REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
الجـمـهـوريـة الجزائـريـة الديـمـقـراطيـة الشـعـبـيـة

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

HIGHER SCHOOL IN APPLIED SCIENCES
--T L E M C E N--

وزارة التعليـم العالـي والبحـث العلمي

المـدرسـة العليـا في العلوم التطبيقيـة
-تلمسان-

End of study thesis

To obtain the master degree

Branch: electrical engineering
Speciality: Energy and Environment

Presented by: ELOUDJEDI TALET Ikram

State of the art in the field of energy storage and development prospects in Algeria

Presented on 01 / 09 / 2020, in front of the committee:

Dr. BRAHAMI Mustapha	Maitre de conférences A	ESSA. Tlemcen	President
Dr KHERBOUCHE Djamila	Maitre de conférences A	ESSA. Tlemcen	Supervisor
Dr BOUKHALFA Yaïci	Directeur Général	Cluster Energie Solaire	Co-supervisor
Dr Chialli Aniss	Maitre de conférences B	ESSA. Tlemcen	Examiner 1
Dr GHOMRI Amina	Maitre de conférences A	ESSA. Tlemcen	Examiner 2

Année universitaire : 2019/2020

Acknowledgements

First and above all, I thank the Lord Almighty to whom I owe my very existence for giving me the strength, knowledge, ability and providing me this opportunity and granting me the capability to proceed successfully. I am grateful for His provision of joys, challenges and grace for growth that have been bestowed upon me during this research work, and indeed, throughout my life, without his blessings, this achievement would not have been possible.

I submit my heartiest gratitude and my most sincere appreciations for my supervisor Mr. **YACI Boukhalfa** , the Managing Director of Cluster Energie Solaire. During these 7 months' thesis project, he provided me very valuable advice on my work, timely feedbacks on the content and great encouragement for the progresses. The working load in this thesis project was rather heavy, but with Professor Boukhalfa Yaïci's encouragement, I finally overcame all kinds of difficulties and reached my destination.

I also would like to thank my supervisor from my superior school ESSA-T, Mrs **FARADJI KHERBOUCHE Djamila** whose insight and knowledge into the subject matter steered me through this research. She provided me significant instructions and advice on how to better arrange the working schedule, organize the thesis content, and solve particular technical problems I met in my work.

I wish to acknowledge the help provided by Mr. **AGGABI Mohammed**, Ortech Power Solutions' CEO for his guide and support during this journey. I would also like to show my deep appreciation to Mr. **DZIRI Abdelkrim** who has taken from his time to discuss and enrich my work.

I am deeply indebted to my parents for giving birth to me at the first place and supporting financially and spiritually throughout my life. I revere the patronage and moral support by my sisters whose passionate encouragement made it possible for me to complete this thesis.

My joy knows no bounds in expressing my cordial gratitude to my beloved classmates who made all every day at school special, from whom I learned plenty of lessons and with whom I spent the most beautiful 3 years making great memories. Special thanks to my friend Rabie for never complaining and helping me with my work.

I humbly extend my thanks to all my teachers at the superior school of applied science and the staff who were involved in the validation survey for this thesis.

At the end of my thesis, it is a pleasant task to express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me.

Dedication

The sake of Allah, my Creator and my Master,

To my sweet and loving parents, Razika and Abdelkader whose words of encouragement and push for tenacity ring in my ears. Who have never stopped praying for me and encouraging me, may God protect them.

To my lovely sisters Ghizlaine, Dalal and Ikhlas who have never left my side and lead me through the valley of darkness with light of hope and support. To my brother-in-law Adel for his support and kindness.

To my grandmother, my ant Saida, my uncle and my cousins who have never stopped praying for me.

To my best friends Hiiba and Piika, both of you have been my best cheerleaders.

To my beloved people, Raghed, Rachid, Rabie, Samado and Imen for bringing joy to my life.

To my dearest friends Farah, Wissal, Meriem and Wissem for supporting me all the way long.

To Daiiki, for his companionship and emotional support.

I dedicate this thesis.

Contents

List of Figures

List of Tables

Abstract

Renewable Energy Sources are generally utilized in power generation nowadays. Energy storage is a governing factor. It can decrease power variation, improve the framework adaptability, empowers the capacity and dispatching of power produced by renewable energy sources, for example wind, solar etc. In this work, we document the different energy storage systems: like Compressed Air Energy Storage System (CAES), Voltage Regulation-Battery energy storage system are utilized in electric power framework. We demonstrate also the role of EES in on-grid / off-grid/ smart grid areas, as well as the roles from the viewpoint of a utility, from the viewpoint of consumers and from the viewpoint of generators of renewable energy. Lastly, we discussed the renewable energies availability and potential in Algeria, and our government program and expectations about renewable energy feasibility.

Résumé

De nos jours, les sources d'énergie renouvelables sont de plus en plus utilisées dans la production d'électricité. Le stockage d'énergie est un facteur déterminant. Il peut réduire la variation de puissance, améliorer l'adaptabilité du cadre, renforcer la capacité et la distribution de l'énergie produite par des sources d'énergie renouvelables, par exemple éolienne, solaire, etc. Dans ce travail, nous documentons les différents systèmes de stockage d'énergie : comme le système de stockage d'énergie à air comprimé (CAES), le système de stockage d'énergie de régulation de tension-batterie est utilisé dans le cadre de l'énergie électrique. Nous démontrons également le rôle de l'EES dans les zones on-grid / off-grid / smart grid, ainsi que les rôles du point de vue d'un service public, du point de vue des consommateurs et du point de vue des producteurs d'énergie renouvelable. Enfin, nous avons discuté de la disponibilité et du potentiel des énergies renouvelables en Algérie, de notre programme gouvernemental et des attentes concernant la faisabilité des énergies renouvelables.

ملخص

في الوقت الحاضر، يتم استخدام مصادر الطاقة المتجددة بشكل متزايد في إنتاج الكهرباء. تخزين الطاقة هو عامل حاسم. يمكن أن يقلل من تباين الطاقة، ويحسن قابلية الإطار للتكيف، ويعزز قدرة وتوزيع الطاقة التي تنتجها مصادر الطاقة المتجددة، على سبيل المثال الرياح، والطاقة الشمسية، إلخ. في هذا العمل، نقوم بتوثيق أنظمة تخزين الطاقة المختلفة: مثل نظام تخزين طاقة الهواء المضغوط(CAES) ، يتم استخدام نظام تخزين الطاقة لتنظيم الجهد والبطارية كجزء من 'طاقة كهربائية. نوضح أيضًا دور التقييم البيئي الاستراتيجي في مناطق الشبكة / خارج الشبكة / الشبكة الذكية، بالإضافة إلى الأدوار من منظور المرافق ومنظور المستهلك ومنظور المنتج. طاقة متجددة. أخيرًا، ناقشنا مدى توفر وإمكانات الطاقات المتجددة في الجزائر، وبرنامج حكومتنا وتوقعاتنا فيما يتعلق بجدوى الطاقات المتجددة

General Introduction

General Introduction

The pursuit of a low carbon energy mix is leading to a rise in variable renewable energy sources. The world today, needs to find a better way to utilize energy: not only in the field of energy production, transmission, distribution, and consumption, but also in the area of energy storage.

The unpredictability of these sources will cause energy flow fluctuations in the network inducing a greater stress for the grid and, therefore, increasing the need for flexibility, and bringing energy storage as a solution. With the fact that wind energy and solar energy, are timely-based energy sources, whose available energy densities are variable during different hours. Here, the energy storage technology can be used for storing the excess renewable energy in high production hours, to make up the trough during low production hours, and to better integrate the energy generator into the local electricity grid.

With the energy storage technology, we can overcome the imbalance between the energy production and consumption, alleviate the stressed production load of the power plant at the peak hours, and reduce consumers' electricity costs by avoiding higher peak hour tariffs.

Moreover, the energy storage is badly needed to minimize the shortcomings of renewable energy technologies. The renewable energy sources which has an incredible potential to produce electricity as they are inexhaustible in nature, economical and is less dangerous for environment. However, they are uncertain energy source as the power cannot be produced at the time when required.

If in case there is deficient load to require their output, they can be shut down totally and the energy is saved until it is needed. By contrast, renewable energy could not be turned off or balanced as when wind stops blowing or sun stops shining, no power is generated. On the other hand, when the wind is speedy and the sun bright, then the amount of power generated is more than it is needed.

Energy storage is especially beneficial when utilized in association with non-dispatch able renewable energy sources such as wind and solar energy. Dispatch able energy sources such as natural gas power plants can adapt to their capacity result here and there according to required by system operators.

The projections in this work focus on the different energy storage systems and aims to clarify why the prospects for energy storage in Europe are not as good as they are in the USA and put light on where the Algerian strategy is, in the field of sustainable energy and EES.

Chapter I: Energy storage technologies

I. 1. Introduction

Energy storage has become an important part of renewable energy technology systems. It is essential whenever there is a mismatch between the supply and consumption of energy.

Energy storage systems are designed to accumulate energy when production exceeds demand, and to make it available at the user's request. They can help to match energy supply and demand, exploit variable renewable (solar and wind) energy sources, increase the overall efficiency of the energy system and reduce carbon-dioxide emissions.

Various storage techniques have been developed over the past four decades. To help understand the diverse approaches currently being deployed around the world, and depending on the form in which the electrical energy can be stored, energy storage technologies have been divided into five main categories: thermal storage, Mechanical storage, electrochemical storage, chemical energy storage and electrical storage systems

I. 2. Thermal storage systems

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and in industrial processes.

TES systems can help balance energy demand and supply on a daily, weekly and even seasonal basis. They can also reduce peak demand, energy consumption, CO2 emissions and costs, while increasing overall efficiency of energy systems. Furthermore, the conversion and storage of variable renewable energy in the form of thermal energy can also help increase the share of renewable in the energy mix. TES is becoming particularly important for electricity storage in combination with concentrating solar power (CSP) plants where solar heat can be stored for electricity production when sunlight is not available.

Based on the state of energy storage material, it can be divided into "sensible heat storage", "latent heat storage" and "thermo-chemical heat storage". [1]

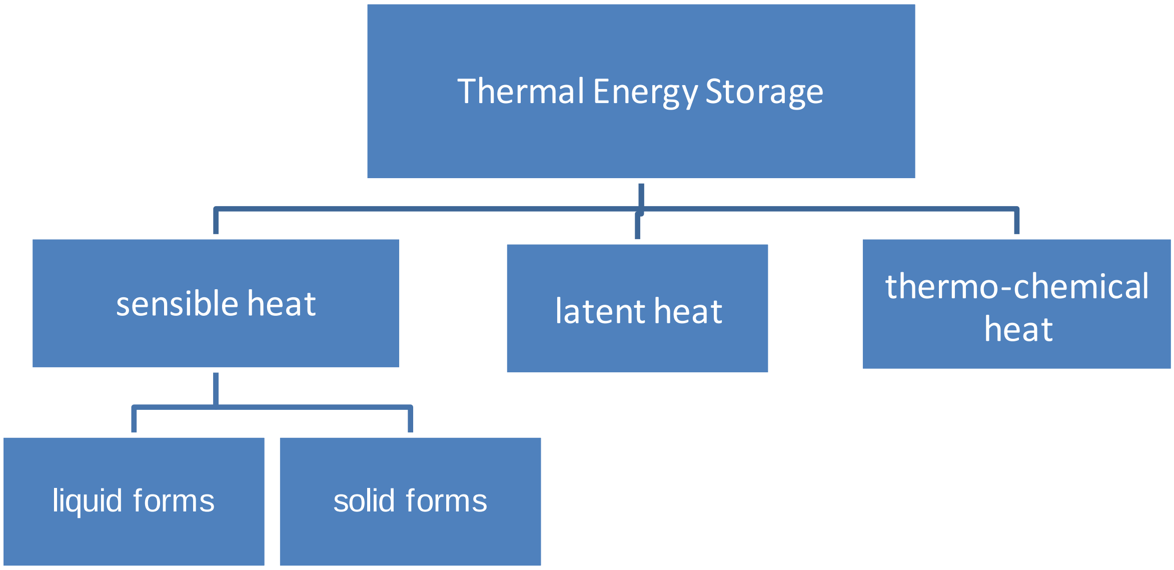

Figure I-1: *Classification of thermal energy storage based on the state of the material*

I. 2. 1. Sensible heat storage

Sensible heat storage system exchanges the solar energy into sensible heat in a storage medium, and releases it when necessary. The energy is stored or extracted by heating or cooling a liquid or a solid, which does not change its phase during this process. These include liquids like water; heat transfer oils and certain inorganic molten salts, and solids like rocks, pebbles and refractory.

This storage system is relatively inexpensive compared to other systems and is applicable to domestic systems, district heating and industrial needs. However, in general sensible heat storage requires large volumes because of its low energy density. Furthermore, sensible heat storage systems require proper design to discharge thermal energy at constant temperatures.

The amount of energy (heat) stored in a material depends on the specific heat of the medium, the temperature change and on its heat capacity (energy density). It can be expressed in the form:

$$Qs = m \int_{T1}^{T2} CpdT = m.Cp(T2 - T1)$$

Where Qs is the quantity of heat stored, in Joules; m is the mass of heat storage medium, in kg; cp is the specific heat, in J/ (kg.K); T1 is the initial temperature, in °C; T2 is the final temperature, in °C. [2]

The sensible heat storage can be categorized by the state of storage material into liquids and solids. Both states have their own characteristics and application fields, the choice of the substance used depends largely on the temperature level of the application, water being used for temperature below 100°C and refractory bricks being used for temperatures around 1000°C. Sensible heat storage systems are simpler in design than latent heat or bond storage systems; however, they suffer from disadvantage of being bigger in size.

I. 2. 2. Liquids form

I. 2. 2. 1. Water storage

The most commonly used liquid for sensible heat storage is water. According to the aforementioned four characteristics, water has relatively high specific heat capacity, almost no degradation under thermal cycling, good compatibility with most of containment material (stable, mild and no corrosive chemical properties), and most importantly, widely available and cheap.

The hot water tank is one of the best known thermal energy storage technologies. The hot water tank serves the purpose of saving energy when applied to, e.g., a solar tap water system or an energy supply system with cogeneration. The major aim of an electrically heated hot water tank in a tap water system is to shave the peak in electricity demand and consequently improve the efficiency of electricity supply. Water tank storage technology has become mature and reliable.

