than $5,000. The second component is the storage unit (batteries). The total number of batteries is 3000 batteries, and cost of each and the price of each battery is around 200$. In this case, the total cost of all batteries will be estimated at $600,000. The municipality may compel subscribers to install these batteries at their own expense, as they do not constitute more than 11.5% of total individual system. If the batteries to be installed by the municipality at specific governmental buildings, then the municipality will fund this component of the project. In return, a $200 connection fees will be paid by each customer before installing his DG system. Which means, for the proposed 1000 DG there is an income to the municipality which is estimated at $200,000. Therefore, this proposal is $605000 cost and revenue of $200000 in cash, in addition, to reducing electricity consumption bill from the Israeli company by $48000, and technical benefits to reduce losses.

# Chapter Six
# Cost Benefit Analysis

## 6.1. Introduction

The purpose of this chapter is to discuss about the significance and a detailed feasibility study of practical implementation of Smart Grid in Tulkarem. Smart grid refers to an electric power system that enhances grid reliability and efficiency by automatically responding to system disturbances. As explained in previous chapters, power crisis is the major problem for a Tulkarem network at this moment. Efficient transmission and distribution of electricity with essential energy resources is a fundamental requirement to provide citizens and economies.

In this context, we have defined a comprehensive assessment framework of Smart Grid projects centered on a cost-benefit analysis (CBA). This model is organized to analyze the Net Present Value (over a 15 year at 7.5% discount rate) of the Smart Meters, main processors and Smart Grids strategy components. Both Smart Meters and Smart Grids, are organized under the accompanying Cost Benefit Analysis (CBA) components:

- Costs, as far as capital (capex) and operating expenditures (opex) required to realize such speculations inside the networks and to run related operations

- Benefits linked to the organization of such technologies, comparing to reducing costs or emerging incomes, separated into: Direct, and Indirect.

At first, we should study the following assumptions regarding the current situation of the electrical system and expected development under business as usual (BAU) scenario:

**Table 6-1: Business as usual assumption**

| | Current situation | BAU after 15 year |
|---|---|---|
| Peak Demand | 31,000 KW | 52,000 |
| Consumption | 162,000,000 KWh/y | 729,000,000 KWh/y |
| Number of customer | 16,500 | 25,000 |
| Power Capacity | 25,530 KW | 38,867 |

The Smart Grids proposed arrangements consider the following quantified benefits, described as follows:

## 6.2. Direct Benefits Assumptions:

- Reduced operating costs: The optimization of operating costs because of automated operations has been expected considering worldwide experiences that reported savings between - 5% and - 10%. The benefit of operating cost reduction potential has been expected equivalent to - 8%. Such saving potential has been applied to distribution operations and maintenance costs. This benefit is worth 0.1 million dollar toward the finish of the analyses period.

- Improved load management and losses: The reduction of losses on the power distribution systems, optimization of load dispatching and management. Expecting the losses equivalent to 7% of energy consumption. This benefit is worth 18.6 million dollar toward the finish of the analyses period.

- Reduced duration of outages: This benefit considers the reduced duration of blackouts because of automated reactions to some type of blackouts and quicker exploring and repair for others. Since no performance evaluation information to Tulkarm cannot benefit financially. This benefit is worth 0.1 million dollar toward the finish of the analyses period.

### 6.3. Indirect Benefits Assumptions

- Optimized energy consumption: as expected, the Smart Grids solutions and integration of alternative energies inside the electrical networks that will cover mostly power demand during the peak hours. In addition, the Application of network management policies to optimize energy use. This benefit is worth 25.4 million dollar toward the finish of the analyses period.

- Reduced GHG emissions: This benefit will be identified with the lower emanations of GHG ($CO_2$), connected to a lessening of the internal consumption of oil fuel, to lower oil-based power generation. In system for trading GHG emission certificates would be set up, as it is as of now the case in many Countries, this lessening would suggest a cost reduction for the national entity responsible for GHG emissions. This benefit has been assumed considering a CO2 price of $135 per ton, based on an emission rate of 0.635 tons of CO2 per MWh, so it is worth 2.6 million dollar toward the finish of the analyses period.

### 6.4. Costs of Smart Grid Solutions:

As for cost segments of Smart Grids, the following article have been considered:

- Implementation pace: For the implementation of Smart Grids solutions, of 7 years has been viewed as, relating to investment cycle and considering the system scale contrasted with different Countries with a larger amount of mechanization created. Be that as it may, the best possible implementation pace should be created considering particular system qualities and engineering, accessibility and efficiency of assets required in such investment by distribution administrator.

- SG Distribution capex:

− The installation cost of system hardware for SG distribution system has been figured accepting the installation of distribution SG systems (Intelligent recloses and relays, Voltage and Power Flow control equipment, Direct Load Control, Sensors Capacitor Banks,…) to all system feeders.

− The cost of supporting IT and communication system has been assumed equal to 0.5 million dollar.

− In outline, total capex related to distribution SG are worth 5.4 Million dollar over the analyses period (15 years).

