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Khedir Med Sofiane & Yazi Messaoud

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Study and simulation of a standalone house powered by renewable energies and assisted by hydrogen production and storage

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In front of the jury:

Mr.	Charrad Nourdinne	President	University KasdiMerbah Ouargla
Mr.	Ballhia Hocine	Examiner	University KasdiMerbah Ouargla
Mr.	Dokkar Abdelghani	Mentor	University KasdiMerbah Ouargla

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Abstract

To reduce the emissions of polluted gases caused by producing energy using fossil fuels, renewable energies can be an attractive solution, particularly in remote areas. However, some problems appear with using renewable energies which can minimize their benefits, such those related to weather conditions and daylight limitation. This work is study and simulation of the energy system for a standalone house powered by renewable energies systems such as, photovoltaic system and wind turbine. The electricity produced and not used by the user will be accumulated in two different storage systems: a battery bank and a hydrogen storage system to reuse it when required. The main objective of this work is to reach the optimal sizing of the energy system, as a result, maximize the ability to respond to energy demand and minimize the investment cost.

Keywords: Renewable energy, Hybrid system, Hydrogen, optimal sizing

Résumé

Pour réduire les émissions de gaz pollués causées par la production d’énergie des combustibles fossiles, les énergies renouvelables peuvent être une solution attrayante. Toutefois, certains problèmes apparaissent avec l’utilisation des énergies renouvelables qui peuvent réduire au minimum leurs prestations, telles celles liées aux conditions météorologiques et à la limitation de la lumière du jour. Ce travail est l’étude et la simulation du système d’une maison autonome alimenté par des systèmes d'énergies renouvelables telles que les panneaux photovoltaïque et éolienne. L’électricité produite et non consommée par le toxicomane s’accumuleront dans deux systèmes de stockage différents : un groupe de batteries et un système de stockage d’hydrogène pour la réutiliser au besoin. L’objectif principal de ce travail consiste à atteindre le dimensionnement optimal du système énergétique, par conséquent, de maximiser la capacité de répondre à la demande d’énergie et de réduire au minimum le coût de l’investissement.

Mots-clés: Les énergies renouvelables, système Hybride, hydrogène, size optimal

ملخص

للحد من انبعاثات الغازات الملوثة الناجمة عن إنتاج الطاقة من الوقود الأحفوري، الطاقة المتجددة يمكن أن يكون حلاً جذاباً. ومع ذلك، تظهر بعض المشاكل باستخدام مصادر الطاقة المتجددة التي يمكن التقليل إلى أدنى حد من فوائدها، مثل تلك المتصلة بالأحوال الجوية والحد من ضوء النهار. وسوف يكون هذا العمل دراسة ومحاكاة نظام الظروف التشغيلية لمنزل مستقل مدعوم من مصادر الطاقة المتجددة مثل الطاقة الكهربائية الضوئية, وطاقة الرياح. سوف تتراكم الكهرباء المنتجة وغير المستخدمة من قبل المستخدم في أنظمة تخزين مختلفة اثنين: بنك بطارية ونظام تخزين هيدروجين إعادة استخدامها عند الحاجة. الهدف الرئيسي لهذا العمل هو الوصول إلى الحجم الأمثل لنظام الطاقة، وكنتيجة لذلك، وزيادة القدرة على الاستجابة للطلب على الطاقة، والتقليل من تكلفة الاستثمار.

الكلمات المفتاحية: الطاقة المتجددة، النظام الهجين، الهيدروجين، التحجيم الأمثل

Summary

Chapter1 : Renewable energies used in small units

Chapter 2 : Hydrogen techniques

Chapter3 :Modeling and methods

Chapter 4 : Results and discussions

Nomenclature

Symbols	Definition	Unite
Cb	Storage capacity of the battery	Wh
Cele	initial cost of electrolyze	$
Cg	global cost	$
Cinv	initial cost of the invert	$
Cstok	initial cost of storage	$
Cpem	initial cost of fuel cell	$
Cpv	initial cost of the photovoltaic	$
Cwt	initial cost of the wind turbine	$
dvsys	Life of the system years	Year
dvwt	Life of the wind turbine	Year
dvpv	Life of the photovoltaic	Year
dvinv	Life of the inverter	Year
dvb	Life of the battery	Year
dvstok	Life of the tank	Year
E_{ch}	load demand	Wh
Eg	total energy generated by PV array and wind generators	Wh
E_{elect}	Power electrolyze	Wh
Epv	Photovoltaic energy	Wh
Ew	Wind turbine energy	Wh
DOD	depth of discharge of the battery	%
G^t	Hourly irradiance	Wh/m^2
m_{stok}	mass of the hydrogen	Kg
NOCT	Nominal cell operating temperature	(°C)
Npv	Number of panel Photovoltaic	
Pg	power developed by the WT and PV	Wh
Pr	rated power of wind turbine	W
P_{pv}	power photovoltaic	W
P_{WT}	power wind turbine	Wh
S_{pv}	Solar cell array	m^2

T_{cref}	reference cell temperature	(°C)
T_c	Cell temperature	(°C)
T_a	Ambient temperature	(°C)
T_{cref}	reference cell temperature	(°C)
V	Wind speed	m/s
Vr	nominal speed	m/s
Vcut-out	cut-out wind speed	m/s
Vdata	wind speed at the height of the measurements	m/s
Z	the surface roughness length	m
η_{pv}	PV generator efficiency	%
η_{pc}	Power conditioning efficiency	%
η_r	Reference module efficiency	%
ηB	battery bank efficiency	%
ηinv	Inverter efficiency	%
β	Efficiency temperature coefficient	%
σ	self-discharge rate	%
α	power law exponent	

Acronyms

AIE	**A**gency **I**nternational **E**nergy
LCC	**L**ife **C**ycle **C**ost
PV	**P**hoto**v**oltaic
WT	Wind turbine
PEM	polymer electrolyte membrane
WB	World Bank

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Introduction

Energy demand increases exponentially due to the growth in industry and population. The International Energy Agency (IEA) forecasts that the global demand for energy is expected to increase 53% by 2035 (IEA, 2014). For this reason the World Bank (WB) and IEA estimate doubling in installed capacity of energy over the 4 following decades. Conventional energy sources includes oil, gas and coal are the main resources for world energy supply, however these fossil energies have several disadvantages, such as greenhouse gas (CO_2, CFC gases) .

Furthermore, more than a billion of people in the world live without electricity, a lot of them in isolated areas, which are not connected to electric network (off-grid). Due to high investment costs for expanding the public grids and low power requirements, it would be uneconomical to connect these remote areas to the utilities in the medium run. Under these circumstances, Variable Distributed Generation (DG) presents an attractive alternative to avoid technical and economic problems in electricity transmission to remote regions. The usually diesel generators used to overcome the local energy needs in such regions are facing several constraints such as instability in fuel prices, fuel supply, besides the relative high costs of operation and maintenance. Hence, renewable resources are becoming more suitable in providing energy to remote regions.

The excellent geographical location of Algeria gives several advantages for extensive use of most of the renewable energy resources. Algeria is the largest country in Africa, with a surface nearly 2.4 million km². Most of this surface is occupied by the Sahara.

Renewable sources are usually free of pollution. The Integration of renewable energies with efficient storage system would provide a better system reliability making it suitable for remote stand-alone applications. (Granqvist,1999)

Among these sources, Solar and wind energy are the most abundant natural resource in Algeria. It becomes imperative for Algeria to exploit these important resources. Combine between these sources, can be intrusting and attractive solution to supply isolated houses, army, rural farm, and telecommunication unites. For example, mobiles phone operators companies seek to extend their markets in remote areas. So, they must solve the problem of electricity supply in cost-effective way (Dokkar, 2016).

Renewable energies such as hydrogen is a promising energy carrier for the future energy supply, it benefits as an environmentally friendly, versatile, and efficient fuel. The transition to renewable energy based hydrogen systems appears to be an interesting solution and provides an opportunity to address the challenges. Especially production by using solar and wind, to meet needs from remote standalone. Today Attention around the world has focused reach the optimal sizing of the energy system maximize the ability to respond to energy demand and minimize the investment cost.