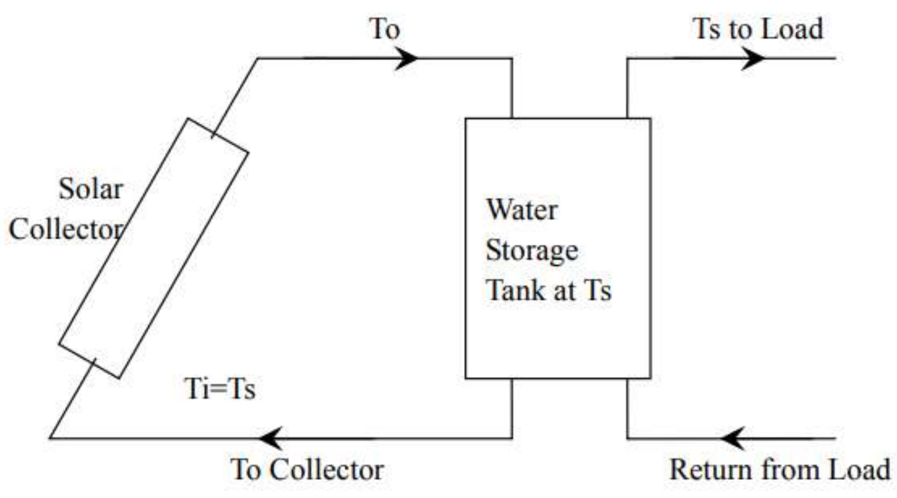

Figure I-2: *A typical solar thermal system using water storage technology [3]*

Storage as sensible heat in water is still unbeaten regarding simplicity and cost. Further development of water storage could be focus on improving the storage efficiency by means of ensuring optimum stratification in the tank and vacuum insulation.

Water storage Stratification is the temperature gradient existing in the water storage, where typically the water temperature at the bottom will be relatively lower than the water at the top. Almost all the water storage tanks have certain degrees of stratification, depending on the size, volume, geometries, water flow rates, and circulation conditions of the storage system.

I. 2. 2. 2. Molten salts

Water as a medium of storage has the limitation that its normal boiling point is only 100˚ C. At Solar reserve's Solar Two facility, a typical site, a mixture of Sodium nitrate and potassium nitrate having a melting point of 238˚ C and can be safely heated to 566˚C. It is circulated through pipes in a heat exchanger heated by concentrated solar power in a central tower. The heated liquid is stored in an insulated storage tank till it is required for generating power. With minimal losses the liquid is available for making steam at temperatures above 538˚ C. [4]

When required the hot liquid is routed through a heat exchanger in the steam generator, where it gives up heat and returns to a cold tank. Throughout the process it remains in liquid state with a viscosity similar to that of water (easy flow). The cooled liquid is again routed to the CSP tower for heating. Operating a turbine at that high temperature means a thermal efficiency close to 40% can be obtained. Length of the salt loop must be minimized to avoid freezing. Alternate systems use a second working fluid to carry heat from solar troughs the storage, and from the storage to generation. Such systems cannot raise the fluid to a high temperature are less efficient.

The salts are heated and stored in an insulating container during off-peak hours. When energy is needed, the salt is pumped into a steam generator that boils water, spins a turbine, and generates electricity. The conversion of thermal energy to electricity can proceed by different cycles such as the Rankine, Brayton, and Air-Brayton cycles.

There are two different configurations for the molten salt energy storage system: two-tank direct (figure 3) and thermo cline (figure 4). The two-tank direct system, using molten salt as both the heat transfer fluid (absorbing heat from the reactor or heat exchanger) and the heat storage fluid, consists of a hot and cold storage tank. [5]The thermo cline system uses a single tank such that hot and cold salt are separated by a vertical temperature gradient (due to buoyancy force) to prevent mixing. [6]

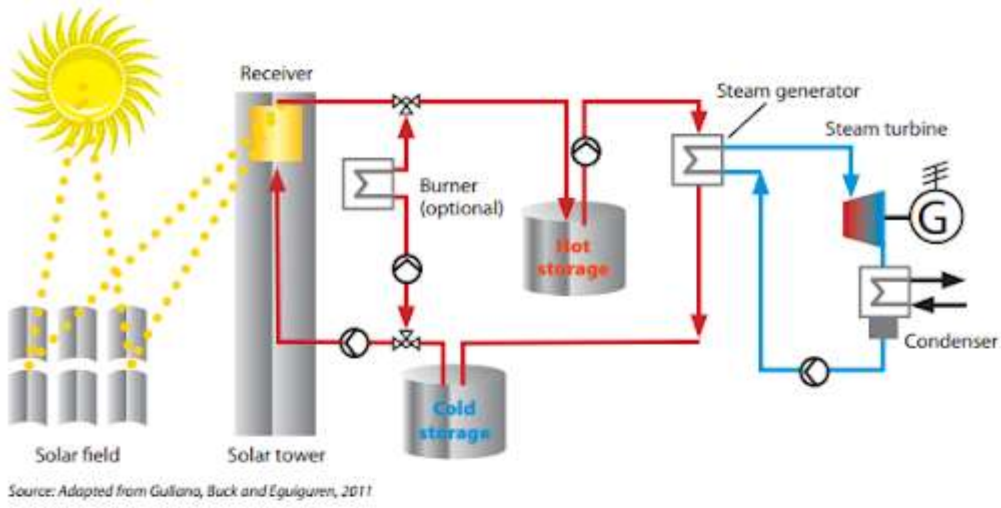

***Figure I-3**: Structure of the two-tank solar-molten salt energy storage system.*

Heliostats (solar mirrors) focus the sun onto a central tower, which heats the molten salt fluid inside. The liquid which is heated (in this case a combination of sodium and potassium nitrate) is transferred to a storage tank, then fed through a steam generator to turn a turbine and generate electricity. The cooled salt is fed back into the tower to repeat the process.

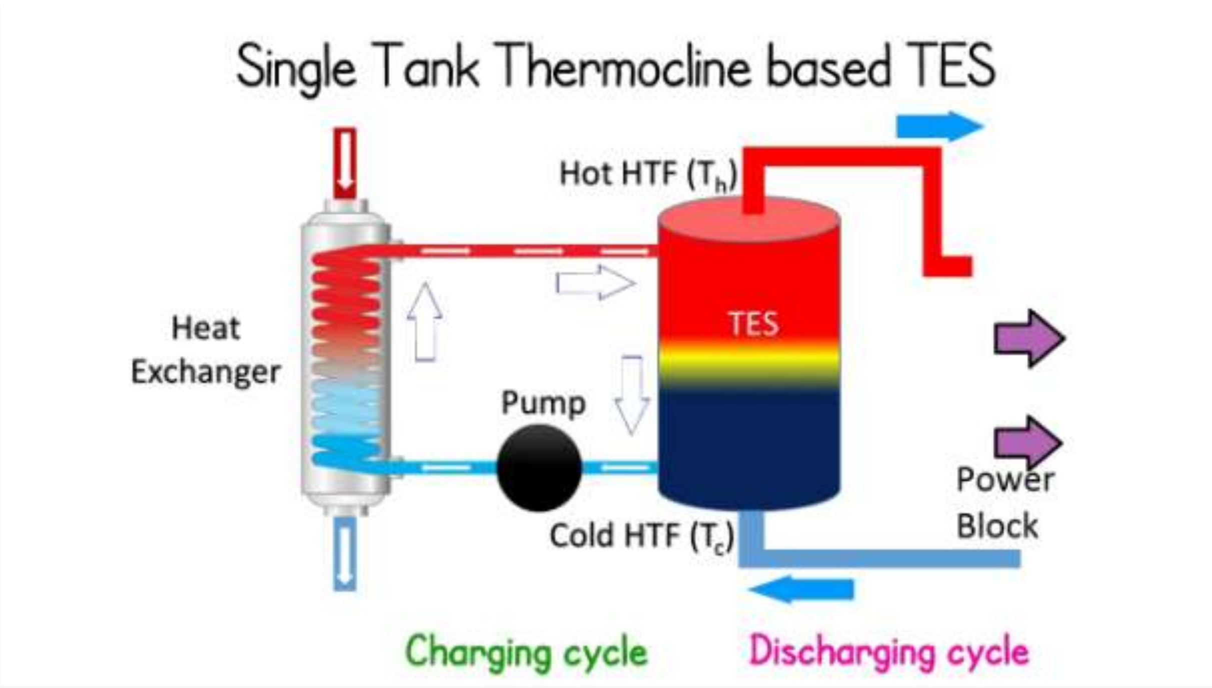

***Figure I-4:** Single tank thermo cline storage*

There are two cycles in the thermocline system: charging and discharging. To charge, salt flows out of the cold side, is heated by the heat exchanger (reactor), and flows into the tank's hot side. To discharge, salt flow out of the hot side, transfers heat to generate power (turbine), and flows into the tank's cold side. [5] The thermocline system reduces costs through a single tank and cheap filler material in the tank to act as thermal storage; the estimated cost relative to the two-tank direct system is about 35%. [6]

The difference between the molten salt and other liquids that are used in this sort of system is that the molten salt retains heat for a long enough time that it can effectively time-shift the stored solar energy from when it is most efficiently generated to when it is most needed.

I. 2. 2. 3. Solid forms

In addition to the water, other commonly used materials can be the solid materials, such as rock, metal, concrete, sand, brick, etc. The operating temperature range can be over 100 °C. As compared with water storage, solid storage has several inherent advantages: it can endure much higher temperatures; it has no leakage problem with their containment; sold heat storage material has good conductivity. Rock is the commonly used heat storage material. Even though it has a lower volumetric thermal capacity, it can work at temperatures higher than 100 °C. One example is Harry Thomason's technique using both water and stone as storage media, as shown in Fig. 5. The collected heat can be stored both in the stone and the water tank. The stored energy could warm the cool air.

Regarding the solid storage materials, the compatibility of the material with HTF used is very important. The storage performance is strongly dependent on the solid material's size, shape, the packing density, the type of HTF, etc. While, the main drawback for solid storage materials is their low specific heat capacity (1200 kJ/m3 K, where water is 4200 kJ/m3 K), which makes a relatively lower storage density by volume. To achieve the same amount of heat storage, the solid storage usually needs three times more space than the water-based storage system. In addition, there are other kinds of storage systems, such as the ground and soil storage. [1]

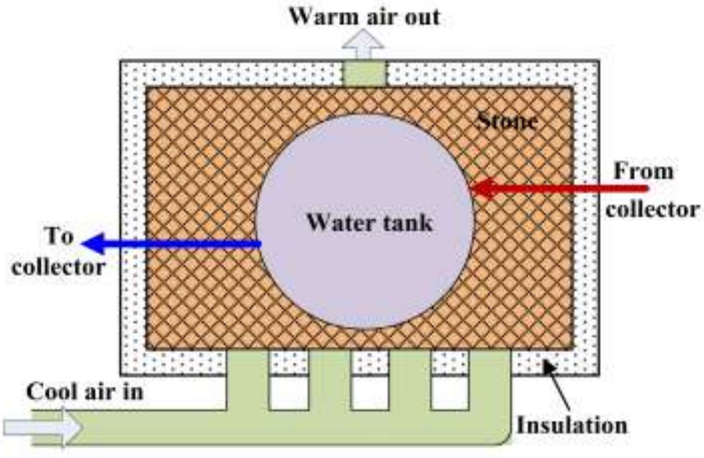

Figure I-5: *Harry Thomason's technique using both water and stone as storage media [2]*

I. 2. 3. Latent heat storage

Phase Change Materials (PCM) are latent heat storage materials. As the source temperature rises, the chemical bonds within the PCM break up as the material changes phase from solid to liquid (as is the case for solid-liquid PCMs, which are of particular interest here). The phase change is a heat-seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished. The heat stored during the phase change process (melting process) of the material is called latent heat.

Latent heat storage has two main advantages:

it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density;

Because the change of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations.

The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached. PCM storage volume is two times smaller than that of water. Latent heat storage can be used in a wide temperature range. A large number of PCMs are known to melt with a heat of fusion in any required range. The PCM to be used in the design of thermal storage systems should accomplish desirable thermo-physical, kinetics and chemical properties. [3]

I. 2. 4. thermo-chemical storage

Some reversible chemical reactions can also be used as one of the solutions to store the thermal energy. The basic principle of this thermo-chemical heat storage has been depicted in Equation :

$$\begin{cases} Endothermique\ reaction: AB + Q1 \rightarrow A + B \\ Exothermique\ reaction: A + B \rightarrow AB + Q2 \end{cases}$$

During the endothermic reaction, i.e. charge process, the compound reactant “AB” absorbs certain amount of thermal energy under relatively higher temperature conditions (compared with reverse exothermic reaction, except for the photochemical reactions), decomposing into the resultants of “A” and “B”. On the other hand, during the exothermic reaction, i.e. discharge process, the resultants of “A” and “B” experiences a combination reaction, forming the compound “AB” while releasing certain amount of thermal energy.

In order to avoid the simultaneous reverse reaction during the charge process, resultants “A” and “B” are advised to be separately collected. Therefore, if “A” and “B” are in different phase forms, for example one is in gas and the other one is in solid phase, then the corresponding reversible reaction will be more convenient for the implementation of thermo-chemical heat storage. Well separation of resultants “A” and “B” guarantees the stable storages for the reactants, and this feature is very important for the long-term thermal energy storage. However, up till now, most of the endothermic reactions are operated either under a much higher temperature or with more special reaction requirements than the condition for normal building applications, thus the thermo-chemical heat storage has been scarcely utilized in this area. [4]

I. 3. Chemical storage systems

Chemical storage topics covered in this section focuses on converting excess or off-peak electrical energy preferably from renewable resources such as solar and wind into environmentally benign, carbon-free, high energy density transportable fuels via electro synthesis. In this regard, electrochemical production of hydrogen and synthetic natural gas (SNG) are presented and reviewed below.

It is important to note that chemical energy storage in hydrogen and SNG also offers environmentally benign solutions towards decarbonisation of the global energy systems, and they could have a significant impact on the storage of electrical energy in large quantities.

Chemical energy storage is the only concept which allows storage of large amounts of energy, up to the TWh range, and for greater periods of time – even as seasonal storage. Another advantage of hydrogen and SNG is that these universal energy carriers can be used in different sectors, such as transport, mobility, heating and the chemical industry.

I. 3. 1. Hydrogen

A typical hydrogen storage system consists of an electrolyser, a hydrogen storage tank and a fuel cell. An electrolyser is an electrochemical converter which splits water with the help of electricity into hydrogen and oxygen. It is an endothermal process, i.e. heat is required during the reaction. Hydrogen is stored under pressure in gas bottles or tanks, and this can be done practically for an unlimited time. To generate electricity, both gases flow into the fuel cell where an electrochemical reaction which is the reverse of water splitting takes place: hydrogen and oxygen react and produce water, heat is released and electricity is generated. For economic and practical reasons oxygen is not stored but vented to the atmosphere on electrolysis, and oxygen from the air is taken for the power generation.