- Meter layer capex: The installation cost of system hardware for smart meter, and the cost of supporting IT and communication system, the total capex related are worth 10 million dollar.

- Demand control and RE integration capex: The installation cost of system hardware for demand control and RE integration, and the cost of supporting IT and communication system, the total capex related are worth 12.4 million dollar.

- SG systems opex: The cost of support and operations of the previously mentioned SG system and hardware has been accepted equivalent to $ 10,000 every year, as a comprehensive synthetic opex pointer, in view of industry models.

## 6.5. Compare Costs and Benefits

The benefits of a proposed smart grid project happen over the lifetime of the project. The costs, conversely, ordinarily include a vast cost toward the start of the project, conceivably took after by a considerably littler yearly spending for O&M. So, how can the different costs and benefits occurring at different times be compared? Luckily, there are a budgetary investigation tools for such an issue.

Net present value (NPV) is a straightforward of general costs and benefits. To figure NPV, all future money related costs and benefits are changed into an identical current-day costs or benefits. Future costs and benefits are reduced to reflect the time estimation of cash and additionally the proper societal discount rate. This consolidates all the costs and benefits into one number, which can be considered as the present day estimation of the whole project. If this value is positive, it can reasoned that the project is cost-effective without thought of the qualitative factors.

Comparing Costs and Benefits In our proposed project, we assess the costs and benefits of smart grid support from rooftop PV, storage system, and smart meters to detect the theft, and use DR strategies. The following table 6-2 illustrated the total cost and the benefits.

**Table 6-2: Comparing Cost and Benefits.**

| Cost | NPV (million USD) |
|---|---|
| Smart meter | -10 |
| Storage system | -7 |
| Automated distribution system | -5.4 |
| Demand response system | -6.4 |
| Total | -28.8 |
| Benefit | NPV (million USD) |
| Deferred distribution investments | 25.4 |
| Reduced equipment failures | 0.1 |
| Reduced operation cost | 0.1 |
| Reduced electricity losses | 18.3 |
| Reduced CO2 emissions | 2.6 |
| Reduced non-CO2 emissions | 1.1 |
| Total | 47.6 |

The net benefit, excepting qualitative factors, is (47.6 – 28.8) = USD 18.8 million. The benefit-to-cost ratio is (47.6/28.8) = 1.65. This project is cost-effective.

## 6.6. Sensitivity Analysis

Once a last outcome, either a NPV or benefit to-cost proportion is acquired, it is extremely valuable to back and play out a sensitivity analysis, which is an evaluation of how the outcomes fluctuate when different sources of info and assumptions are changed. While doing as such, concentrate on those sources of info and suppositions that are both uncertain and significant, which means they strongly affects the outcomes.

This project has many benefits and can be reversed, which is network transmission shift, improving performance and service quality, access to optimal operating. Leading to delay investment in traditional network. If decision makers are confident that costs will be under this assumption, it is possible to be sure that the project will be positive in General.

# Chapter Seven

# Conclusions and Future Recommendations

## 7.1. Conclusions

The main objective of this thesis was to explore the potential advantage of smart grid technologies for solving the problems in Tulkarem distribution network. These problems include but not limited to exceeding allowable peak, high losses both technical and non-technical, lack of ability for load control and incompetence to distributed generation.

Based on the research findings, the Tulkarm power grid suffers from lack of monitoring system and data logging units, which causes huge losses which are difficult to identify as technical or non-technical. Moreover, over the last years the electric power grid operate over capacity so there must be effective utilization of electric sources traditional and sustainable. This is in addition to the presence primitive network, cause unreliability that increases the number of hours of outages, and adds additional staff and types of equipment.

Smart grid strategies were studied for increasing the efficiency of the electrical network of Tulkarem. Smart Grid technologies measured showed a positive impact on some indices of reliability, flexibility, efficiency, and turned out to be financially attainable. Therefore, the investigation of a change over the presence primitive distribution network to the smart grid, keeping in mind the end goal to obtain higher efficiencies, to lessen the

IEC bill, and to enable these systems to adapt to the increased demand without the need increment capacity.

Life cost analysis of the project to establish the Smart Grid in Tulkarem has proven the feasibility of the project as an investment. For the lifespan of the project of 15 years, the benefit-to-cost ratio equals 1.65. This means the investment will make profit and feasible from the economical point of view.

## 7.2. Recommendations

The accompanying recommendations are drawn out of this thesis are guided to decision makers.

- An implementation of the smart grid as a pilot project in Tulkarem can be done by a subsidy from the government, this will make it possible to deploy this technology for the rest of the networks of Palestine. The implementation of a smart grid is a well-ordered strategy to supplant the old power network components or planning to assemble facilities based on existing network.

- An implementation of the smart meter in Tulkarem network it must be the first priority, with a strategic plan to be completed within five years. This will benefit monitoring system, can collect and transmit the data, contribute accurate short-term load forecasting. Furthermore, outline a fitting interest reaction or further load shedding plan to prevent loads of over capacity from the network.