We have divided the project into four chapters, the first chapter is a general description of renewable energies, particularly, solar, wind and hybrid system, and their use in small units. The aim of the second chapter is to explore the different ways of hydrogen production, focusing on water electrolysis using renewable energies, Also The technique that use to store hydrogen as either gas, liquid or solid. In addition to produce electricity (DC) by electro-chemical reactions in fuel cell, we study a scenario of using hydrogen directly as cooking gas.

In the third chapter, we show weather data of solar and wind, and calculate loads of a stand-alone house based on the work of (R. Ghedamsi ET al.2016), then, we present the mathematical models of the different electric components.

Finally, in the fourth chapter, we developed a program of Matlab to simulate and determine the optimal component sizes in technical and economic point of view, and demonstrate and discuss the results.

Chapter 1: Renewable energies and small scale use

Renewable energy sources have been important for humans since the beginning of civilization. Biomass has been used for heating, cooking, steam rising. Solar also has been used for heating and drying food. Hydropower and wind energy have been utilized for movement of boats and milling turbines. Renewable energy sources generally depend on energy flows through the Earth's ecosystem from the isolation of the sun and the geothermal energy of the Earth.

Furthermore, many renewable technologies are suited to small off-grid applications, good for rural, remote areas, where energy is often crucial in human development. At the same time, such small energy systems can contribute to the local economy and create local jobs.

1.1. Solar Energy

The earth obtains solar energy from the sun. In one hour, the earth receives enough solar energy to meet its energy needs for nearly a year. Generally, there are two main types of using solar energy; solar thermal and photovoltaic.

1.1.1. Solar Thermal

Concentrated Solar Power (CSP) systems (also known as thermal solar power systems) do not directly convert sunlight into electricity like PV panels. These systems consist of an array of mirrors or lenses that focus the sun rays onto a thermal receiver. The concentrated energy is used to heat water, and the resulting steam is used to drive turbines which generate electricity (N REL, 2014).Solar collectors may also be used for hot water production and heating during the cold season. The overall performance of a solar cooling system is therefore of a great.

1.1.2. Photovoltaic Panels

Photovoltaic is the direct conversion of sunlight to electricity. It is an attractive alternative to conventional sources of electricity for many reasons: it is safe, silent, and non-polluting, renewable, highly modular in that their capacity can be increased incrementally to match with gradual load growth, and reliable with minimal failure rates and projected service lifetime is of 20 to 30 years (R.A. Messenger.2003). Figure 1.1.

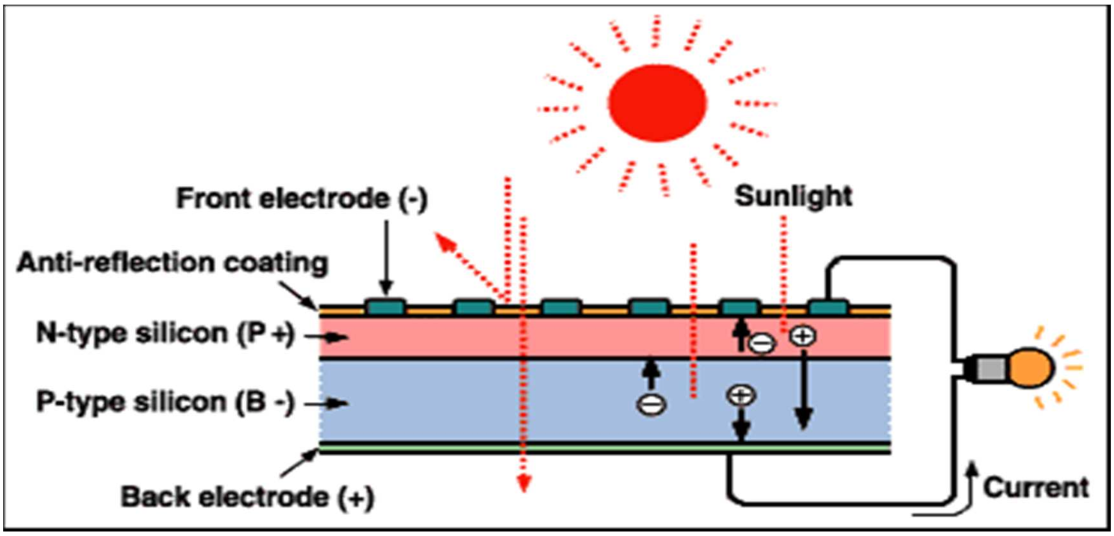


Figure1.1: convert sunlight to electricity

1.1.3. Different Panel type technology

A. Monocrystalline

Monocrystalline silicon panels are made of the highest-grade silicon, making them the most efficient type of panel. These panels convert 15-20 percent of incoming sunlight into electricity. Because monocrystalline panels are the most efficient type, they require the least surface area per unit of energy produced. They are the most expensive panel type (RRE, 2015)

B. Polycrystalline

Polycrystalline silicon panels contain lower-grade silicon than monocrystalline panels. The panels are less efficient than monocrystalline panels, converting only 13-16 percent of incoming sunlight into electricity. These panels require a larger surface area to generate the same amount of electricity produced by monocrystalline panels. (RRE, 2015)

C. Thin-film PV

Thin-film solar cells consist of one or more ultra-thin light-absorbing layers. The thin-film manufacturing process is simpler than the monocrystalline or polycrystalline manufacturing process but results in panels with lower electricity conversion rates that range from 7-13 percent. Because of these lower conversion rates, even more surface area is needed to achieve the same energy generation as either of the other panel types. Thin-film solar cells are the cheapest PV panel system (Maehlum, 2015).

1.1.4. Investment Cost:

Solar is a more expensive electricity source than traditional alternatives like coal or natural gas. Cost estimates for electricity production are typically given in the form of a Levelized Cost of Electricity (LCOE), which measures a power plant's average costs over its lifetime, including its construction, fuel, operations, maintenance, and efficiency. Solar power plants may have zero fuel costs, but their electricity still comes at a high price compared to other electricity sources when lifetime costs are taken into consideration. (EI Administration. 2015). There are many companies that consider as leaders in manufacturing solar panels. In this study we chose Polycrystalline - (250W) Table 1.1

Table1.1: Specifications of PV panel

Parameters	Value
Type	NMC CHSM6610P ‘’ Polycrystalline”
Nominal peak power	250(W)
Reference efficiency (%)	14
Dimensions (L x W x H)	1652 x 994 x 45 mm
Life time	20 year
Cost	200 $

1.2. Wind Energy

Wind is a form of solar energy. The irregular heating of Earth's atmosphere by the Sun causes the air mass to move from regions of high pressure to regions of lower pressure. The kinetic energy of the moving air "wind energy" can be transformed directly into mechanical or electrical energy using wind turbines. (Journal, 2017)

1.2.1. Wind turbine

By definition, wind energy is the energy produced by wind. It is the result of the action of wind turbines, wind-driven electrical machines and whose function is to produce electricity.

Blades pulled in rotation by the strength of the wind allow the mechanical or electric power production in any sufficiently windy site. The energy that the mill rotating pulls out of the wind drives the rotor which converts mechanical energy into electrical energy through a generator. (Journal, 2017)

The amount of energy produced by a wind turbine depends primarily on the speed of wind but also on the area swept by the blades and the air density.

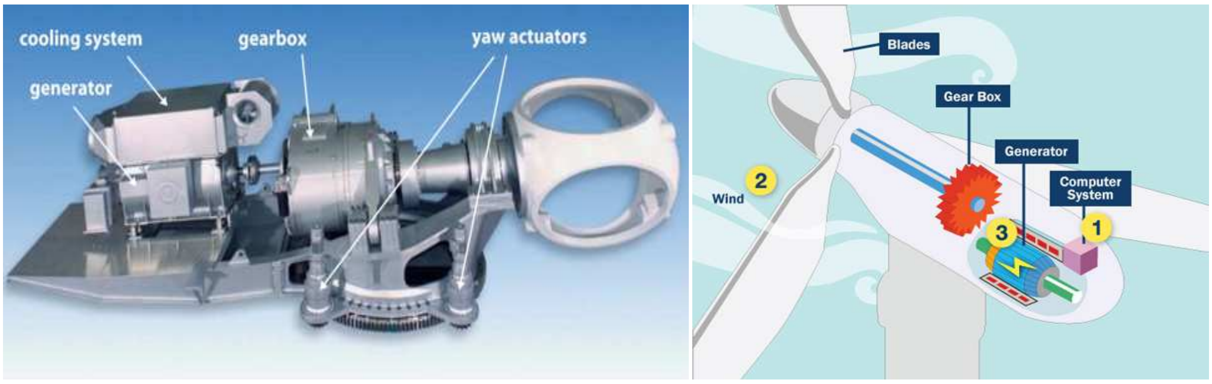


Figure1.2: the basic components wind

The figure1.2 above shows the basic components that go to make up a typical wind turbine design. A wind turbine extracts the kinetic energy from the wind by slowing the wind down, and transferring this energy into the spinning shaft so it is important to have a good design.