In addition to fuel cells, gas motors, gas turbines and combined cycles of gas and steam turbines are in discussion for power generation. Hydrogen systems with fuel cells (less than 1 MW) and gas motors (under 10 MW) can be adopted for combined heat and power generation in decentralized installations. Gas and steam turbines with up to several hundred MW could be used as peaking power plants. The overall AC-AC efficiency is around 40 %. [5]

I. 3. 2. Synthetic natural gas (SNG)

Synthesis of methane (also called synthetic natural gas, SNG) is the second option to store electricity as chemical energy. Here a second step is required beyond the water splitting process in an electrolyser, a step in which hydrogen and carbon dioxide react to methane in a methanation reactor. As is the case for hydrogen, the SNG produced can be stored in pressure tanks, underground, or fed directly into the gas grid. Several CO2 sources are conceivable for the methanation process, such as fossil-fuelled power stations, industrial installations or biogas plants. To minimize losses in energy, transport of the gases CO2 (from the CO2 source) and H2 (from the electrolysis plant) to the methanation plant should be avoided.

The main advantage of this approach is the use of an already existing gas grid infrastructure (e.g. in Europe). Pure hydrogen can be fed into the gas grid only up to a certain concentration, in order to keep the gas mixture within specifications (e.g. heating value). Moreover, methane has a higher energy density, and transport in pipelines requires less energy (higher density of the gas). The main disadvantage of SNG is the relatively low efficiency due to the conversion losses in electrolysis, methanation, storage, transport and the subsequent power generation. The overall AC-AC efficiency, [5]

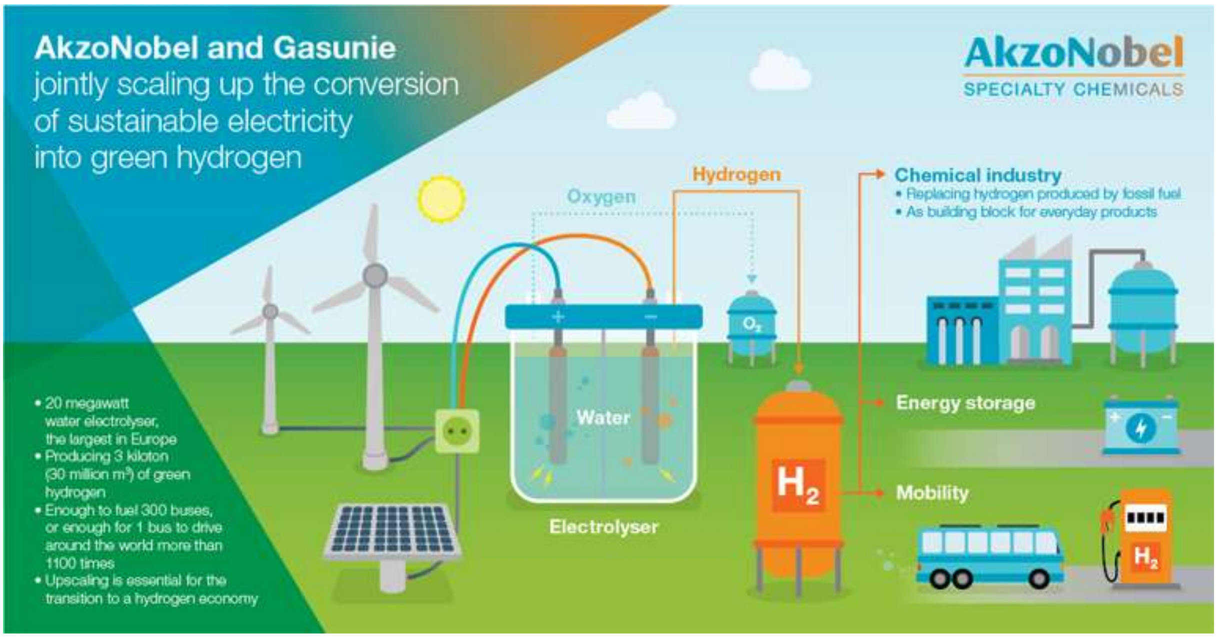

Figure I-6: *A typical hydrogen storage system*

I. 4. mechanical storage systems

In mechanical storage systems, inexpensive electrical energy is converted into mechanical energy during off-peak times. Mechanically stored energy is converted back into electricity when the supply of electricity falls short of demand.

The most common mechanical storage systems are pumped hydroelectric power plants (pumped hydro storage, PHS), compressed air energy storage (CAES) and flywheel energy storage (FES).

I. 4. 1. Pumped hydro storage (PHS)

Typical pumped hydro storage systems (PHS) use two water reservoirs at different elevations to pump water during off-peak hours from the lower to the upper reservoir (charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (discharging).

Hence, the amount of stored energy is proportional to the height difference between the reservoirs and the mass of water stored according to equation (1):

$$E = mgh \quad (1)$$

There are different options for the upper and lower reservoirs, e.g. high dams can be used as pumped hydro storage plants. For the lower reservoir flooded mine shafts, other underground cavities and the open sea are also possible.

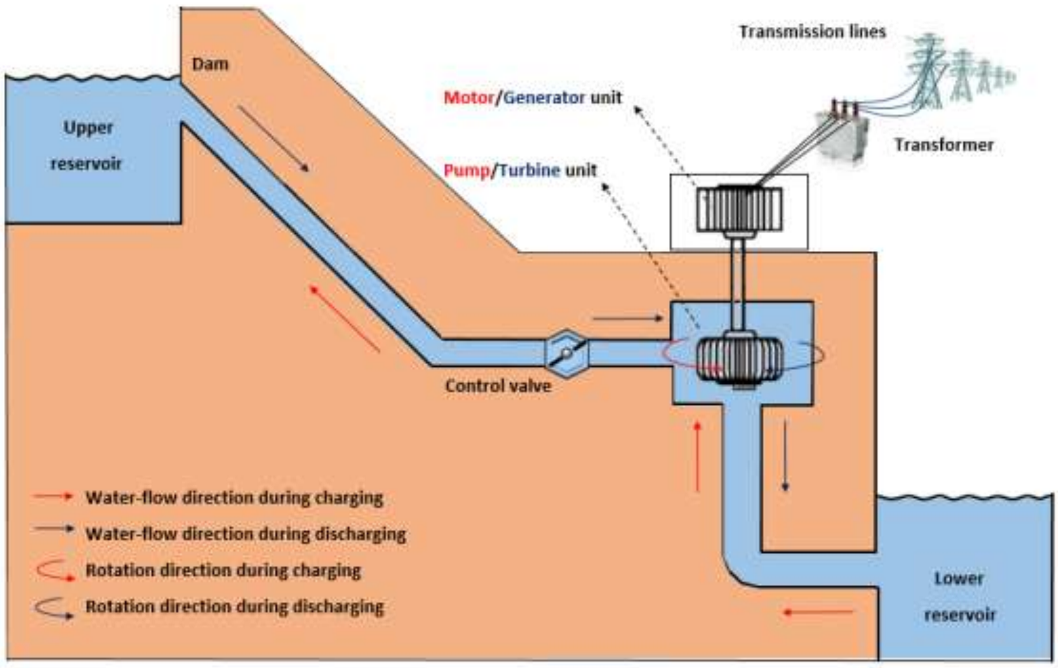

***Figure I-7**: schematic diagram of pumped hydro storage plant [6]*

Typical discharge times range from several hours to a few days. The efficiency of PHS plants is in the range of 70 % to 85 %. Advantages are the very long lifetime and practically unlimited cycle stability of the installation. Main drawbacks are the dependence on topographical conditions and large land use. The main applications are for energy management via time shift, namely nonspinning reserve and supply reserve.

I. 4. 2. Compressed air energy storage (CAES)

Compressed air (compressed gas) energy storage (Figure 2-3) is a technology known and used since the 19th century for different industrial applications including mobile ones. Air is used as storage medium due to its availability. Electricity is used to compress air and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine. Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES and results in low round-trip efficiencies of less than 50 %.

The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

I. 4. 3. Flywheel energy storage (FES)

In flywheel energy storage (Figure 8) rotational energy is stored in an accelerated rotor, a massive rotating cylinder. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/ generator mounted onto the stator 7). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device. Flywheels of the first generation, which have been available since about 1970, use a large steel rotating body on mechanical bearings. Advanced FES systems have rotors made of high-strength carbon

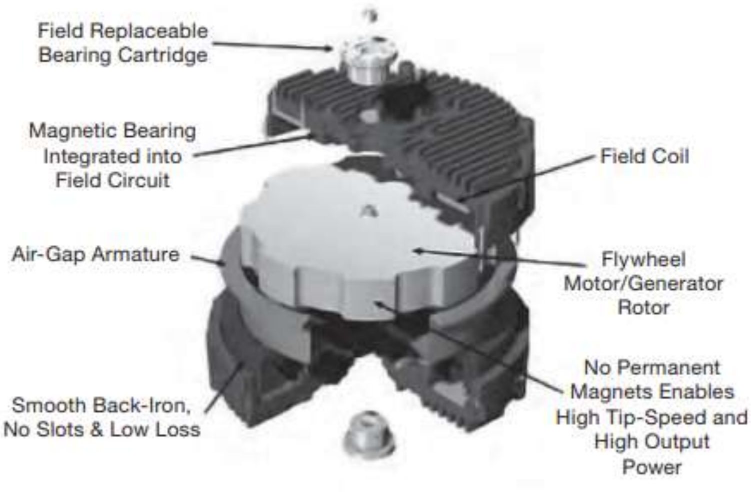

Figure I-8: *Flywheel energy storage*

I. 5. Electrical storage systems

I. 5. 1. Capacitor and Supercapacitor

A capacitor consists of two conducting metal-foil electrodes separated by an insulating dielectric material normally made of ceramic, glass or plastic film. The stored energy is a result of the electric field produced by opposite charges, which occur on the electrodes' surface when a voltage is applied. Already commercialized, capacitors can be charged faster and offer higher specific power than conventional batteries, but they experience a high self-discharge rate and lower energy density.

Super-capacitors (also named ultra-capacitors, electrochemical capacitors or electric double-layer capacitors), are energy storage devices with special features, somewhere between conventional capacitors and batteries. As illustrated in Figure 9, their structure includes two metal electrodes with a carbon surface, separated by a porous membrane soaked in an electrolyte, which simultaneously has the role of electronic insulator and ionic conductor.

Super-capacitors ideally store electric energy in the electrostatic field of the electrochemical double layer, rather than perform any chemistry, thus can be cycled millions of times and have a much longer lifetime compared to batteries.

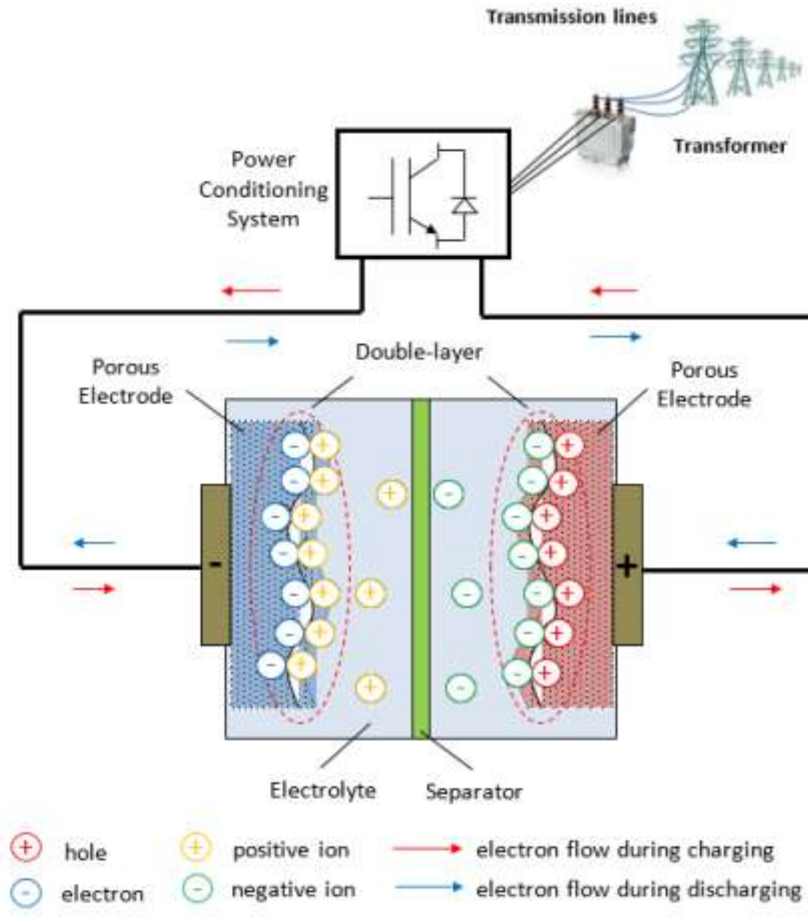

Figure I-9: *schematic diagram of electrochemical double-layer capacitor*

I. 5. 2. Superconducting magnetic energy storage (SMES)

Superconducting magnetic energy storage (SMES) systems work according to an electrodynamics principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature.

In order for the superconducting state to be maintained, the device must be cooled to -264◦C (9.2K), allowing current to flow permanently through the inductor.

I. 6. Electrochemical storage systems

Batteries are by far the most common form of storing electrical energy; they are classified as either primary ones, which are non-rechargeable, or secondary, which can be recharged. Secondary batteries consist of cells each comprising two electrodes immersed in an electrolyte and they can store and provide energy by electrochemical reversible reactions. Generally, during these reactions, the anode or negative electrode is oxidized, providing electrons, while the cathode or positive electrode is reduced, accepting electrons through an external circuit connected to the cell terminals [6]

I. 6. 1. Secondary batteries

Nickel cadmium and nickel metal hydride battery (NiCd, NiMH)

Ni–Cd batteries have a nickel hydroxy-oxide cathode, metallic cadmium anode, and a potassium hydroxide electrolyte. Ni–Cd batteries have high discharge rates, and on the drawback side, it is not environmentally friendly.

From a technical point of view, NiCd batteries are a very successful battery product; in particular, these are the only batteries capable of performing well even at low temperatures in the range from -20 °C to -40 °C. Large battery systems using vented NiCd batteries operate on a scale similar to lead acid batteries. However, because of the toxicity of cadmium, these batteries are presently used only for stationary applications in Europe. Since 2006 they have been prohibited for consumer use.

Lithium ion battery (Li-ion)

Lithium ion batteries have become the most important storage technology in the areas of portable and mobile applications.

The cathode is made of lithiated metal oxide, and the anode is made of a graphitic carbon. The electrolyte is made of lithium salts dissolved in organic carbonates [6]. These batteries have high energy density, high efficiency, long life cycle, and are light weight. The disadvantages are high cost and thermal runaway effect. [6]

The main obstacle is the high cost of more than USD 600/kWh due to special packaging and internal overcharge protection circuits.