- Demand response is one of the basic perspectives for consumers participating in a network. New evaluating approaches, for example, dynamic pricing and system operation procedures. With stakeholders awareness of energy saving and sustainable energy policies

- Intelligent systems for reliability improvement and decision-making tools for system designing and planning for improved security of electricity supply system with higher reliability and optimization. Moreover, complex scenarios will be considered such as the distributed generation.

- Smart grid will make the grid ready for integration with distributed generation included PV systems on large scale. We recommend considering distributed generation of solar PV's a priority in the strategic plan for the energy sector in Palestine.

- Smart metering will provide a good tool for two way communication with customers for implementing important strategies such as dynamic pricing and direct load control. It is essential to use this tool for educating the customers and involving them in all load control activities.

- It is essential to consider Smart Grids as a component of more advanced system, which includes Smart Cities and Smart Buildings. The integration of all of them must be studied on a large scale planning for better future.

- Sustainability and green buildings must be considered as a strategic tool in energy conservation and energy management.

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جامعة النجاح الوطنية

كلية الدراسات العليا

# الشبكة الذكية كحل ممكن لمشاكل الشبكة الكهربائية في مدينة طولكرم / فلسطين

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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2017

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**الملخص**

في القرن الحادي والعشرين، إن أهم المسائل الحاسمة والمهمة المتصلة بنظم الطاقة هي تكنولوجيات الشبكة الذكية وتكنولوجيات الطاقة المتجددة. إن تطوير الجيل المركزي الحالي من خلال استخدام الإنتاج الموزع للطاقة المتجددة وخاصة الطاقة الشمسية والشبكات الذكية يوفر فرصة كبيرة للقضاء على العديد من المشاكل المتعلقة بكفاءة الطاقة وأمنها ونوعية الطاقة وعيوب البنية التحتية القديمة لنظام الطاقة الذي عفا عليه الزمن. فالنظم الكهربائية الحالية في فلسطين لم تجدد منذ عقود من الزمن وتعتمد على معدات تقترب من نهاية عمرها الافتراضي. ومن هنا فإن الشبكة الذكية توفر الفرصة لتحديث البنية التحتية لشبكة الكهرباء، وضمان استمرار الوفاء بمعايير السلامة، وتزويد الطاقة باستمرار، وإدارتها بكفاءة لتقليل الخسائر وخفض التكلفة.

تناولت الأطروحة مبدأ عمل وتقنيات الشبكات الذكية والميزات الكبيرة التي تتوفر بها مما يجعلها أداة فعالة في حل مشاكل الشبكات الكهربائية في العالم الحديث. خاصة وأنها تعتمد على تقنيات الاتصالات الحديثة وتبادل المعلومات، وقد قام الباحث بتصميم شبكة ذكية لمدينة طولكرم التي تواجه شبكتها الكهربائية مشاكل عديدة أهمها الانقطاع المتكرر للتيار الكهربائي بسبب النقص في إمدادات الكهرباء من المصدر، حيث قام بوضع مراحل متعددة لتنفيذها تبدأ بتركيب العدادات الذكية على جميع المحولات الرئيسة ومن ثم الانتقال الى كبار المستهلكين وأخيرا جميع المستهلكين خلال مدة لا تزيد عن ستة سنوات، وسيتم من خلالها تقليل الفاقد الناتج عن السرقات أو الأعطال في العدادات من خلال آلية محوسبة وسريعة وكذلك اكتشاف العيوب في توزيع الأحمال أو التحميل الزائد على بعض المحولات والخطوط الرئيسة، حيث وجد من خلال المحاكاة والتحليل إمكانية تقليل الفاقد بنسبة 10% من قيمة الاستهلاك الحالي والمقدر ب 2 مليون دولار سنويا من

خلال منع السرقات في شبكة المدينة (دون المخيمات) وتوفير 5% من خلال تقليل الفاقد في الشبكة بعد اكتشاف العيوب الفنية بها. الباحث قام أيضا بدراسة أثر وجود محطات توليد الطاقة المتجددة على الشبكة الكهربائية وكيفية قيام الشبكة الذكية بإدارتها بشكل فعال يضمن استقرار الشبكة وتقليل استيراد الطاقة الكهربائية من الشركة القطرية، كما درس آلية تخزين جزء من الطاقة لضمان منع حدوث أي اضطرابات بالشبكة عند حدوث أحوال طبيعية غير متوقعة، وأخيرا درس الباحث كيفية استخدام الشبكة الذكية بالتحكم بالأحمال بطريقة مباشرة وغير مباشرة خاصة في ساعات الذروة بما يضمن عدم تجاوز المسموح به وعدم قطع التيار الكهربائي عن المستهلكين. واثبت من خلال تحليل الجدوى الاقتصادية أن إقامة الشبكة الذكية هو مشروع اقتصادي ناجح ويوفر مبالغ طائلة على شركات التوزيع وتأخير الحاجة لشراء زيادة على القدرة إضافة لفوائدها الكبيرة في تطوير الشبكة وزيادة فعاليتها وزيادة عناصر السلامة بها.