-Rotor blades: The rotor blades are the elements of the turbine that capture the wind energy and convert it into a rotational from.

-Hub: The hub is the connection point for the rotor blades and the low speed shaft.

-Gearbox: The gearbox takes the rotational speed from the low speed shaft and transforms it into a faster rotation on the high-speed shaft.

-Mechanical brake: The mechanical brake is a physical brake, similar to a disc brake on the wheel of a car, connected to the high-speed shaft. It is used for servicing the equipment to ensure that no components start to rotate, endangering the repair worker.

-Generator: The generator is connected to the high-speed shaft and is the component of the system that converts the rotational energy of the shaft into an electrical output.

-Cooling system: The cooling system is used to ensure that the components do not overheat and cause damage to themselves or any other component. A typical cooling system is either an electrical fan or a radiator system.

-Yaw mechanism: The yaw mechanism is used to ensure that the rotor blades are parallel to the flow of the wind, to be at their most efficient.

-Controller: The controller is a computer system that monitors and controls various aspects of the turbine. It has the ability to shut down the turbine if a fault occurs.

-Tower: The tower is used to support the nacelle and rotor blades.

-Nacelle: The nacelle is the unit located at the top of the tower that encapsulates all the components of the turbine.

1.2.2. Classifying wind turbines

Modern turbines evolved from the early designs and can be classified as two or three-bladed turbines with horizontal axes and upwind rotors. Today, the choice between two or three-bladed wind turbines is merely a matter of a trade-off between aerodynamic efficiency, complexity, cost, noise and aesthetics. (Wind Power, 2009)

A- Horizontal axis wind turbine

Horizontal axis wind turbine dominates the majority of the wind industry. Horizontal axis means the rotating axis of the wind turbine is horizontal, or parallel with the ground. In big wind application, horizontal axis wind turbines are almost all you will ever see. However, in small wind and residential wind applications, vertical axis turbines have their place. The advantage of horizontal wind is that it is able to produce more electricity from a given amount of wind. So if you are trying to produce as much wind as possible at all times, horizontal axis is likely the choice for you. The disadvantage of horizontal axis however is that it is generally heavier and it does not produce well in turbulent winds. (Wind power, 2009)

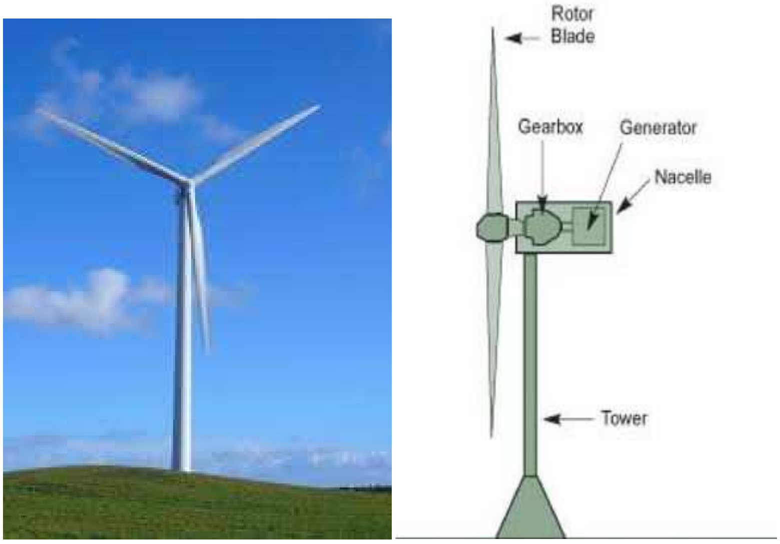


Figure1.3: Horizontal axis wind turbine

B- Vertical axis wind turbine

In comes the vertical axis wind turbine. With vertical axis wind turbines the rotational axis of the turbine stands vertical or perpendicular to the ground. As mentioned above, vertical axis turbines are primarily used in small wind projects and residential applications. Vertical-Axis-Wind-Turbine this niche comes from the OEM’s claims of a vertical axis turbines ability to produce well in tumultuous wind conditions. Vertical axis turbines are powered by wind coming from all 360 degrees, as u shown in this Figure. Even some turbines are powered when the wind blows from top to bottom. Because of this versatility, vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind. (Wind power, 2009)

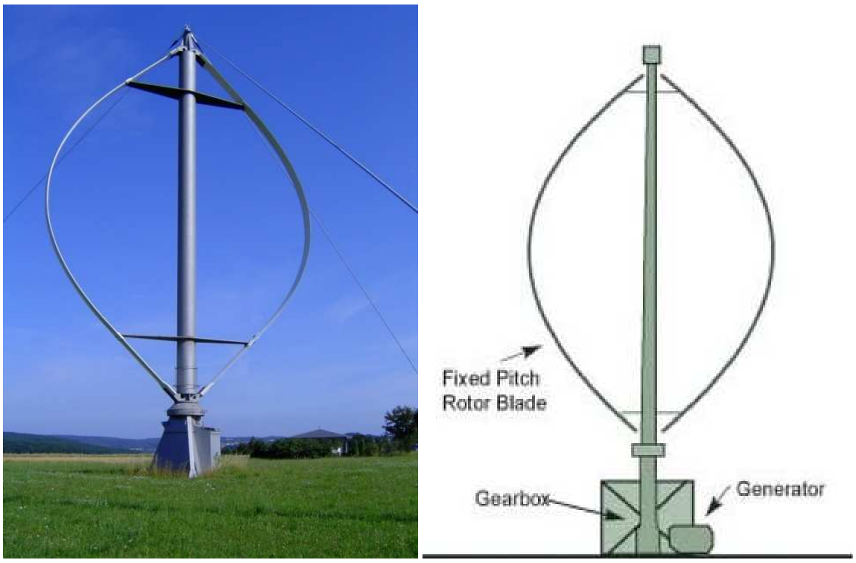


Figure1.4: Vertical axis wind turbine

1.2.3. Number of rotor blades

The three-bladed concept is the most common concept for modern wind turbines. A turbine with an upwind rotor, an asynchronous generator and an active yaw system is usually referred to as the Danish concept. This is a concept, which tends to be a standard against which other concepts are evaluated.

Relative to the three-bladed concept, the two and one-bladed concepts have the advantage of representing a possible saving in relation to the cost and weight of the rotor. However, their use of fewer rotor blades implies that a higher rotational speed or a larger chord is needed to yield the same energy output as a three-bladed turbine of a similar size. These of one or two blades will also result in more fluctuating loads because of the variation of the inertia, depending on the blades being in horizontal or vertical position and on the variation of wind speed when the blade is pointing upward and downward. Therefore, the two and one bladed concepts usually have so-called teetering hubs, implying that they have the rotor hinged to the main shaft. This design allows the rotor to teeter in order to eliminate some of the unbalanced loads. One-bladed wind turbines are less widespread than two-bladed turbines. This is due to the fact that they, in addition to a higher rotational speed, more noise and visual intrusion problems need a counterweight to balance the rotor blade. (DNV/Risø.2002)

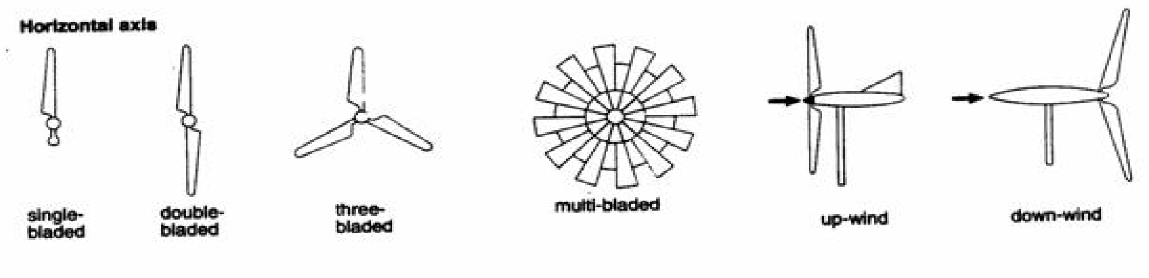


Figure1.5: design and concept using blades

1.2.4. International wind turbines manufacturers

Table1.2 presents the main manufacturers of wind turbines and their specifications (Wind Energy Center, 2015). In this study we focus on small turbine sizes.