Lithium ion batteries generally have a very high efficiency, typically in the range of 95 % - 98 %. Nearly any discharge time from seconds to weeks can be realized, which makes them a very flexible and universal storage technology.[7]

Metal air battery (Me-air)

A metal air battery has a metal anode (zinc or lithium), liquid electrolyte, and air as the cathode. It is ultra-light weight and has a high energy density. On the drawbacks side, it has a low charge/discharge life cycle, high cost, and low energy efficiency. Oxidation reaction takes place at the anode, and reduction reaction takes place at the cathode. In addition, during charging the process is reversed, the anode becomes the cathode and vice versa, i.e. metal plating at the anode and oxygen evolution at the cathode.

Currently only a zinc air battery with a theoretical specific energy excluding oxygen of 1.35 kWh/ kg is technically feasible. Zinc air batteries have some properties of fuel cells and conventional batteries: the zinc is the fuel, the reaction rate can be controlled by varying air flow, and oxidized zinc/ electrolyte paste can be replaced with fresh paste.

Sodium sulphur battery (NaS)

Sodium sulphur battery comprises of a molten sulphur cathode and molten sodium anode separated by a solid beta alumina ceramic electrolyte.

Sodium sulphur batteries consist of liquid (molten) sulphur at the positive electrode and liquid (molten) sodium at the negative electrode; the active materials are separated by a solid beta alumina ceramic electrolyte. The battery temperature is kept between 300 °C and 350 °C to keep the electrodes molten. NaS batteries reach typical life cycles of around 4 500 cycles and have a discharge time of 6.0 hours to 7.2 hours. They are efficient (AC-based round-trip efficiency is about 75 %) and have fast response. These attributes enable NaS batteries to be economically used in combined power quality and time shift applications with high energy density.[7]

These batteries are suitable for applications with daily cycling. As the response time is in the range of milliseconds and NaS batteries meet the requirements for grid stabilization, this technology could be very interesting for utilities and large consumers.

Pb acid Lead acid batteries are the most mature rechargeable battery technology. It has a lead dioxide cathode, lead anode, and sulphuric acid electrolyte. Lead acid batteries have low cost and are readily available. Lead carbon batteries are an advanced form of lead acid batteries that are competitive to NiMH performance wise. Lead acid batteries have high maintenance, low reliability, low safety, and short life cycle. [7]

Sodium nickel chloride battery (NaNiCl)

the sodium nickel chloride (NaNiCl) battery, better known as the ZEBRA (Zero Emission Battery Research) battery, is – like the NaS battery – a high-temperature (HT) battery, and has been commercially available since about 1995. Its operating temperature is around 270 °C, and it uses nickel chloride instead of sulphur for the positive electrode. NaNiCl batteries can withstand limited overcharge and discharge and have potentially better safety characteristics and a higher cell voltage than NaS batteries. They tend to develop low resistance when faults occur and this is why cell faults in serial connections only result in the loss of the voltage from one cell, instead of premature failure of the complete system. These batteries have been successfully implemented in several electric vehicle designs (Think City, Smart EV) and are an interesting opportunity for fleet applications.

I. 6. 2. Flow Batteries

In conventional secondary batteries, the energy is charged and discharged in the active masses of the electrodes. A flow battery is also a rechargeable battery, but the energy is stored in one or more electro active species which are dissolved in liquid electrolytes. The electrolytes are stored externally in tanks and pumped through the electrochemical cell that converts chemical energy directly to electricity and vice versa. The power is defined by the size and design of the electrochemical cell whereas the energy depends on the size of the tanks. With these characteristic flow batteries can be fitted to a wide range of stationary applications. Originally developed by NASA in the early 70s as EES for long-term space flights, flow batteries are now receiving attention for storing energy for durations of hours or days with a power of up to several MW. Flow batteries are classified into redox flow batteries and hybrid flow batteries.

In contrast to conventional batteries, which store energy in solid state electrodes, flow batteries convert electrical energy into chemical potential, which is stored in two liquid electrolyte solutions located in external tanks, the size of which determines the capacity of the battery.

The three principal existing types of flow batteries are vanadium-redox (reduction-oxidation), zinc-bromine and polysulfide bromide. Flow batteries may require additional equipment, such as pump sensors and control units. They may also provide variable and generally low energy density, but they present major advantages in comparison with standard batteries as they have long cycle life, quick response times can be fully discharged and can offer unlimited capacity through increasing their storage tank size. The vanadium redox flow battery (VRB) is one of the most mature flow battery systems. In such a system, vanadium in sulphuric acid is employed in both the electrolyte loops but in different valence states.

Redox flow battery (RFB) in redox flow batteries (RFB) two liquid electrolyte dissolutions containing dissolved metal ions as active masses are pumped to the opposite sides of the electrochemical cell. The electrolytes at the negative and positive electrodes are called anolyte and catholyte respectively. During charging and discharging the metal ions stay dissolved in the fluid electrolyte as liquid; no phase change of these active masses takes place.

Anolyte and catholyte flow through porous electrodes, separated by a membrane which allows protons to pass through it for the electron transfer process. During the exchange of charge a current flows over the electrodes, which can be used by a battery powered device. During discharge the electrodes are continually supplied with the dissolved active masses from the tanks; once they are converted the resulting product is removed to the tank. Theoretically a RFB can be "recharged" within a few minutes by pumping out the discharged electrolyte and replacing it with recharged electrolyte. That is why redox flow batteries are under discussion for mobile applications. However, up to now the energy density of the electrolytes has been too low for electric vehicles.

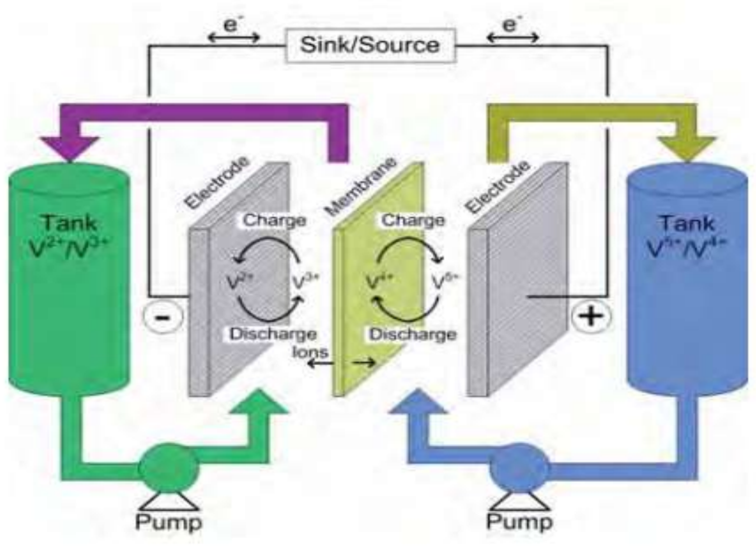

Figure I-10: *schematic of a Vanadium Red-ox Flow Battery*

Hybrid flow battery (HFB) in a hybrid flow battery (HFB) one of the active masses is internally stored within the electrochemical cell, whereas the other remains in the liquid electrolyte and is stored externally in a tank. Therefore hybrid flow cells combine features of conventional secondary batteries and redox flow batteries: the capacity of the battery depends on the size of the electrochemical cell. Typical examples of a HFB are the Zn-Ce and the Zn-Br systems. In both cases the anolyte consists of an acid solution of Zn2+ ions. During charging Zn is deposited at the electrode and at discharging Zn2+ goes back into solution. As membrane a micro porous polyolefin material is used; most of the electrodes are carbon-plastic composites. Various companies are working on the commercialization of the Zn-Br hybrid flow battery, which was developed by Exxon in the early 1970s.

In the United States, ZBB Energy and Premium Power sell trailer-transportable Zn-Br systems with unit capacities of up to 1 MW/3 MWh for utility-scale applications 5 kW/20 kWh systems for community energy storage are in development as well.

I. 7. Conclusion

Energy storage represents an essential part of renewable energy technology systems. It is necessary whenever there is a mismatch between the supply and consumption of energy.

Energy storage technologies are designed to accumulate energy when production exceeds demand, and to make it available at the user’s request. They can help to match energy supply and demand, exploit variable renewable (solar and wind) energy sources, increase the overall efficiency of the energy system and reduce carbon-dioxide emissions.

Chapter II: The roles of electrical energy storage technologies in electricity use

II. 1. Introduction

Energy storage technologies present a number of operating benefits to the grid that enable improved reliability and increased power utilization and efficiency. Therefore, Electrical energy storage is crucial for the effective proliferation of an electric economy and for the implementation of many renewable energy technologies.

Two characteristics of electricity lead to issues in its use, and by the same token generate the market needs for EES. First, electricity is consumed at the same time as it is generated. The proper amount of electricity must always be provided to meet the varying demand. An imbalance between supply and demand will damage the stability and quality (voltage and frequency) of the power supply even when it does not lead to totally unsatisfied demand. The second characteristic is that the places where electricity is generated are usually located far from the locations where it is consumed. Generators and consumers are connected through power grids and form a power system. In function of the locations and the quantities of power supply and demand, much power flow may happen to be concentrated into a specific transmission line and this may cause congestion. Since power lines are always needed, if a failure on a line occurs (because of congestion or any other reason) the supply of electricity will be interrupted; also because lines are always needed, supplying electricity to mobile applications is difficult. The following sections outline the issues caused by these characteristics and the consequent roles of EES.

II. 2. Applications:

The technical characteristics of each energy storage technology are key to understanding their applicability and their compatibility with the energy supply structures. There are a wide variety of storage technologies with a variety of different technical characteristics (especially in terms of power and capacity). This, together with the fact that many of their potential benefits (both economic and technical) are currently under research means that the analysis of their applications becomes a complicated and wide-ranging task.

Category 1 — Electric Supply
1. Electric Energy Time-shift
2. Electric Supply Capacity
Category 2 — Ancillary Services
3. Load Following
4. Area Regulation
5. Electric Supply Reserve Capacity
6. Voltage Support
Category 3 — Grid System
7. Transmission Support
8. Transmission Congestion Relief
9. Transmission & Distribution (T&D) Upgrade Deferral
10. Substation On-site Power
Category 4 — End User/Utility Customer
11. Time-of-use (TOU) Energy Cost Management
12. Demand Charge Management
13. Electric Service Reliability
14. Electric Service Power Quality
Category 5 — Renewables Integration
15. Renewables Energy Time-shift
16. Renewables Capacity Firming
17. Wind Generation Grid Integration

Figure 11:Table 4: Five categories of energy storage applications [2]

II. 2. 1. Dynamic, local voltage control :

Several of the energy storage technology applications on the distribution side listed in the previous section can be grouped together if voltage control is considered. Voltage profile control is becoming a key concern for DSO’s because small-scale RES generation (intermittent in nature) is increasing as a proportion of the DERs connected to the distribution grid. Solutions which can avoid voltage sags and momentary outages typically caused by RES by using energy storage are therefore of great interest to DSO’s since they are responsible for the stability and quality of service (QoS) of the distribution grid. The main benefit derives from the deferral of upgrades to the distribution grid infrastructure that would otherwise be necessary to meet the voltage control requirements [5].

distribution grid voltage support can be achieved by both reactive power and active power injection. Compensation of the reactive power by storage technologies is made possible via their grid connect converters: the power electronic requirements will also be derived from specific use cases in the project. Distribution grid power quality and intentional islanding: Another set of applications of storage with respect to the distribution grid are related to the improvement in power quality and reliability: these require the monitoring of performance metrics concerning resilience, continuity of supply and power quality. The first storage applications were focused on providing a Uninterruptible Power Supply (UPS) as a backup power to prevent short duration (momentary) outages normally for commercial and industrial (C&I) customers requiring the highest reliability standards. [5] this application intentional islanding making explicit that outages can happen either under planned or unplanned conditions. IEEE-1366 defines the limit between short (momentary) and long (sustained) duration outages as 5 minutes, but most European countries fixe it as 3 minutes [8].

According to [8] most regulators evaluate only SAIDI and SAIFI, due to the difficulty in measuring MAIFI. The authors point out that current smart meters in the scope of smart grids monitoring tools should enable the measurement of MAIFI and many authors recommend that SAIFI, SAIDI and MAIFI should be evaluated together since some current solutions (such as automated re-closers) that reduce SAIFI and SAIDI may cause an increase of momentary interruptions. The application of storage technologies with their flexible configurations is definitely the most appropriate solution to respond to both momentary and long duration outages. The use of storage to maintain a DSO's predefined voltage profiles increases power quality whose assessment is now achievable with smart-grid technologies, which allow Real Time monitoring and control of grid-embedded storage resources to maintain line voltage profiles in order to fulfil nominal grid voltage requirements. Super-capacitors, flywheels and most electrochemical storage technologies are suitable for providing this capacity characterised mainly by high power discharge rates and short.