Table1.2: Wind turbines specification

Types	Rated power (KW)	Cut-in wind speed m/s	Rated wind speed m/s	Cut-off wind speed m/s	Turbine Diameter (m)	Hub height(m)
FLYT F-1000	1	2.5	8	45	2,8	30
FLYT F-1001	1	2.5	10	45	2,8	30
FLYT FK-2000	2	2.5	8	40	3,2	30
FLYT FK-2001	2	2.5	10	50	3,2	30
FLYT FK-3000	3	3	10	45	5,2	30
FLYT F-5K	5	3	10	40	6,1	30
Kingspan	6	3	10	45	6,5	30
MAX/XG-10KW	10	3.5	10	50	7,2	30
OEM HAWT	15	3.5	10	50	9	30

1.2.5. Investment Cost:

Compared to other renewable energies for domestic or business use, wind turbine costs vary considerably between manufacturers and installers. Our advice, first of all, is to make sure that this is the right technology for you.

The total project cost will depend on many factors, including the cost of the turbine itself, the extent and scope of supporting environmental work for the planning application, the cost of any electrical distribution network (‘grid’) upgrades and the cost of site works including access roads, foundation and cabling costs.(Renewable First.2015)

Table1.3: Cost of some wind turbine

Maximum Power Output (KW)	Typical Turbine Type	Cost($)
1	FLYT F-1000	750
1	FLYT F-1001	850
2	FLYT FK-2000	960
2	FLYT FK-2001	1000
3	FLYT FK-3000	1900
5	FLYT F-5K	3500
6	Kingspan	3278.7
10	MAX/XG-10KW	9000
15	OEM HAWT	13000

1.3. Inverter

This report focuses on DC to AC power inverters, which aim to efficiently transform a DC power source to a high voltage AC source, similar to power that would be available at an electrical wall outlet. Inverters are used for many applications, as in situations where low voltage DC sources such as batteries, solar panels or fuel cells must be converted so that devices can run off of AC power. One example of such a situation would be converting electrical power from a car battery to run a laptop, TV or cell phone. (Jim Doucet.2007)

1.3.1. DC and AC Current

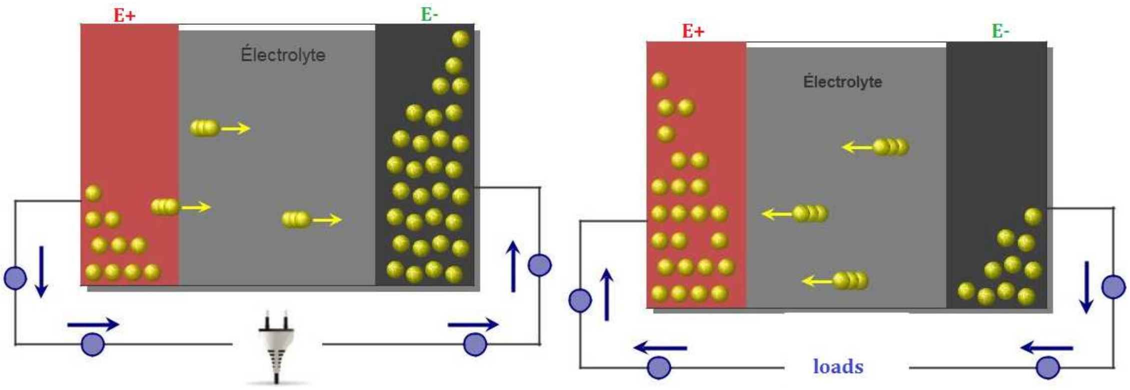
In the world today there are currently two forms of electrical transmission, Direct Current (DC) and Alternating Current (AC), each with its own advantages and disadvantages. DC power is simply the application of a steady constant voltage across a circuit resulting in a constant current. A battery is the most common source of DC transmission as current flows from one end of a circuit to the other. Most digital circuitry today is run off of DC power as it carries the ability to provide either a constant high or constant low voltage, enabling digital logic to process code executions. (Jim Doucet.2007).Table1.4 show the cost of the inverter

Table1.4: Cost of the inverter

Inverter	Cost ($)
ESG1000W	100
GP2022-12/24v-2kw	260
GP3022-12/24V-3kw	300
GP5032-12/48V-5kw	400
AN-PSW03-7000W	500
ARNB-1000VA	600

1.4. Battery Energy Storage

Battery Energy Storage is the most effective storage technology for rural electrification applications, and has already been implemented globally in numerous off-grid and mini-grid installations. The cathode (the positive part) is separated from the anode (the negative part) by a porous separator, and ions are allowed to flow between the two charges via an electrolyte. The chemical reaction creates current and voltage (which together create power) that can be supplied to a load (EPRI and DOE, 2013). In flow batteries, the electrolyte is stored in external tanks and is pumped through a central reaction unit. This consists of a cathode and anode through which a current is either taken in (charged) or supplied (discharged) to the external demand/supply this is by use.



Battery discharging Battery charging

Figure 1.6: Battery energy storage: charge/discharge

1.4.1. Batteries use classification

A- Starting batteries

(Sometimes called SLI, for starting, lighting, ignition) batteries are commonly used to start and run engines. Engine starters need a very large starting current for a very short time. Starting batteries have a large number of thin plates for maximum surface area. The plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. (N.ARIZONA, 2014)

B-Deep cycle batteries

Deep cycle batteries are designed to be discharged down as much as 80% time after time, and have much thicker plates. The major difference between a true deep cycle battery and others is that the plates are solid lead plates - not sponge. This gives less surface area, thus less "instant" power like starting batteries need. Although these can be cycled down to 20% charge, the best lifespan vs. cost method is to keep the average cycle at about 50% discharge. (N.ARIZONA, 2014)

1.4.2. Batteries types

There are many types of batteries, however the most available in the market are:

A) **Lead acid batteries** are made from a mixture of lead plates and sulfuric acid. This was the first type of rechargeable battery, invented way back in 1859.(N.ARIZONA, 2014)

B) **Lithium ion batteries** have only been around in a commercially viable form since the 1980′s.Lithium technology has become well proven and understood for powering small electronics like laptops or cordless tools, and has become increasingly common in these applications, edging out the older NiCad (Nickel-Cadmium) rechargeable battery chemistry due to lithium’s many advantages.(N.ARIZONA, 2014)

Table1.5: Comparison between lead acid batteries and lithium battery

Lithium batteries	Advantages: 1-High specific energy and high load capabilities with Power Cells 2-Long cycle and extend shelf-life; maintenance-free 3-High capacity, low internal resistance, good efficiency 4-Short charge times
	limitations: 1-Requires protection circuit to prevent thermal runaway if stressed 2- Degrades at high temperature and when stored at high voltage 3- Transportation regulations required when shipping in larger quantities
Lead acid batteries	Advantages: 1-inexpensive and simple to manufacture; low cost per watt-hour 2-Low self-discharge; lowest among rechargeable batteries 3-Good in high temperature performance

	Limitations: 1-Low specific energy; poor weight-to-energy ratio 2-Slow charge; fully saturated charge takes 14-16 hours 3-Limited cycle life; repeated deep-cycling reduces battery life 4-Flooded version requires watering 5-Not environmentally friendly

Table1.6: Specifications of battery

Parameters	Value
Types	Lead acid battery deep cycle. 12v 200Ah DOD 50% Maintenance Free
Size:	520*240*214 mm
The self –discharge	3% per month
Cost	50$

1.5. Hybrid systems

Hybrid systems, generally, refers to the combination of any two or more input sources, here solar PV can be integrated with, Wind Turbines, Bio-mass or any other renewable on non-renewable energy sources. Solar PV systems will generally use battery bank and sometimes hydrogen to store energy output from the panels to accommodate a pre-defined period of insufficient sunshine, there may still be exceptional periods of poor weather when an alternative source is required to guarantee power production. PV-hybrid systems combine a PV module with another power sources - typically a diesel generator, but occasionally another renewable supply such as a wind turbine. The PV generator would usually be sized to meet the base load demand, with the alternate supply being called into action only when essential (M.S. Ismail.2011)

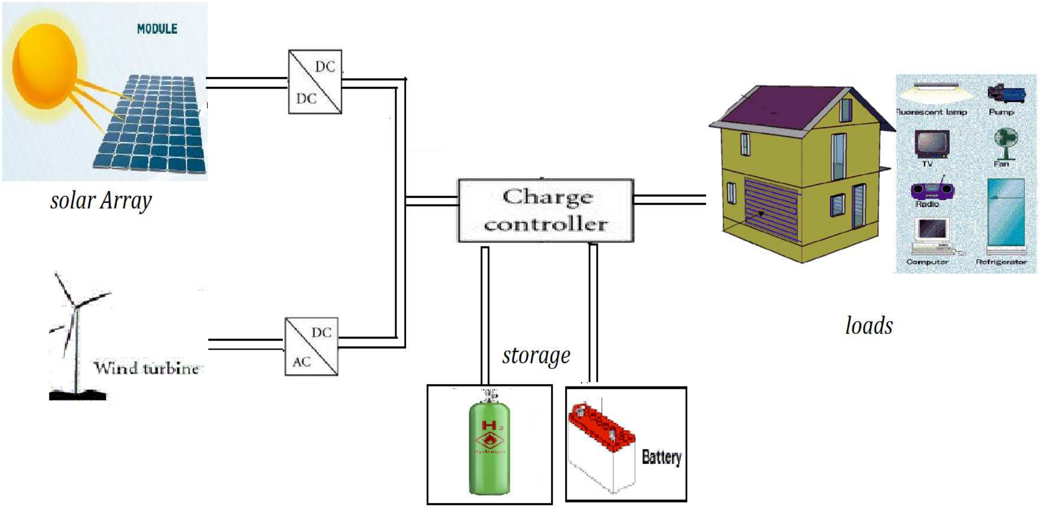


Figure1.7: Solar/wind hybrid power systems

1.6. Potential and applications of renewable energy in Algeria

The potential of renewable energy development in Algeria, particularly from solar and wind resources and to a lesser extent geothermal and biomass is a great one. These technologies offer a number of simple, feasible, and economically viable applications that can be implemented both in the short and long terms. The ability to generate heating or electricity from renewable can greatly enhance the quality of life in Algeria, create jobs, develop technical skills, reduce the country's dependence on oil and gas, while meeting obligations of reduced greenhouse effects and global warming. Increased renewable energy production will also enable better management of fuel based reserves.

Algeria is very well placed to be a major player in the lucrative market of renewable energy. However, transition to more renewable energy use will need to start immediately, at least using hybrid technologies. Genuine political will and favorable policies are essential if we are to fully embrace the renewable energy age.

A. solar energy

Algeria is a country with an enormous renewable energy (RE) potential. it provides for one of the highest solar potentials in the world. Algeria has a strong potential for solar and wind energy. Solar energy has two main technologies: solar thermal and photovoltaic (or PV). Solar thermal technology can provide both heat and electrical energy. About 169,440TWhr/year, which is equivalent to 5000 times the current energy usage in the country, may potentially be harnessed and used to support various applications (A. Zino,2010) .For domestic use, Algerian houses can be fitted with solar thermal systems, exploiting solar radiation to heat water through flat plate collectors or evacuated tubes. For electricity generation, it is possible to use concentrating solar technology to focus solar energy and run steam and gas turbine plants that drive electric generators. On the MW scale, solar farms (with many solar units) may be installed in the Algerian desert using solar towers (as operational in Spain) where solar radiation is focused onto the top of a tower from concentrating mirror. With PV panels, solar radiation is directly converted into electricity. This technology is widely used around the world and is considered a well-developed and mature technology. Algeria's capacity from PV is estimated at 13.9Twhr/year (A. Zino, 2010) and can be applied in various contexts, such as attaching small panels to the roofs of houses, large panels on schools, hospitals and supermarkets, and installing large scale PV farms. The electricity generated from PV can also benefit isolated communities to support farming activities, e.g. by pumping water from wells or by operating solar refrigerators to preserve food and medicine. A major industrial application of PV panels is for desalination plants to produce drinking water.

B. Wind energy

Wind speed increases with height, the wind turbines exploit this property by using blades to harness wind and convert mechanical energy into electricity. Wind turbine technology is also a well-established and mature technology and its adaptation in Algeria should be accelerated using both onshore (on land) and off shore (on sea) wind turbines. Indeed, recent studies show that wind energy is the second most important renewable resource in Algeria the same studies showed that. The strongest winds are located in the south west regions of the country, particularly near Adrar, it is first wind farm in this region operational between 2014 and 2015 and generating around 10MW (S. Himri, 2012).

Perhaps contrary to intuition, the coastal regions offer far less potential for harnessing wind than the southern regions. A possible explanation for this is that the Mediterranean Sea is quite a sheltered region from the open vast regions of the ocean, whereas the southern west region is facing the Atlantic Ocean to the west. However, more studies are needed in order to establish a fuller assessment of wind resources in the country (A. B. Stambouli, 2011).

In terms of practical applications, wind turbines can be used at university, hospitals, airports and large stores. In fact, wind turbines can be raised wherever there is enough blowing wind, e.g. in isolated rural areas that are cut off from the national grid, and a long stretches of highways. Coastal cities could benefit from offshore wind farms that can be connected to the grid using subsea cables. Individuals can also install small wind turbines to power their own homes (S. Himri, 2012).

Conclusion

The main goal of this chapter was presenting a general description of renewable energies used in small units and different components of a hybrid system. One of the most widely developed renewable energy sources is solar energy. Solar energy applications are constantly increasing in the last few years, such as used in small units and they are considered perhaps the most promising that can significantly contribute to the total electricity generation. Another source is wind, wind energy is the fastest growing energy source in the world and it is one of the most widely used alternative sources of energy today. The kinetic energy of wind is converted to mechanical power and then to electricity. However, these energies are highly related to weather conditions. This reason gives more importance to hybrid systems solution.

Chapter 02: Hydrogen utilizations

Hydrogen gas (H_2) is an abundant element on earth, it is found in compounds with almost every other element,such as water, hydrocarbons, alcohol, and biomass, and rarely caught in isolation. Hydrogen is not a primary energy source, it is, however widely regarded as an ideal energy storage medium. To store energy, water is convertedinto hydrogen and oxygen components by electrolysis process, then H_2 isstored to reuse it when required, using a fuel cell,or burn it directly as many researches (2 articles) approval.

Hydrogen as an energy vector can increase the penetration of renewable and intermittent sources and it can serve as an energy vector that may allow reaching 100% renewable energy supply (HaraldMiland,February 2005). Creating a large market for hydrogen as an energy vector offers effective solutions to both emissions control and the security of energy supply.

In this section of the study,we interest in explaining the importance of hydrogen as a future fuel as well as an energy carrier. Furthermore, we present hydrogen production methods and fields of application.

2.1. Hydrogen energy

Neither the use of hydrogen as an energy vector nor the vision of a hydrogen economy is new. Until the 1960s, hydrogen was used in many countries in the form of town gas for street lighting as well as for home energy supply. The idea of a hydrogen-based energy system was already formulated in the aftermath of the oil crises in the 1970s (AFH2, 2011) Moreover, hydrogen is an important chemical feedstock, for instance for the hydrogenation of crude oil or the synthesis of ammonia. Being a secondary energy carrier that can be produced from any primary energy source, hydrogen can contribute to a diversification of automotive fuel sources and supplies and offers the long term possibility of being solely produced from renewable energies. Hydrogen could further be used as a storage medium for electricity from intermittent renewable energies such as wind, solar, biomass, hydraulic power as far as the security of supply or greenhouse gas emissions are concerned, any advantage from using hydrogen as a fuel depends on how the hydrogen is produced.

2.2. Hydrogen as future fuel

Hydrogen is a secondary form of energy that has to be manufactured like electricity. The majority of the experts consider that renewable hydrogen has a great role to play as an important energy carrier in the future energy sector.

The use of hydrogen as a fuel for transportation and stationary applications is receiving much favorable attention as a technical and policy issue. Hydrogen gas is being explored for use in internal combustion engines and fuel cell electric vehicles.