II. 3. the role in: on-grid / off-grid/ smart grid

II. 3. 1. Off-grid areas

In off-grid areas where a considerable amount of energy is consumed, particularly in the transport sector, fossil energy should be replaced with less or non-fossil energy in such products as plug-in hybrid electric vehicles (PHEVs) or electric vehicles (EVs) (see Figure 1). More precisely, fossil fuels should be replaced by low-carbon electricity produced mainly by renewable generation. The most promising solution is to replace petrol or diesel-driven cars by electric ones with batteries. In spite of remaining issues (short driving distance and long charging time) EES is the key technology for electric vehicles.[5]

II. 3. 2. On-grid areas

In on-grid areas, the increased ratio of renewable generation may cause several issues in the power grid (see Figure 1). First, in power grid operation, the fluctuation in the output of renewable generation makes system frequency control difficult, and if the frequency deviation becomes too wide system operation can deteriorate. Conventionally, frequency control is mostly managed by the output change capability of thermal generators. When used for this purpose thermal generators are not operated at full capacity, but with some positive and negative output margin (i.e. increases and decreases in output) which is used to adjust frequency, and this implies inefficient operation. With greater penetration of renewable generation this output margin needs to be increased, which decreases the efficiency of thermal generation even more. Renewable generation units themselves in most cases only supply a negative margin. If EES can mitigate the output fluctuation, the margins of thermal generators can be reduced and they can be operated at a higher efficiency. Secondly, renewable energy output is undependable since it is affected by weather conditions. Some measures are available to cope with this. [8]

II. 3. 3. Smart Grid uses

EES is expected to play an essential role in the future Smart Grid. Some relevant applications of EES are described below. First, EES installed in customer-side substations can control power flow and mitigate congestion, or maintain voltage in the appropriate range. Secondly, EES can support the electrification of existing equipment so as to integrate it into the Smart Grid. Electric vehicles (EVs) are a good example since they have been deployed in several regions, and some argue for the potential of EVs as a mobile, distributed energy resource to provide a load-shifting function in a smart grid. EVs are expected to be not only a new load for electricity but also a possible storage medium that could supply power to utilities when the electricity price is high.[9] A third role expected for EES is as the energy storage medium for Energy Management Systems (EMS) in homes and buildings. With a Home Energy Management System, for example, residential customers will become actively involved in modifying their energy spending patterns by monitoring their actual consumption in real time. EMSs in general will need EES, for example to store electricity from local generation when it is not needed and discharge it when necessary, thus allowing the EMS to function optimally with less power needed from the grid.[8]

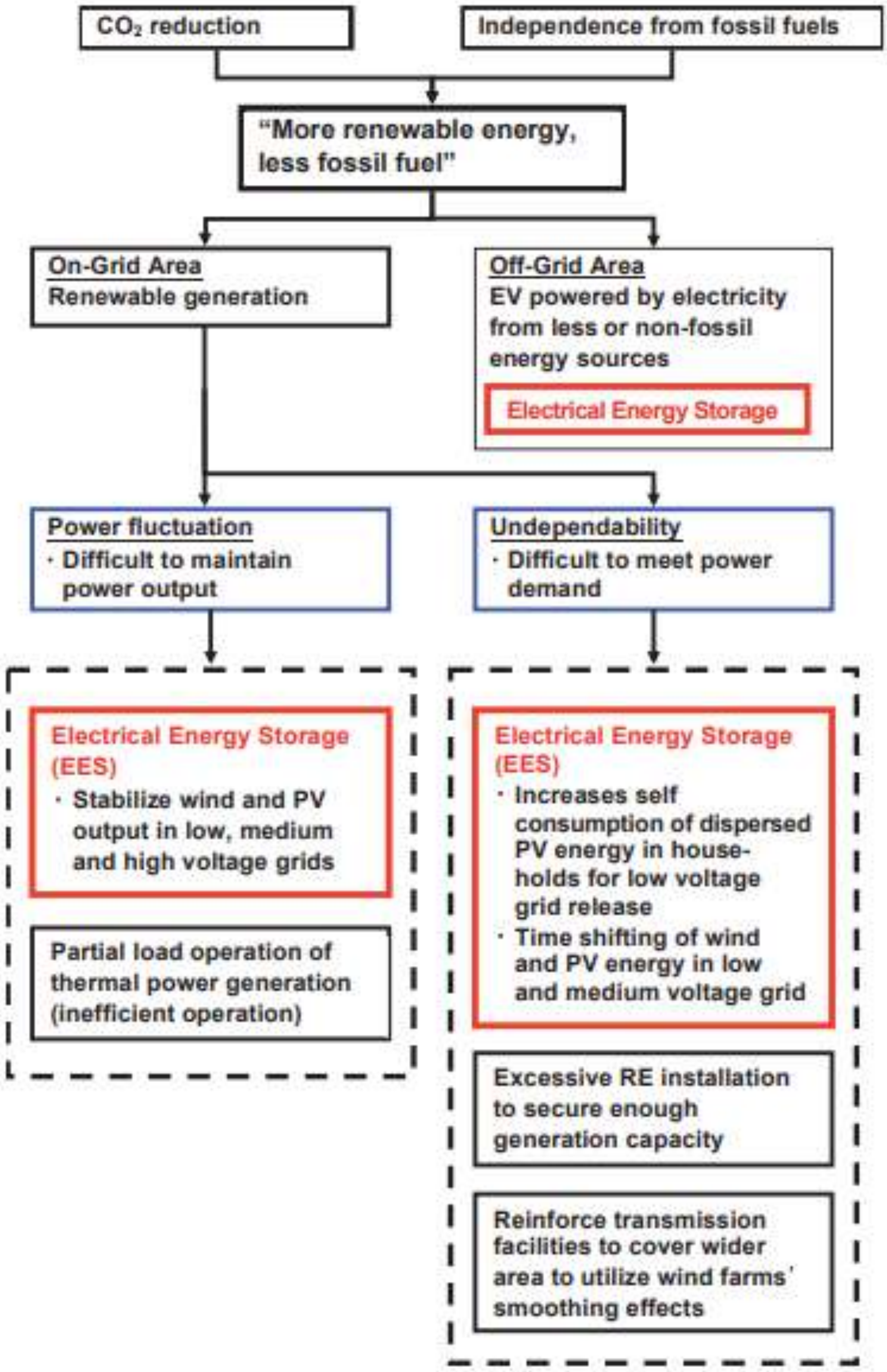

Figure II-12: *Electrical energy storage being a solution for different energy problems*

II. 4. the roles from the viewpoint of a utility

II. 4. 1. Time shifting Utilities

Constantly need to prepare supply capacity and transmission/distribution lines to cope with annually increasing peak demand, and consequently develop generation stations that produce electricity from primary energy. For some utilities generation cost can be reduced by storing electricity at off-peak times, for example at night, and discharging it at peak times. If the gap in demand between peak and off-peak is large, the benefit of storing electricity becomes even larger. Using storage to decrease the gap between daytime and night-time may allow generation output to become flatter, which leads to an improvement in operating efficiency and cost reduction in fuel. For these reasons many utilities have constructed pumped hydro, and have recently begun installing large-scale batteries at substations.

II. 4. 2. Frequency regulation

Frequency regulation is needed to maintain a balanced system. Although daily, weekly and seasonal patterns exist, it is impossible for power consumption to be predicted accurately, leading to generation-demand imbalances (or nominal-frequency deviations), which can cause brownouts or blackouts [10]. Stored energy in these applications is requested to increase or decrease the output for seconds or less, to continuously maintain the frequency within electricity network standards.[11]

II. 4. 3. Power quality

A basic service that must be provided by power utilities is to keep supply power voltage and frequency within tolerance, which they can do by adjusting supply to changing demand. Frequency is controlled by adjusting the output of power generators; EES can provide frequency control functions. Voltage is generally controlled by taps of transformers, and reactive power with phase modifiers. EES located at the end of a heavily loaded line may improve voltage drops by discharging electricity and reduce voltage rises by charging electricity. The converter systems associated with energy storage devices can also provide power quality benefits by acting like a system filter and eliminating unwanted variations in frequency and voltage. Energy storage systems will also support better angular stability and enhance grid reliability and enable greater power delivery capacity.

II. 4. 4. Isolated grids

Where a utility company supplies electricity within a small, isolated power network, for example on an island, the power output from small-capacity generators such as diesel and renewable energy must match the power demand. By installing EES the utility can supply stable power to consumers.[5]

II. 4. 5. Making more efficient use of the network

In a power network, congestion may occur when transmission/distribution lines cannot be reinforced in time to meet increasing power demand. In this case, large-scale batteries installed at appropriate substations may mitigate the congestion and thus help utilities to postpone or suspend the reinforcement of the network. As a T&D investment, energy storage plants must be integrated and operated as a normal component of the power delivery system. In certain applications energy storage can defer capital investments. Other benefits could include decreased transmission losses and reduced transmission congestion.[12]

II. 4. 6. Emergency power supply for protection and control equipment

A reliable power supply for protection and control is very important in power utilities. Many batteries are used as an emergency power supply in case of outage

II. 4. 7. A. Facilitating Renewable/Intermittent Generation Integration:

To integrate increased penetration levels of variable renewable generation, the electrical grid will require more fast-start and fast-ramping resources to make up for generation shortfalls when such resources are not operating at their expected output levels.

The 2008 CPUC Nexant Study indicated that thousands of MWs of new peaking and/or energy storage assets would be needed to accommodate a 33 percent RPS scenario. Further studies are needed to determine appropriate energy and capacity requirements of energy storage. Better wind resource forecasting methodologies will need to be incorporated into independent system operators plans if wind and solar are to be considered viable and dispatchable energy resources.

II. 5. the roles from the viewpoint of consumers:

II. 5. 1. Time shifting/cost savings

Power utilities may set time-varying electricity prices, a lower price at night and a higher one during the day, to give consumers an incentive to flatten electricity load. Consumers may then reduce their electricity costs by using EES to reduce peak power needed from the grid during the day and to buy the needed electricity at off-peak times.

The main benefits of load shifting at the customer side come from the flexibility in consumption that local storage provides, making it adaptable to flexible contractual solutions with retailers (dual tariffs, flexible demand contracts).

The use of heat storage in combination with dual tariffs has been the most widely used application in recent decades. It was particularly popular in the UK during the 1970's because it represented a tailored solution to optimise supply in the traditional centralised electricity supply chain infrastructure (based on large thermal power plants), which was not able to power down at night. The fact that this application has required no infrastructure refurbishment has made it very attractive, and in modern scenarios in Europe, where large thermal power plants are being dismantled, new use cases for this application that address cheap infrastructure upgrades are being re-assessed. Some of them in the scope of the SENSIBLE project will explore how dual tariffs can be adapted to new generation patterns or work in combination with local RES generation. More advanced upgrades are required for implementing flexible demand solutions where retailers make use of more modern smart-grid technologies and new smart-meters to "buy" flexibility from customers. The main idea behind this application is to put part of a customer's load under the retailers control so that supply adjustments (both reductions and increases) can be adapted to market energy prices – Demand Side management (DSM). Local storage devices may be part of this flexible equipment, together with home appliances, PVs, etc., whose status is notified to retailers by monitoring signals and whose control will be by activation/deactivation set-points.

II. 5. 2. Maximise self-consumption, local RES, security of supply :

A second set of storage applications at the customer side comprises the solutions with the capacity to manage local storage and RES generation resources in response to local load by maximising the value of self-consumption i.e. exploiting the "microgrid" concept.

This is probably the most powerful application of storage at least when considering its wide range of possibilities (home, building, districts) and also when considering it may represent an easily scalable solution in developing countries which lack large centralised infrastructures.

The use of electrochemical and thermal storage are definitely the most appropriate storage technologies in both residential and commerce and industrial (C&I) areas. Project use cases will analyse both residential and C&I storage managed by Home and Building energy management systems (HEMS and BEMS) in smart-grid scenarios. The HEMS, comprising electrochemical and thermal storage and PV generation will maximise the flexibility offered to retailers while optimising self-consumption.

The BEMS use case is mainly focused on optimising the use of heat storage in combination with a CHP generation unit in a scenario where large customers may have a more direct access to energy markets. In both cases the benefits in terms of efficiency, cost savings and reliability will be explored. District storage is another level of self-consumption under consideration in the project that contemplates future scenarios where cooperative economies might develop.

This application considers the possibility of centralising the location of storage at larger scales in communities while sharing its ownership. The benefit will come from a higher local RES penetration by combining complementary energy consumption patterns (residential, schools, commercial buildings).

The capacity of these solutions to operate off-grid will lead to an improvement in the security of supply impacting the security indicators being considered in the project. More specifically a reduction in the SAIDI and CAIDI performance indicators previously mentioned will effectively take place every time these systems operate in islanding mode due to grid supply interruptions.

II. 5. 3. Emergency power supply and independence from the grid

Consumers may possess appliances needing continuity of supply, such as fire sprinklers and security equipment. EES is sometimes installed as a substitute for emergency generators to operate during an outage. Semiconductor and liquid crystal manufacturers are greatly affected by even a momentary outage (e.g. due to lightning) in maintaining the quality of their products. In these cases, EES technology such as large-scale batteries, double-layer capacitors and SMES can be installed to avoid the effects of a momentary outage by instantly switching the load off the network to the EES supply. A portable battery may also serve in an emergency to provide power to electrical appliances.

II. 5. 4. Electric vehicles and mobile appliances:

Electric vehicles (EVs) are being promoted for CO2 reduction. High-performance batteries such as nickel cadmium, nickel metal hydride and lithium ion batteries are mounted on EVs and used as power sources. EV batteries are also expected to be used to power in-house appliances in combination with solar power and fuel cells; at the same time, studies are being carried out to see whether they can usefully be connected to power networks. These possibilities are often abbreviated as “V2H” (vehicle to home) and “V2G” (vehicle to grid).

II. 5. 5. Autonomy and self-sufficiency

Individual households deploy domestic energy storage for the purposes of using (more) self-generated solar energy. The rationality of this mode is optimizing self-consumption of electricity produced by PV panels. Self-consumption itself is a gratifying project for many PV panel owners. Beyond this, two main motivations are at play here: (long-term) economic reasoning, and desire for autonomy or self-sufficiency.[13]

II. 6. the roles from the viewpoint of generators of renewable energy

II. 6. 1. Time shifting

Renewable energy such as solar and wind power is subject to weather, and any surplus power may be thrown away when not needed on the demand side. Therefore, valuable energy can be effectively used by storing surplus electricity in EES and using it when necessary; it can also be sold when the price is high.

II. 6. 2. Effective connection to grid

The output of solar and wind power generation varies greatly depending on the weather and wind speeds, which can make connecting them to the grid difficult. EES used for time shift can absorb this fluctuation more cost-effectively than other, single-purpose mitigation measures (e.g. a phase shifter). [6]

II. 6. 3. Role of mature energy storage technologies:

adapts and shifts from balancing demand variation to enabling intermittent supply PHS has been installed in France, Japan and other regions to compensate for the inertia of nuclear reactors. Nuclear-powered reactors from the 1970s and 1980s have only a limited ability to modulate their power output. Hence, PHS has taken over this role and the revenues are based on storing power when prices are low during baseload periods at night and selling power when prices are high during the day.

In addition, the only two compressed air energy storage (CAES) plants in the world play the same role – supporting baseload power plants to meet variable demand. At the time of construction, these storage facilities were part of a system controlled by a single player. For instance, Electricité de France operated the full system, from nuclear power plants, transmission grid and PHS to distribution and could fully internalize the benefits of the PHS. Now, PHS and CAES depend on the transparent price signals provided by the wholesale markets.

These plants currently participate in the wholesale market, though prices on the European continent are not yet offering sufficient incentives for the construction of new ones. The business models for large energy storage systems like PHS and CAES are changing. Their role is tradition ally to support the energy system, where large amounts of baseload capacity cannot deliver enough flexibility to respond to changes in demand during the day.

Now, these large energy storage systems deliver the flexibility to respond to the intermittency of renewable energy sources. For instance, in northern Chile a proposed project for a 300 MW PHS will ensure a continuous power supply to mining companies from a 600 MW solar PV plant.

Thanks to the low costs of PHS and solar PV, the system can run without subsidies. In Northern Ireland a proposed CAES facility will exploit several revenue streams and support the full energy system. Intermittent wind energy in Northern Ireland requires substantial balancing efforts, as the grid is not well-connected to other regions.

CAES will help reduce the current high overall system costs – so reliance on costly gas-fired backup capacity will be reduced – and it will provide ancillary services. Revenues will come from the spread on wholesale markets and ancillary services market.

Given the scale of the disruption that synthetic fuels could create for the chemical industry, chemical companies need to monitor the developments carefully. Though these synthetic fuels are currently more expensive than fossil fuels, declining costs and changing regulations and stricter CO2 emissions policies could lead to the adoption of these synthetic fuels in the coming decades. Besides focusing on production technology, these companies should reinforce their capabilities to deal with power market trading. The value of power-to-gas comes from sourcing electricity at times when prices are low. Partnerships with utility companies could enable these capabilities to grow.

II. 7. Conclusion

Energy storage technologies present various working advantages to the grid that empower improved dependability and expanded power use and proficiency. Along these lines, Electrical energy storage is pivotal for the powerful expansion of an electric economy and for the execution of numerous sustainable energy technologies.

Chapter III: Updated Status and forecast of Renewable Energy Projects in Algeria

II. 1. Introduction

Currently, in most countries, the electric power demand is increasing continuously. The control of this energy becomes one of the major priorities of the states. Being located in a strategic region of the world, Algeria is one of the important solar belt countries, with an enormous potential in solar energy. The exploitation and promotion of these energy resources offer the opportunity of tackling energy-related and economic challenges, and to contribute to a sustainable development in our countries. Our government tends towards renewable energies in order to provide solutions against the environmental challenges and preservation of fossil energy resources. This strategic choice is motivated by these immense potentials of solar energy. This energy has the major axis of the program dedicated to the solar thermal and solar photovoltaic. The solar energy is expected to reach more than 37% of the national electricity generation in 2030.

Both new and renewable available energetic natural resources and energy efficiency policies play key roles in energy sustainability, provided that take advantage of the capabilities and resources, according to the technical and economic feasibility in the application of a set of policies that take into account the social and economic dimensions of the various categories in each country in addition to increase awareness of the need to preserve the available energy resources and reduce the environmental pollution. This, therefore, requires the participation of all - each in its field - to reach a specific and clear goal, which is to sustain energy and to participate intensively in product manufacturing. Thus, works, actively, to meet the requirements of the development projects and raise the standard of living of the citizens of these countries, especially in rural areas, as well as to create jobs by attracting more foreign investments and encouraging the private sector to participate effectively in this field.

Due to the decline in oil prices in the last three years, Algeria has increased interest in renewable or clean energy production in an unprecedented manner as the government has been keen to diversify the sources of economic income. Hence, Algeria is considered among the most prominent countries nominated by energy experts in the world to play a significant and important role in the energy equation because it has huge natural resources, which can invest in the production of energies, as alternative of energy sources with a gradual obsolescence of fossil fuels.

It is, furthermore, has been ranked among 45 countries in the world due to the strong monitoring of energy policy as well as it has occupied the first place among the countries collected from 67 to 100 which are called the Green Zone points according to the order of yellow and red areas.

II. 2. Renewable energies availability and potential in Algeria

Due to the importance of the Algerian market and its fertility, many European countries are trying to gain partnership opportunities with Algeria in the development and investment of renewable energies. However, Algeria has been concluded several partnership agreements with the European countries, including a memorandum of understanding with Germany in the field of renewable energy and environmental protection in 2009. In addition to, the construction of the hybrid power plant with the Spanish company "Abener ".

It is, furthermore, expected that the production of electricity, from the various renewable energies that Algeria intends to develop during the period 2021- 2030, is about 22,000 MW in 2030, which is equal to 40 percent of the total electricity production. Algeria also plans to export 10,000 MW from 22,000 MW that have been programmed over the next two decades, while providing 12,000 MW to meet the national demand for electricity. The distribution of this program by technology activities [14] is illustrated in Table 1.

Table III-1: *Planning of renewable energy projects for electric energy production - three phases of implementation [2]*

Target date	1st phase 2010-2013 (MW)	2nd phase 2015-2020 (MW)	3rd phase 2021-2030 (MW)	TOTAL (MW)
Photovoltaic	6	3000	13500	16581
Solar Thermal	25	1025	2000	3850
wind	10	1010	5010	6030
Biomass	-	360	100	460
Others	-	260	450	710
TOTAL	41	6455	21135	27631

II. 2. 1. Solar Energy

Due to the large area and weather diversity and on account of its geographical location, Algeria holds one of the highest potential of solar energy particularly in the Saharan region (southern regions), with duration of sunshine is about 7.3 hours in the north, 8.3 hours in the highlands and more than 9 hours in the southern regions [15], which is suitable for solar energy applications like photovoltaic (Grid-connected, electrification of villages, water pumping..) or Concentrated Solar Power (CSP).

Indeed, Algeria plans to invest heavily in solar power plants, especially it has an enormous potential for the production and export of solar energy as it receives bright sunlight for more than 3000 hours per year. The details of this potential are given in Table 2 and Figure 1.

***Table III-2**: Solar potential in Algeria*

Areas	Coastal area	High plains	Sahara
Surface (%)	4	10	86
Area (km2)	95.27	238.174	2.048.297
Mean daily sunshine duration (h)	7.26	8.22	9.59
Average duration of sunshine (h/year)	2650	3000	3500
Received average energy(kWh/m2 /year)	1700	1900	2650
Solar daily energy density(kWh/m2)	4.66	5.21	7.26

Solar PV energy, as exceedingly versatile system, is being developed in Algeria mainly for 6 applications: domestic uses, water pumping, refrigeration, village electrification in situations where no electricity is available, lighting, and telecommunication.

It is estimated that there are more than 900 homes using PV system at the moment in eighteen (18) villages of the great south (provinces of Adrar, Illizi, Tindouf and Tamanrasset)[16].

According to SKTM company, the total installed capacity of RES was 354.3 MW at the end of 2018 (344.1 MW from PV and 10.2 wind). Furthermore, the electricity produced from RES in 2018 was around 1340 GWh which represented 1% of the total electricity production in that year.

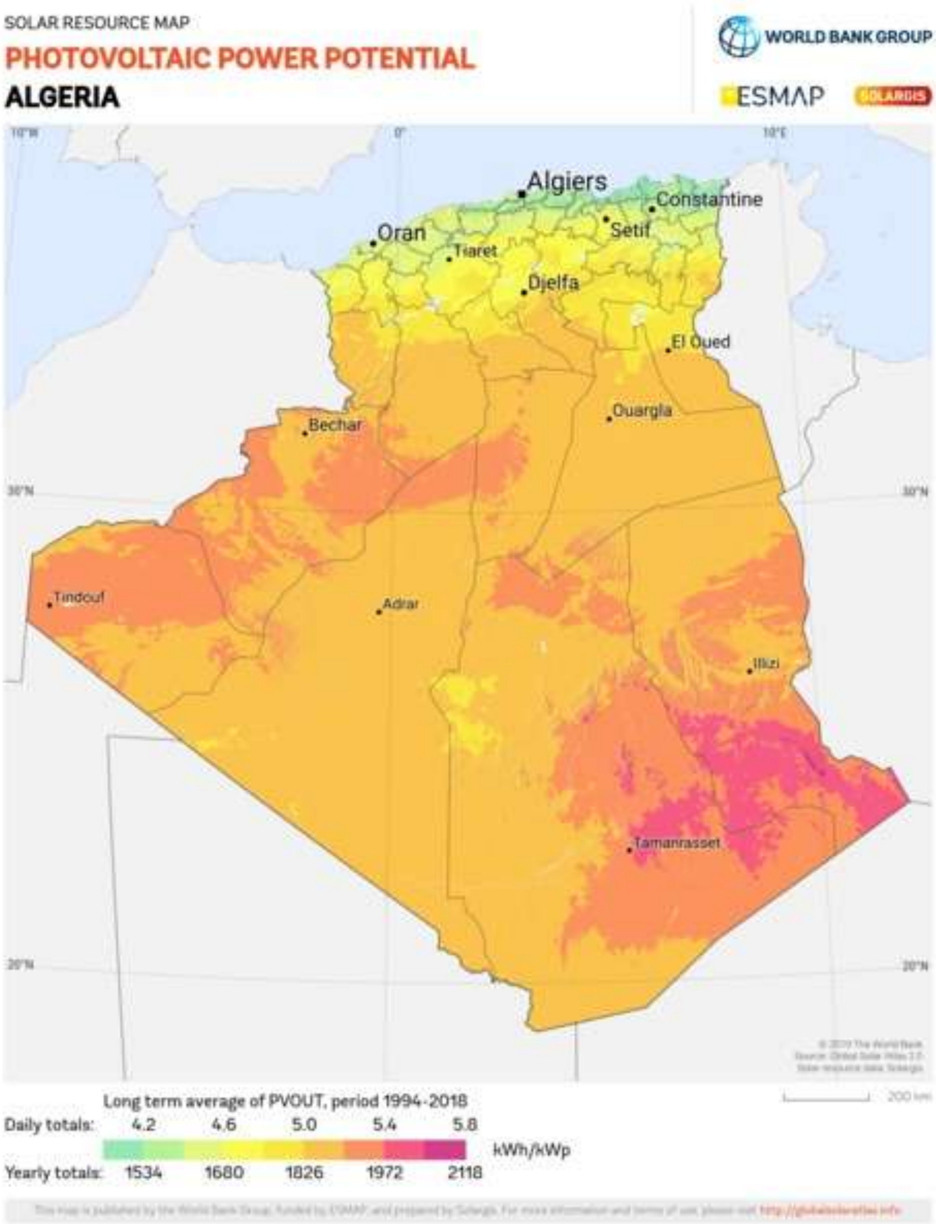

Figure III-1: *Algeria global horizontal irradiation* [17]

II. 2. 2. Concentrated Solar Power (CSP)

Many parts of the world are physically suitable for CSP development including the whole of the MENA region. The Algerian's Sahara belongs to these areas and it is particularly attractive for early market development given the land availability and proximity to large high paying markets. The potential for power generation is enormous compared to regional and global energy demands-roughly 2% of the Sahara desert could meet the world demand and 0.4% could meet Europe (EU) demand. The long-term target of achieving 20% renewable energy power by 2030 is to be met primarily from the CSP (70% CSP, 20% wind and 10% PV) which would make it among the world's most ambitious CSP programs.

II. 2. 3. Wind energy

Algeria has distinguished climate ranges between the northern and the southern halves of Algeria. Northern half, is overlooking the Mediterranean, it has the Atlas Mountains and other high plains. But the northern winds aren't as strong as the southern ones, where, the southern winds speeds range from 4m/s - 6m/s, but most southern lands are lower in latitude than the northern region that climate and topography helped in existence of huge wind power. 78% of Algeria's surface is characterized by velocities higher than 3 m/s with about 40% of these speeds exceeding 5 m/s.[18]

The results showed that maximum mean wind speed values are reached in the localities of Adrar (Sahara) and Tiaret (high plateaus) with a peak of 6.5 m/s.[18]

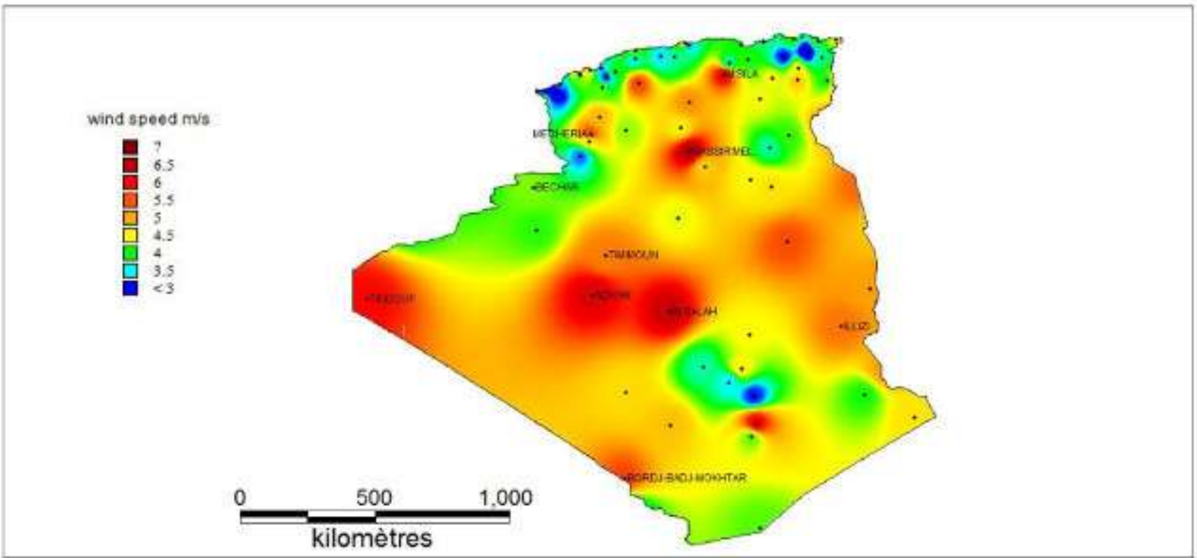

Figure III-2: *Wind atlas of Algeria at 10 m from the ground* [19]

II. 2. 4. Geothermal energy:

The compilation of geological, geochemical and geophysical data has made possible the identification of more than two hundred (200) hot springs that have been inventoried in the northern part of the country. About one-third (33%) of them have temperatures above 45 ° C.

The highest temperatures registered are 98 °C in Guelma province at Hammam El Maskhoutin and 118 °C in Biskra province. The Albian sandstone reservoir located in the south of Algeria has an average water temperature that reaches 57 °C. [20]

The locations of the main geothermal areas in Algeria are shown in Figure 3.