Hydrogen can be used in fuel cells which can achieve a high electric efficiency. The total energy efficiency may even exceed 90%if the waste heat can be used. Hydrogen and fuel cells are often considered as a key technology for future sustainable energy supply.

2.3. Hydrogen production techniques

Production of hydrogen from cheap and renewable sources is the key factor for H2 energy utilization in real life. There are many sources for H2 production namely water, glycerol, biomass, etc. (see figure 2.1).

These technologies cover the state of the art technologies steam reforming of natural gas and alkaline water electrolysis as well as biomass based technologies. Literature survey shows that most of the researchers are emphasizing on the utilization of water as a source of H2 due to its availability (Dutta, 2014).

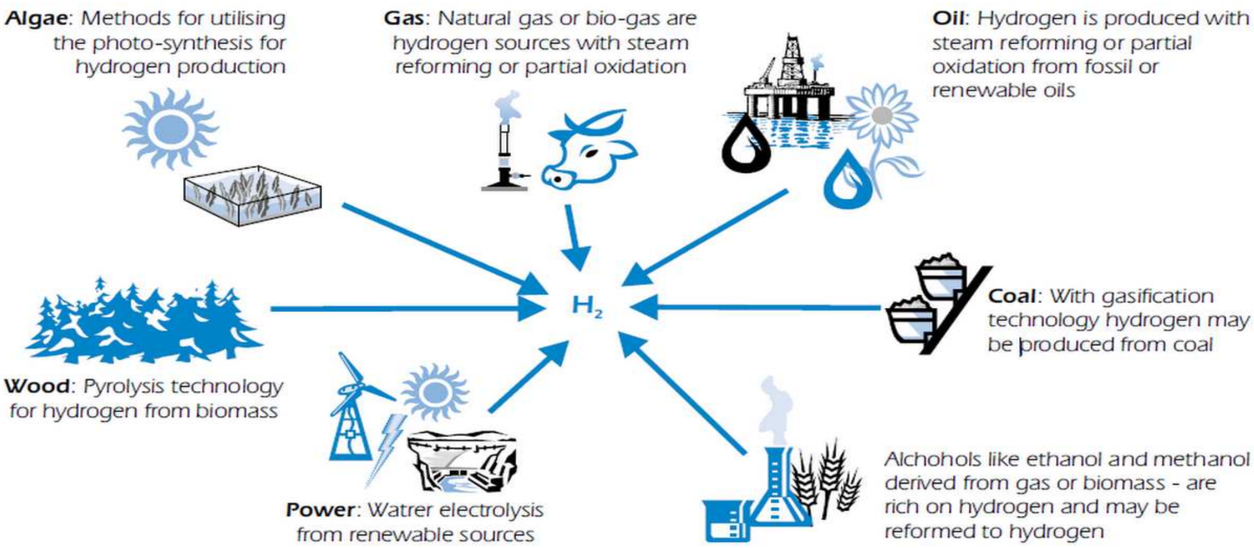


Figure2.1: Some feedstock and process alternatives of H_2 production. (Trygve.R, Elisabet.H, 2006)

2.3.1. Water Electrolysis technologies

Depending on the kind of electrolyte and thus the type ofionic agent (OH^{-}, H^{+}, $O2^{-}$), and the operation temperature, waterelectrolyzers are classified into three main categories: alkaline, polymer–electrolyte membrane (PEM) and solidoxideelectrolyzers (SOE). The operating principles of thesethree main types of electrolysis technologies are presented in figure2(Sapountzi et al, 2017). In this study, we focus on (Alkaline& PEM) water electrolysis.

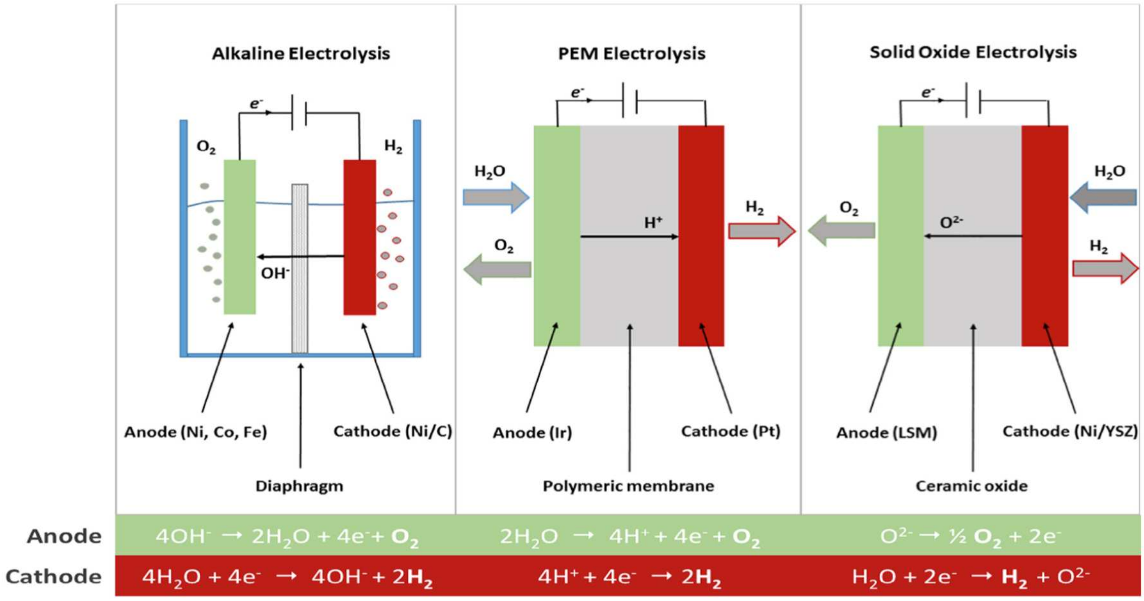


Figure2.2: Operating principles of alkaline, PEM (proton-exchange membrane) and solid oxide water electrolysis.

2.3.2. Alkaline water electrolysis

Water electrolysis is a particular electrochemical process (decomposing electrochemical process, also known as electrolytic process) in which water is split into its basic components, hydrogen and oxygen, through the use of continuous electric current.

The electrolytes more commonly utilized are liquid solutions which may be acidic or alkaline. Alkaline electrolysers use an aqueous NaOH solution (caustic) as an electrolyte that usually circulates through the electrolytic cells (see Fig.3). The following reactions take place inside the alkaline electrolysis cell(N. ChennoufET al.2012):

Anode: $2OH^{-} \longrightarrow 1/2\ O_2 + H_2O + 2e^{-}$

Cathode: $2H_2O + 2\ e^{-} \longrightarrow H_2 + 2OH^{-}$

Electrolyte: $4H_2O \longrightarrow 4H^{+} + 4OH^{-}$

Net reaction: 2H2O ⟶ 2H2 + O2

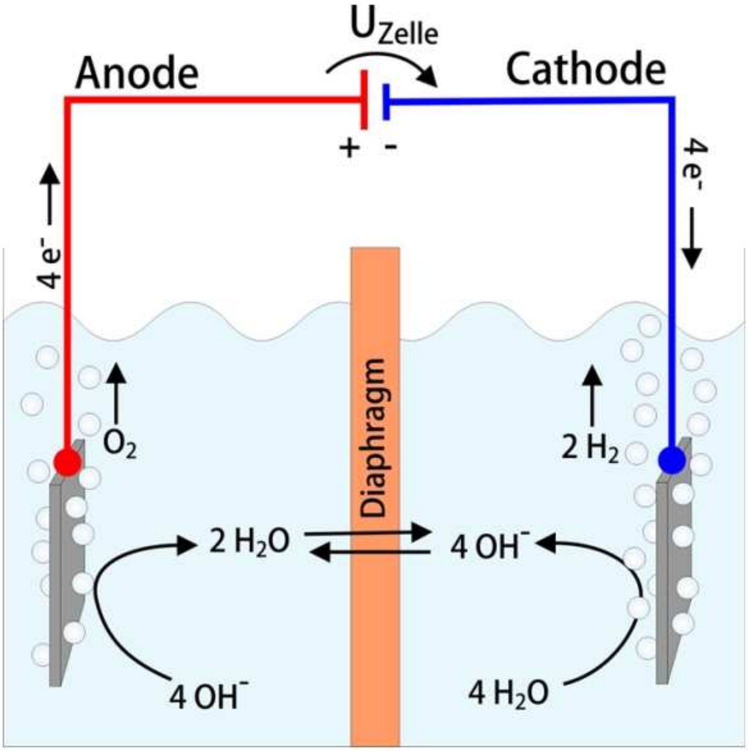


Figure2.3: Principle of alkaline water electrolysis

2.3.3. Polymer electrolyte membrane (PEM) electrolysis

The principle of PEM electrolysis is presented in equations (3.6) and (3.7). PEM electrolysersrequire no liquid electrolyte, which simplifies the design significantly. The electrolyte is an acidicpolymer membrane. PEM electrolysers can potentially be designed for operating pressures up toseveral hundred bar, and are suited for both stationary and mobile applications. The main drawbackof this technology is the limited lifetime of the membranes. The major advantages of PEM overalkaline electrolysers are the higher turndown ratio5, the increased safety due to the absence ofKOH electrolytes, a more compact design due to higher densities, and higher operating pressures.