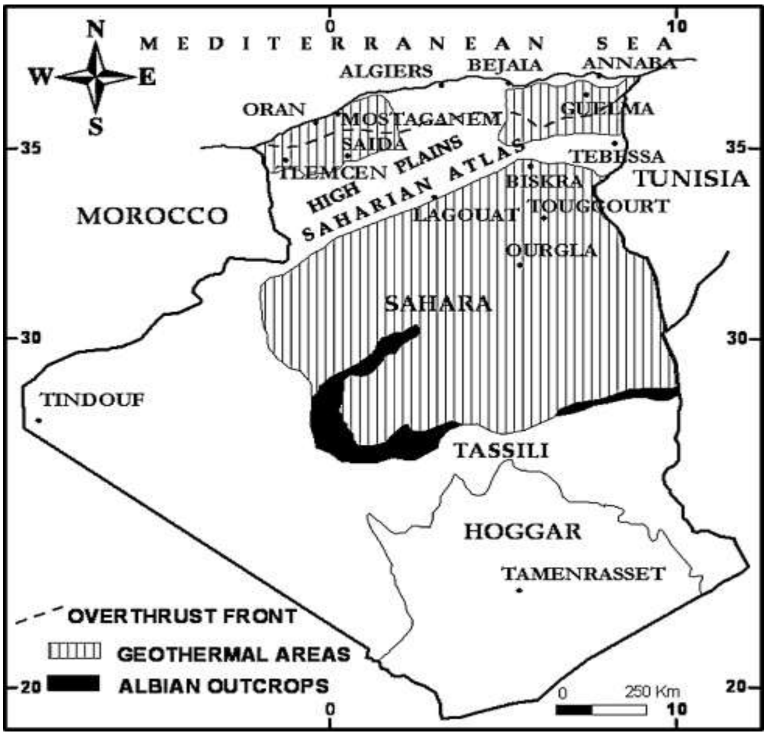

Figure III-3: *Main geothermal areas location in Algeria* [21]

II. 2. 5. Biomass:

Biomass is renewable organic material that comes from plants and animals. Biomass continues to be an important fuel in many countries, especially for cooking and heating in developing countries. The use of biomass fuels for transportation and for electricity generation is increasing in many developed countries as a means of avoiding carbon dioxide emissions from fossil fuel use. [22]

Biomass contains stored chemical energy from the sun. Plants produce biomass through photosynthesis. Biomass can be burned directly for heat or converted to renewable liquid and gaseous fuels through various processes.

Biomass sources for energy include

- wood and wood processing wastes—firewood, wood pellets, and wood chips, lumber and furniture mill sawdust and waste, and black liquor from pulp and paper mills
- Agricultural crops and waste materials—corn, soybeans, sugar cane, switchgrass, woody plants, and algae, and crop and food processing residues
- Biogenic materials in municipal solid waste—paper, cotton, and wool products, and food, yard, and wood wastes

- Animal manure and human sewage [22]

Biomass can be used for fuels, power production, and products that would otherwise be made from fossil fuels. [23]

- **Converting biomass to energy**

Biomass is converted to energy through various processes, including

- Direct combustion (burning) to produce heat
- Thermochemical conversion to produce solid, gaseous, and liquid fuels
- Chemical conversion to produce liquid fuels
- Biological conversion to produce liquid and gaseous fuels

Direct combustion is the most common method for converting biomass to useful energy. All biomass can be burned directly for heating buildings and water, for industrial process heat, and for generating electricity in steam turbines.

Thermochemical conversion of biomass includes *pyrolysis* and *gasification*. Both are thermal decomposition processes in which biomass feedstock materials are heated in closed, pressurized vessels called *gassifiers* at high temperatures. They mainly differ in the process temperatures and amount of oxygen present during the conversion process.

- Biomass energy in Algeria :

Algeria has good biomass energy potential in the form of solid wastes, crop wastes and forestry residues. Solid waste is the best source of biomass potential in the country. According to the National Cadastre for Generation of Solid Waste in Algeria, annual generation of municipal wastes is more than 10 million tons. Solid wastes are usually disposed in open dumps or burnt wantonly. In recent time, **they are starting to use recycled jutebags** to minimize the impact of solid wastes.[24]

The biomass potentially provides big promises with a rate of 3.7 MTOE coming from forests and 1.33 MTOE per year through agricultural and urban wastes. According to a survey presented, an electric potential of more than 1700 GWh can be reached from the recovery of waste. [20]

II. 3. Algeria Renewable Energy Program

The country launched a challenge to install 22 GW from RES to diversify the energy mix, of which 12,000 MW will be intended to meet the domestic electricity demand and 10,000 MW destined for export. This last option depends on the availability of a demand that is ensured on the long term by reliable partners as well as on attractive external funding. This RES program is expected to increase annually to meet the goal of 40% of electricity production by 2030 [16]. It is estimated to generate around 300,000 direct and indirect job, develop the local industry, transfer of technology and expertise via the realization of the first RES projects and saving hundreds of billions of cubic meters of natural gas and significant reduction of CO2.The future perspectives of the electricity system are summarized in Figure 4 for 2030, which shows the expected share of each power technology in the system. [25]

Due to the decline in oil prices in the last three years, Algeria has increased interest in renewable or clean energy production in an unprecedented manner as the government has been keen to diversify the sources of economic income. Hence, Algeria is considered among the most prominent countries nominated by energy experts in the world to play a significant and important role in the energy equation because it has huge natural resources, that can invest in the production of energies, as alternative of energy sources with a gradual obsolescence of fossil fuels. The study entitled "Regulatory indicators for sustainable energy" showed that Algeria has been managed to impose itself as one of the leaders in the field of sustainable energy. It is, furthermore, has been ranked among 45 countries in the world due to the strong monitoring of energy policy as well as it has occupied the first place among the countries collected from 67 to 100 points which are called the Green Zone points according to the order of yellow and red areas.

Algeria's national renewable energy program is aimed to install 22 GW of renewable energy capacity in Algeria by 2030, of which 12 GW will be intended to meet the domestic electricity demand and, under certain conditions, 10 GW destined for export. It is expected that about 30-40% of the electricity produced for domestic consumption will be from solar energy by 2030.

In 2011, Abengoa commissioned a 150 MW Integrated Solar Combined Cycle (ISCC) power plant, which includes 25 MW of solar capacity. The plant, located in Hassi R'Mel in northern Algeria, is composed of a conventional combined cycle and a solar field with a nominal thermal power of 95 MWth. The goal of this project was to integrate the solar thermal technology in a conventional power plant. This combined use reduces the cost and facilitates the deployment of renewable energies in new industrializing countries.

In 2012, the German Aerospace Center announced the first solar tower power in North Africa in Algeria. A solar-gas hybrid power plant with an output of up to seven megawatts, to be constructed in Boughezoul, on the northern edge of the Sahara desert, would serve primarily as a pilot and research facility.

In 2015, Algerian energy minister Youcef Yousfi unveiled plans for 2 GW of CSP by 2030.

The projects for the domestic production of electricity from renewable energy sources will be carried out in three phases:

• The first phase, between 2011 and 2013, will be devoted to the achievement of pilot projects to test the different available technologies,

• The second phase (2014 – 2015) will mark the beginning of the deployment of the program,

• The last phase, between 2016 and 2020, will be devoted to the large-scale deployment of the program.

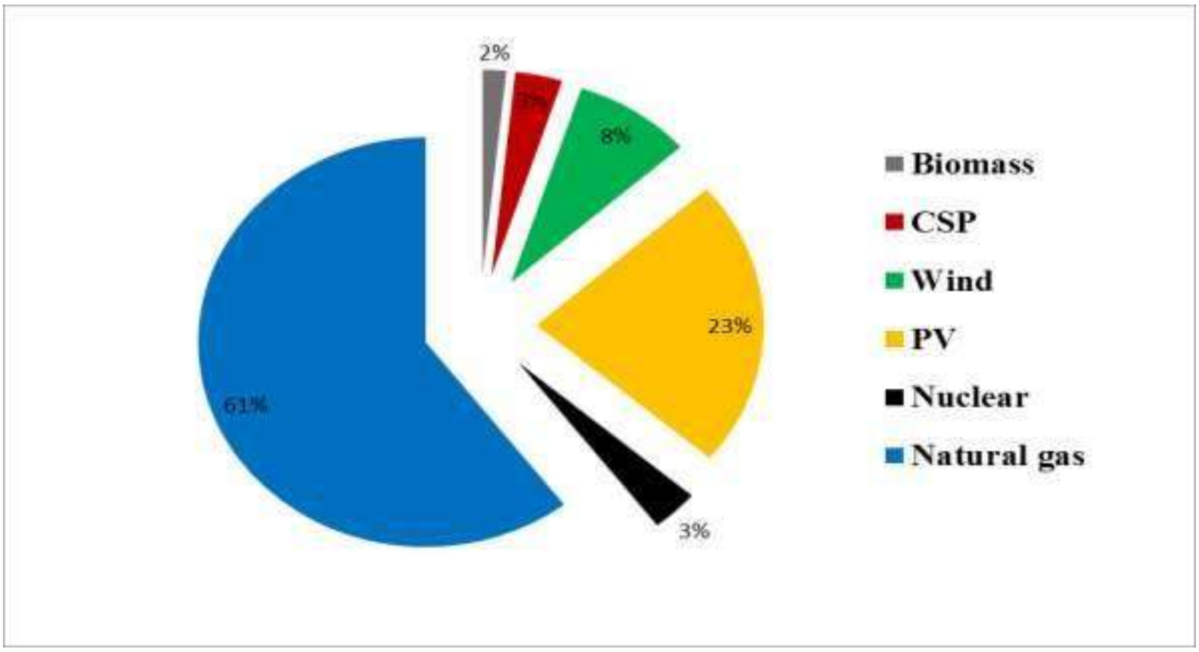

Figure III-4: *Installed capacity of electricity system by 2030* [25]

These phases are a part of Algeria's strategy, which is aimed at developing a genuine solar industry along with a training and capitalization program that will ultimately enable the use of local engineering and establish efficient know-how, including in the fields of engineering and project management.

To achieve the first stage targets, the Algerian government has already established a list of power plant projects, which should be built during the period 2011 to 2020. In total, 60 power plant projects were programmed, including 27 photovoltaic, to connect the north network, six solar thermal and seven wind generation plants. In addition to these plants, Algeria has also included targets related to CSP, for the second period.

In addition to these RE targets, some energy efficiency targets are also included in the National Program in order to reduce GHG emission and energy consumption by 7% and 9%, respectively. These targets mainly refer to three sectors: the building, transport and industry sectors.

Finally, the industry sector is meant to contribute to help realize the programme. Basically, the industry sector will benefit from helping to realize the energy audits, which help organizations better manage their energy use, leading to improved productivity and therefore to achieving the energy management system. Likewise, it is worth noting that the national RE program also aims to promote technology and to adopt measures to help rationalize the endogenous consumption of electricity, increase the energy savings, and consequently decrease the energy losses, because the latter are estimated at 20%.

The renewable energy program will be contributed to the achievement of several future goals, which are listed below:

II. 3. 1. PV solar energy programme

The energy strategy of Algeria is based on the acceleration of the development of solar energy. The government plans launching several solar photovoltaic projects with a total capacity of 800 MWp by 2020 [26]. Other projects with an annual capacity of 200 MWp are to be achieved over the 2021–2030 period. PV industrial integration is expected to reach 60% over the period 2011–2013. This ambitious target will be achieved through the construction by ‘‘Rouiba-Eclairage’’, a subsidiary of the Sonelgaz Group, of a photovoltaic module manufacturing plant with a capacity equivalent to 120 MWp/per year, whose start up is scheduled for late 2013. the RE programme aims to reach a rate of integration upper to 80%. Therefore, the production capacity of the PV modules should be expanded to reach 200 MWp/per year.

On account of its geographical location, Algeria holds one of the highest solar potentials in the in the entire Mediterranean basin447 where an estimated at 169.440 TWh/year and the Average daily solar energy potential ranges between 1.700 to 2.650. In fact, Algeria has enormous natural potential in this area because it has one of the largest solar power sources in the world. Belt countries, Indeed, it plans to invest heavily in solar power plants, especially it has an enormous potential for the production and export of solar energy as it receives bright sunlight for more than 3000 hours per year.

One of the most important projects is the completed project in Hassi Messaoud, where the Spanish companies have set up a hybrid plant to produce electricity, which combines sun and gas in the pioneering experience of the NEAL branch (Algeria for the New Energy). The project cost has amounted to 315.8 million euros for the production of about 15 MW. Thus, the Sonalgaz Foundation has also been able to provide 1,000 households in 20 villages in the southern Algerian states with solar electricity, see Fig. 1. Moreover, the Algerian government is seeking to establish new plants for the production of solar energy under the framework of the scheme approved by its members in February 2016. The scheme sets out the terms of the announcement of the national and international auction for the production and distribution of 4000 MW of electricity, through solar energy.

The National Program for Renewable Energy, which has been approved by the Council of Ministers in February 2011, includes the gradual application of alternative energies, especially thermal and photovoltaic solar energy in the production of electricity over the next twenty years, Fig. 16 shows an overview of distribution of Solar thermal power plants.

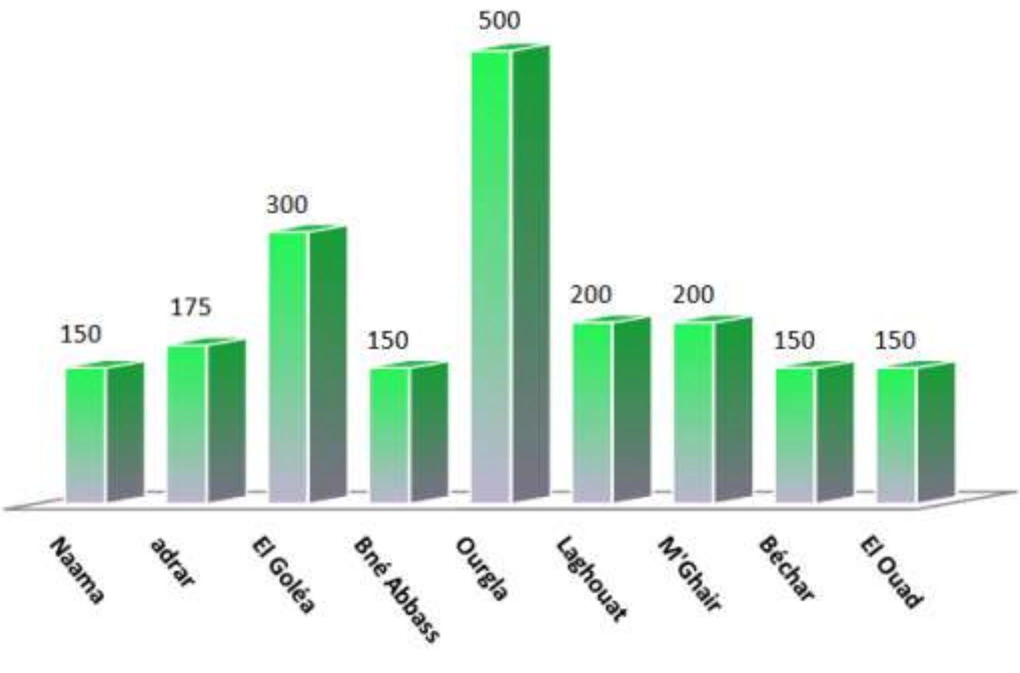

Figure 5: Distribution plan of solar thermal power plants in MW

II. 3. 2. CSP programme

Algeria seeks to develop its solar potential, which is one of the most important in the world, by launching major projects in solar thermal. Pilot projects for the construction of two solar power plants with storage of a total capacity of about 150 MW each, will be launched during the 2011–2013 period. These will be in addition to the hybrid power plant project of Hassi R'Mel with a total power capacity of 150 MW, including 25 MW in solar. Four solar thermal power plants with a total capacity of about 1200 MW are to be constructed over the period 2016–2020. The 2021–2030 plan to tap its large solar potential is to provide the installation of an annual capacity of 500 MW until 2023, then 600 MW per year until 2030.

In addition, the rate of integration, over the 2021–2030 period, should exceed 80% through the implementation of the following projects: Expansion of mirror production capacity. Expansion of heat transfer fluid and energy storage equipment production capacity. Expansion of power blocks equipment production capacity. Design, procurement and construction of power plants by own means.

II. 3. 3. Wind energy programme

Algeria has set a programme plans at first, in the period 2011– 2013, the installation of the first wind farm of a power of 10 MW in Adrar. Between 2014 and 2015, two wind farms with a capacity of 20 MW each are to be developed. Studies, by Sonelgaz, will be led to detect suitable sites to realise the remaining planned projects during the period 2016–2030 for a total goal power of about 1,700 MW. Studies are to be launched by 2013 with a view to implement wind energy industry. The objective for the 2014– 2020 period is to attain an integration rate of 50%[27]. This period will be marked by the following actions:

Development of a wind tower and turbine rotors production plant.

Promotion of a national subtracting network for the manufacturing of the nacelle equipment.

Development of engineering activities and design, procurement and construction capabilities to enable Algerian companies to achieve an industrial integration capacity rate of at least 50%.

The rate of industrial integration is to exceed 80% over the 2021–2030 period with the expansion of wind tower and turbine rotors production capacity and the development of a national subcontracting network for manufacturing the nacelle equipment. There are also plans to design and build wind farms, power plants and brackish water desalination plants using Algeria's own resources[16].

The wind power branch has allocated a capacity of 27 megawatts, where the locations of these stations will be in the Algeria's south but appear to be accomplished in the province of Adrar, (see Fig. 18).

Figure 6: Wind power plant is located at Kabertene, Adrar

Although, the major share of interest is at the moment directed to solar energy, the wind fields in Algeria have been studied in order to determine their wind speed rates and to estimate their eligibility to receive wind-driven power plants instead of diesel-powered power plants Fig. 19 provides an overview to wind farms projects could be set up.

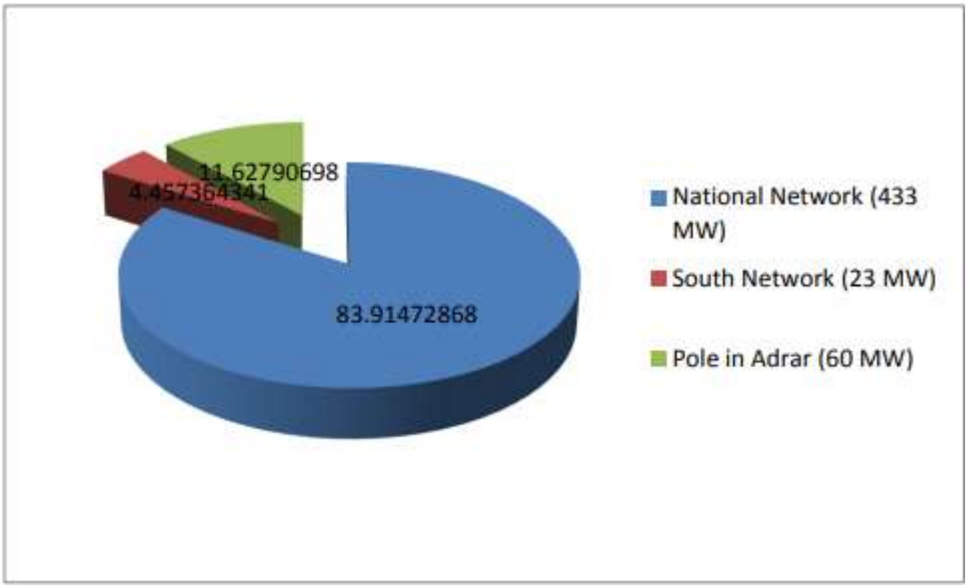

Figure 7: Plan of Distribution of Wind power plants in the Algerian Great

II.3.4. Other Energies

In Algeria, there are more than 200 hot sources in the north of the country. Three of them are considered the important spots for exploiting the groundwater energy, where the temperature of these three sources exceeded more than 45 degrees to reach a temperature of 98 degrees Centigrade in the Hammam Meskhoutine in the province of Guelma, 118 Centigrade in Aïn Oulmene and 119 Centigrade in Biskra. Algeria has good biomass energy potential in the form of solid wastes, crop wastes and forestry residues. Solid waste is the best source of biomass potential in the country. According to the National Cadastre for Generation of Solid Waste in Algeria452, annual generation of municipal wastes is more than 10 million tons. Solid wastes are usually disposed in open dumps or burnt wantonly.

II. 3. 4. Regulation (Legislative Framework)

The RE related legislation has been intensified. The cornerstone of Algeria's legislation on electricity from renewable sources is the law on the utilisation of RE resources for the purpose of generating electricity, enacted in August 2004.

The legislative framework is designed to encourage investment in RE and energy efficiency, and to protect the environment. Some of laws are cited below:

Law No. 04/09 issued on 14 august 2004, the law is linked to establish a National Programme for the promotion of Renewable Energy (RE), until 2020.

Law n 09/09 issued on 30 December 2009 finance act 2010, these laws are linked to create a national fund for renewable energy (FNER), budget of that fund come from licence fee of oil industry, estimated about 1 %, it also comes from other contributions

Decision D/14-15/ CD issued on 17 may 2015, establishing the standard models of power purchase agreement for solar PV and wind and benefiting from the feed-in tariffs.[25]

II.3.4. Promotion of the Scientific Research in the field of Renewable Energy

Algerian scientists perform research to make of renewable energies a true catalyst for the development of a green economy that will increase the value of the different Algerian potentials (human, physical, scientific, etc.).

This section of the study is devoted to scientific research, the role of research is even more crucial that it is a critical element in the acquisition of technologies, the development of know-how and the improvement of the energy performance. Today's Ministry of Higher Education & Scientific Research has a large number renewable energy laboratories for the great big universities throughout the country and specialized research centres working in that field. In addition to the research centres affiliated to companies such as those listed in Table 3.

Acronym	Info
CDER	Center for Renewable Energy Development is responsible for developing and implementing programs of scientific and technological research and development of systems using solar, wind, geothermal and biomass energies
CREDEG	Research and Development Center, which is a subsidiary of Sonelgaz, the energy and mining sector has an Agency for the Promotion and Rational Use of Energy (APRUE).
UDTS	Silicon Technology Development Unit conducts scientific research, technological innovation and advanced and post-graduation training activities in the sciences and technologies of semiconductor materials and processes applied to several areas including photovoltaics, detection, optoelectronics, photonics and energy storage.
IAER	Algerian Institute for Renewable Energies and Energy Efficiency, which play a key role in training efforts deployed by the country and ensures quality development of renewable energies In Algeria.
LCI	Intelligent central laboratory, which is a subsidiary of sonatrach and ENI

Table 3: Table 2: Algerian research centers

II. 4. Conclusion

Algeria is situated in a vital area of the world, it represents one of the countries with a significant sun powered belt nations, with a gigantic potential in solar energy. The exploitation and promotion of these energy resources offer the chance of handling energy related and monetary difficulties, and to add to a feasible improvement in our nation, that has increased recently a strong interest in renewable resources and clean energy production.

General Conclusion

General Conclusion

Algeria has introduced laws and regulations aimed at promoting renewable energy (RE) to introduce an effort for restraining energy demand and improve environmental conditions either in private or public sector. So it is essential in education to learn and make public conscious of energy efficiency and conservation. The implementation of various projects allows Algeria to play an important role not only in the Maghreb countries but also in the Europe.

Within its policy of climate and environment protection, the Algerian government fully supports the objective of the Concentrating Solar Power (CSP), Global Market Initiative (GMI) to build a number of power plants with a total capacity of 5000 MW of CSP worldwide and, secondly, to construct two power system interconnection cables (Algeria–Spain and Algeria–Italy) with an import/export capacity of 1200 MW. Meanwhile, both Algeria and the private sector are aware of Europe's commitment to renewable energy sources, in particular the European Union's aim to have 12% of renewable energy by 2010.

The population distribution in Algeria also shows that there is a great potential market for renewable energies, among which solar energy should be highlighted because of its presence throughout the entire region.

As a conclusion, efforts should increase because of the ever-growing concern regarding environment friendly sources of energy. It is now important to educate the public as well as to introduce special energy legislation to increase the usage of this clean form of energy whether in private or public sectors and show the importance of energy efficiency and conservation.

References

References

[1] G. Li, "Sensible heat thermal storage energy and exergy performance evaluations," *Renew. Sustain. Energy Rev.*, vol. 53, pp. 897–923, 2016, doi: 10.1016/j.rser.2015.09.006.

[2] "Thermal Energy Storage: Systems and Applications - Ibrahim Dincer, Marc Rosen - Google Livres." https://books.google.dz/books?hl=fr&lr=&id=EsfcWE5lX40C&oi=fnd&pg=PA1&ots=7YYt2RCxwy&sig=Dm-G0Xc6pQLQX-OsYq3x4YpRup4&redir_esc=y#v=onepage&q&f=false (accessed Aug. 10, 2020).

[3] S. D. Sharma and K. Sagara, "Latent Heat Storage Materials and Systems: A Review," *Int. J. Green Energy*, vol. 2, no. 1, pp. 1–56, 2005, doi: 10.1081/ge-200051299.

[4] C. Sunliang, "State of the Art Thermal Energy Storage Solutions for High Performance Buildings," p. 201, 2010.

[5] International Electrotechnical Commission, "Electrical Energy Storage," *Int. Electrotech. Comm.*, 2011.

[6] P. Nikolaidis and A. Poullikkas, "Journal of power technologies.," *J. Power Technol.*, vol. 97, no. 3, pp. 220–245, 2011, [Online]. Available: http://papers.itc.pw.edu.pl/index.php/JPT/article/view/1096/776.

[7] J. Sarkar and S. Bhattacharyya, "Application of graphene and graphene-based materials in clean energy-related devices Minghui," *Arch. Thermodyn.*, vol. 33, no. 4, pp. 23–40, 2012, doi: 10.1002/er.

[8] K. K. Zame, C. A. Brehm, A. T. Nitica, C. L. Richard, and G. D. Schweitzer, "Smart grid and energy storage: Policy recommendations," *Renew. Sustain. Energy Rev.*, vol. 82, no. July, pp. 1646–1654, 2018, doi: 10.1016/j.rser.2017.07.011.

[9] B. P. Roberts and C. Sandberg, "The role of energy storage in development of smart grids," *Proc. IEEE*, vol. 99, no. 6, pp. 1139–1144, 2011, doi: 10.1109/JPROC.2011.2116752.

[10] Z. Yu, F. Haghighat, B. C. M. Fung, and H. Yoshino, “A decision tree method for building energy demand modeling,” *Energy Build.*, vol. 42, no. 10, pp. 1637–1646, 2010, doi: 10.1016/j.enbuild.2010.04.006.

[11] R. Latha, S. Palanivel, and J. Kanakaraj, “Frequency control of microgrid based on compressed air energy storage system,” *Distrib. Gener. Altern. Energy J.*, vol. 27, no. 4, pp. 8–19, 2012, doi: 10.1080/21563306.2012.10554219.

[12] G. D. Rodriguez, “A utility perspective of the role of energy storage in the smart grid,” *IEEE PES Gen. Meet. PES 2010*, pp. 4–5, 2010, doi: 10.1109/PES.2010.5589870.

[13] E. Transitions, “Technologies of Engagement : How Battery Storage,” pp. 1–15, 2019.

[14] Djalel Dib Université de Tébessa, “Renewable Energy and Energy Efficiency Program in Algeria (Investigation and Perspectives),” no. May 2012, 2017.

[15] S. Pahlavan, M. Jahangiri, A. A. Shamsabadi, A. Khechekhouche, F. Author, and S. Author, “Journal of Solar Energy Research (JSER),” vol. 3, no. 2, pp. 135–146, 2018.

[16] A. B. Stambouli, Z. Khiat, S. Flazi, and Y. Kitamura, “A review on the renewable energy development in Algeria: Current perspective, energy scenario and sustainability issues,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 7, pp. 4445–4460, 2012, doi: 10.1016/j.rser.2012.04.031.

[17] “Solar resource maps and GIS data for 200+ countries | Solargis.” https://solargis.com/maps-and-gis-data/download/algeria (accessed Aug. 18, 2020).

[18] T. M. Khouildat salah, Zaid Mourad, “Tendances et politiques des énergies renouvelables en Algérie entre réalité et futurs programmes cruciaux,” *Dev. Appl. Econ.*, vol. 01, no. 03, p. 292, 2018.

[19] CDER, “A new wind atlas of Algeria - Renewable Energy Development Center Algeria.” https://www.cder.dz/spip.php?article3585 (accessed Aug. 18, 2020).

[20] A. Bouraiou, A. Neçaibia, N. Boutasseta, and S. Mekhilef, "Status of Renewable Energy Potential and Utilization in Algeria Abstract :," 2019, doi: 10.1016/j.jclepro.2019.119011.

[21] H. Saibi, "Geothermal resources in Algeria," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9. Pergamon, pp. 2544–2552, Dec. 01, 2009, doi: 10.1016/j.rser.2009.06.019.

[22] "Biomass explained - U.S. Energy Information Administration (EIA)." https://www.eia.gov/energyexplained/biomass/ (accessed Oct. 04, 2020).

[23] "Biomass Energy Basics | NREL." https://www.nrel.gov/research/re-biomass.html (accessed Oct. 04, 2020).

[24] "Renewable Energy in Algeria | EcoMENA." https://www.ecomena.org/renewables-algeria/ (accessed Oct. 04, 2020).

[25] H. Brahim, P. Ferreira, and A. Djebli, "RENEWABLE ENERGY SURVEY IN ALGERIA : POLICIES AND PERSPECTIVES RENEWABLE ENERGY SURVEY IN ALGERIA : POLICIES AND," no. July 2020, 2019.

[26] "Algeria adopts renewable energy development plan | Enerdata." https://www.enerdata.net/publications/daily-energy-news/algeria-adopts-renewable-energy-development-plan.html (accessed Aug. 19, 2020).

[27] F. Chellali, A. Khellaf, A. Belouchrani, and R. Khanniche, "A comparison between wind speed distributions derived from the maximum entropy principle and Weibull distribution. Case of study; Six regions of Algeria," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1. Elsevier Ltd, pp. 379–385, 2012, doi: 10.1016/j.rser.2011.08.002.