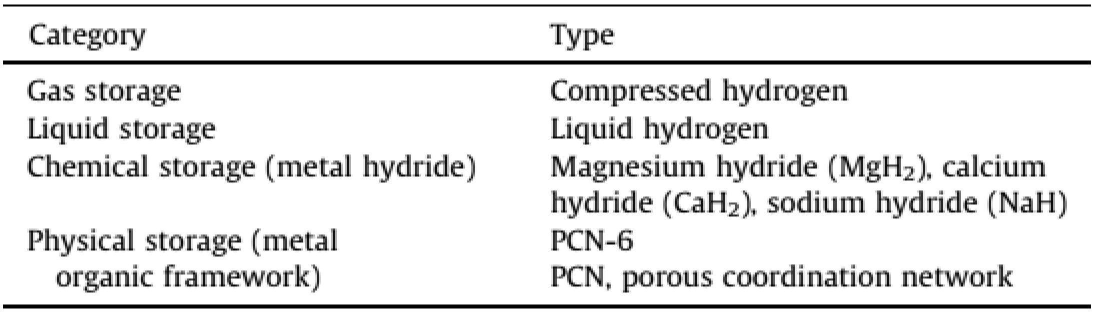
Anode: H2O ➞ 1/ 2O2 + 2 H+ + 2e– (3.6)

Cathode: 2H+ + 2e– ➞ H2 (3.7)

With relatively high cost, low capacity, poor efficiency and short lifetimes, the PEM electrolyserscurrently available are not as mature as alkaline electrolysers. It is expected that the performanceof PEM electrolysers can be improved significantly by additional work in materials development andcell stack design.

2.4. Hydrogen Storage

Table2.1: Hydrogen storage types adapted from (Roes and Patel, 2011) .



Category	Type
Gas storage	Compressed hydrogen
Liquid storage	Liquid hydrogen
Chemical storage (metal hydride)	Magnesium hydride (MgH_2), calcium hydride (CaH_2), sodium hydride (NaH)
Physical storage (metal organic framework)	PCN-6 PCN, porous coordination network

2.5.1. Gaseous Hydrogen

The most common method to store hydrogen in gaseous form is in steel tanks, although lightweight composite tanks designed to endure higher pressures are also becoming more and more common. Cryogas, gaseous hydrogen cooled to near cryogenic temperatures, is another alternative that can be used to increase the volumetric energy density of gaseous hydrogen. A more novel method to store hydrogen gas at high pressures is to use glass microspheres. The next two sections provide further details on two of the most promising methods to store hydrogen gas under high pressure: composite tanks (figure.4).and glass microspheres(Trygve.R, Elisabet.H, 2006).

Compressed:

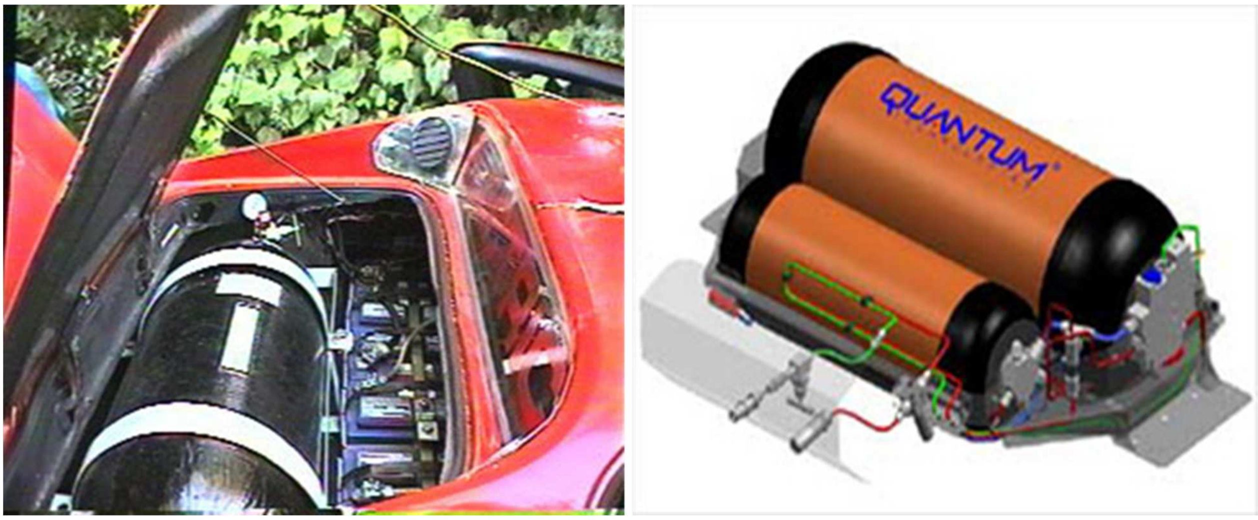


Figure.2.4tank of hydrogen in gaseous

Volumetrically and gravimetrically inefficient, but the technology is simple, so by far the most common in small to medium sized applications.

Table2.2: capacity and pressure of tank of hydrogen

Model	Capacity (m^3)	Pressure(bar)	Cost($)
Haikong	8	8	600-80,000
PLL	0.8 to 200	1-100	850-10,000
ISO229I TPED	0.040-0.050	300-450	1000

ISO 267I (TPED)	0.050-0.080	300-450	2000
CFLY05/1.0	5m3	10	1200-35000
CFL-Y05/1.75	5m3	17.5	1200-35000
CFL-Y10/1.0	10m3	10	1200-35000
CFL-Y10/1.75	10m3	17.5	1200-35000
CFL-Y15/0.8	15m3	8	1200-35000
CFL-Y15/1.75	15m3	17.5	1200-35000
CFL-Y20/0.8	20m3	8	1200-35000
CFL-Y20/1.75	20m3	17.5	1200-35000
CFL-Y30/0.8	30m3	8	1200-35000
CFL-Y30/1.75	30m3	17.5	1200-35000
CFL-Y50/0.8	50m3	8	1200-35000
CFL-Y50/1.75	50m3	17.5	1200-35000
CFL-Y100/0.8	100m3	8	1200-35000
CFL-Y100/1.6	100m3	16	1200-35000
3271522	0.600	300	2,545
3271523	0.900	300	2,765
3271524	1.800	300	3,895
3271525	2.040	300	4,110
3271526	2.160	300	4,435
3271527	2.700	300	4,770

2.4.2. Liquid Hydrogen

The most common way to store hydrogen in a liquid form is to cool it down to cryogenic temperatures (–253 °C). Other options include storing hydrogen as a constituent in other liquids, such as NaBH4 solutions, rechargeable organic liquids, or anhydrous ammonia NH3. This section discusses the three most promising methods: cryogenic H2 (figure.5). NaBH4 solutions, and rechargeable organic liquids(Trygve.R, Elisabet.H, 2006).

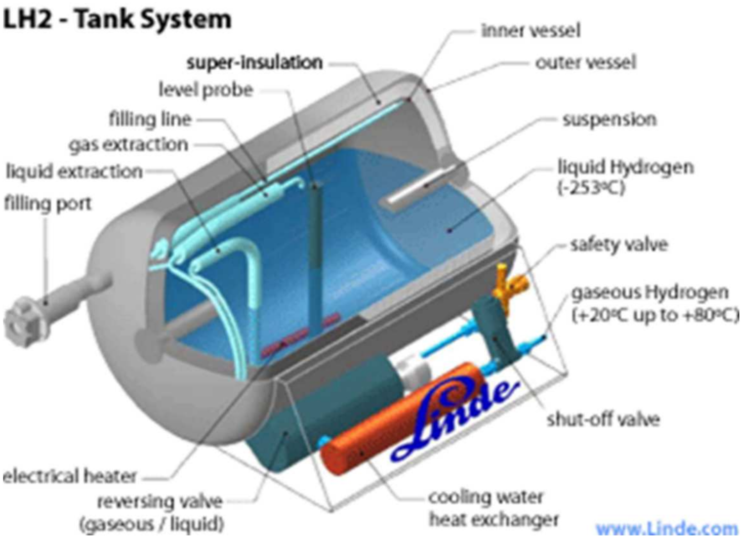


Figure2.5:Tank of hydrogen liquid

Liquid H_2(Cryogenic)

-Compressed, chilled, filtered, condensed.-Boils at 22K (-251 C).

-Slow “waste” evaporation.-Kept at 1 atm or just slightly over.

-Gravimetrically and volumetrically efficient but very costly to compress

2.4.3. Solid Hydrogen

Storage of hydrogen in solid materials has the potential to become a safe and efficient way to store energy, both for stationary and mobile applications. There are four main groups of suitable materials: carbon and other high surface area materials (figure.6); H2O-reactive chemical hydrides; thermal chemical hydrides; and rechargeable hydrides(Trygve and Elisabet.H, 2006).

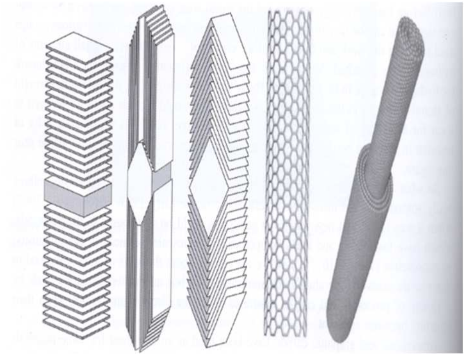


Figure.2.6Schematic representation of different types of carbon Nano-fibers

Carbon Nanofibers

*Complex structure presents a large surface area for hydrogen to “dissolve” into

*Early claim set the standard of 65 kgH2/m2 and 6.5 % by weight as a “goal to beat”

*The claim turned out not to be repeatable

2.5 Fuel Cell

Fuel cells are essentially electrochemical cells and operate following the same basic mechanism as everyday batteries. However, unlike batteries, where all of the chemicals used in the cell are contained and when the reaction is complete the battery is dead, fuel cells have a constant flow of fresh chemicals into the cell and so in theory have an unlimited life.

Hydrogen fuel cells, which are the most commonly used, convert flows of hydrogen and oxygen into water (H2O) and produce electricity in the process.

At the anode, hydrogen is forced through a catalyst (usually platinum powder) where it is ionized: 2H2 ==> 4H+ + 4e-. The electrons then pass through an external circuit, where their flow can be harnessed as electricity, on their way to the cathode.

At the cathode, oxygen reacts with the products from the anode (the protons and electrons) to produce water: O2 + 4H+ + 4e- ==> 2H2O. Along with heat, this is the only by-product of the hydrogen fuel cell: the reactants are normally fully utilized.

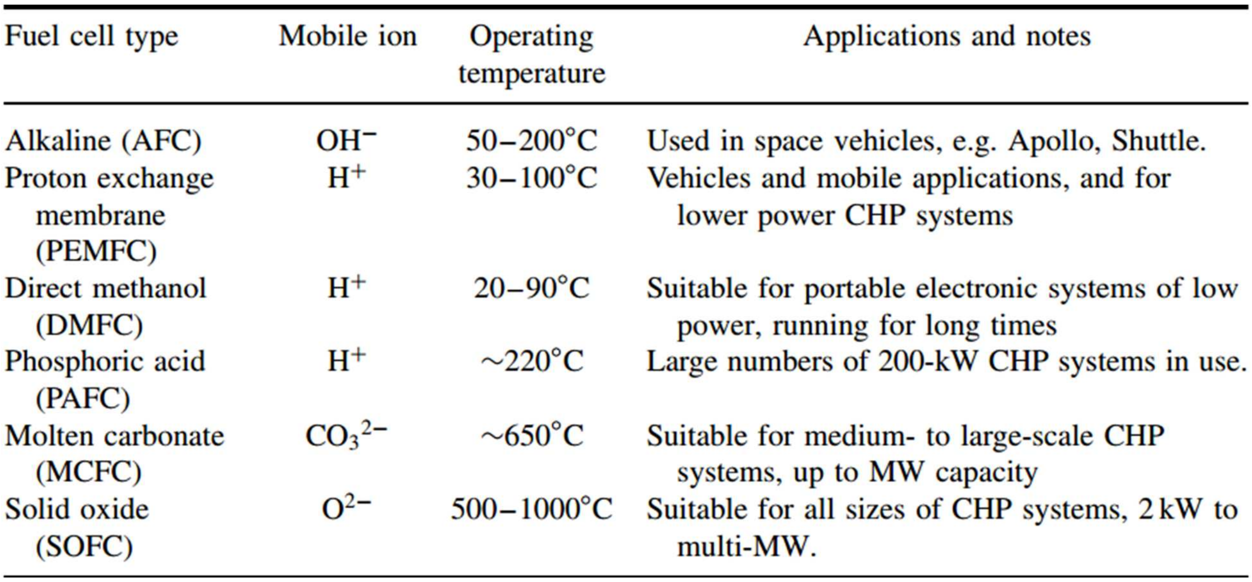
Aside from electricity and heat, which itself can be captured and used, water is the only product from a hydrogen fuel cell. Of course, this is harmless and so the process has huge environmental advantages over polluting combustion engines. However, water builds up in the cell and so it must be removed periodically otherwise it will saturate. This is usually achieved through a water pump or separator.

As explained, fuel cells generate electricity through a chemical process. This means that they are not subject to the Carnot Limit (a theoretical limit on the efficiency of an engine based on the flow of heat between two reservoirs), and that they can effectively extract more energy from fuel than combustion-based methods. Traditional internal combustion engines typically have efficiencies of around 30%, whereas fuel cells can achieve 40-70% efficiency(Lisa Bushby, 2006).

2.5.1 Fuel Cell Types

Six types of fuel cells have evolved in the past decades. They are called after their electrolyte, the substance that transports the ions. The electrolyte dictates the operating temperature of a fuel cell type. Depending on the operating temperature, a specific catalyst is chosen to oxidize the fuel. Fuel cell types therefore all have different catalysts. A brief summary of these six fuel cell types is given below.

Table. 2.3 data for different type of fuel cell. (Larminie and Dicks, 2002)



Fuel cell type	Mobile ion	Operating temperature	Applications and notes
Alkaline (AFC)	OH^-	50–200°C	Used in space vehicles, e.g. Apollo, Shuttle.
Proton exchange membrane (PEMFC)	H^+	30–100°C	Vehicles and mobile applications, and for lower power CHP systems
Direct methanol (DMFC)	H^+	20–90°C	Suitable for portable electronic systems of low power, running for long times
Phosphoric acid (PAFC)	H^+	~220°C	Large numbers of 200-kW CHP systems in use.
Molten carbonate (MCFC)	CO_3^{2-}	~650°C	Suitable for medium- to large-scale CHP systems, up to MW capacity
Solid oxide (SOFC)	O^{2-}	500–1000°C	Suitable for all sizes of CHP systems, 2 kW to multi-MW.

In this study we are interesting in PEMFC

2.5.2. PEM fuel cell

An PEM fuel cell consists of a polymer electrolyte membrane sandwiched between two electrodes (anode and cathode). In the electrolyte, only ions can exit and electrons are not allowed to pass through. So, the flow of electrons needs a path like an external circuit from the anode to the cathode to produce electricity because of a potential difference between the anode and cathode .The overall electrochemical reactions for anPEM fuel cell fed with a hydrogen-containing anode gas and an oxygen-containing cathode gas are as follows (Woon Ki Na, BeiGou, 2007):

Anode: 2H2 ↔ 4H+ + 4e−

Cathode: O2 + 4H+ + 4e− ↔ 2H2O

Overall: 2H2 + O2 ↔ 2H2O+ electricity + heat.

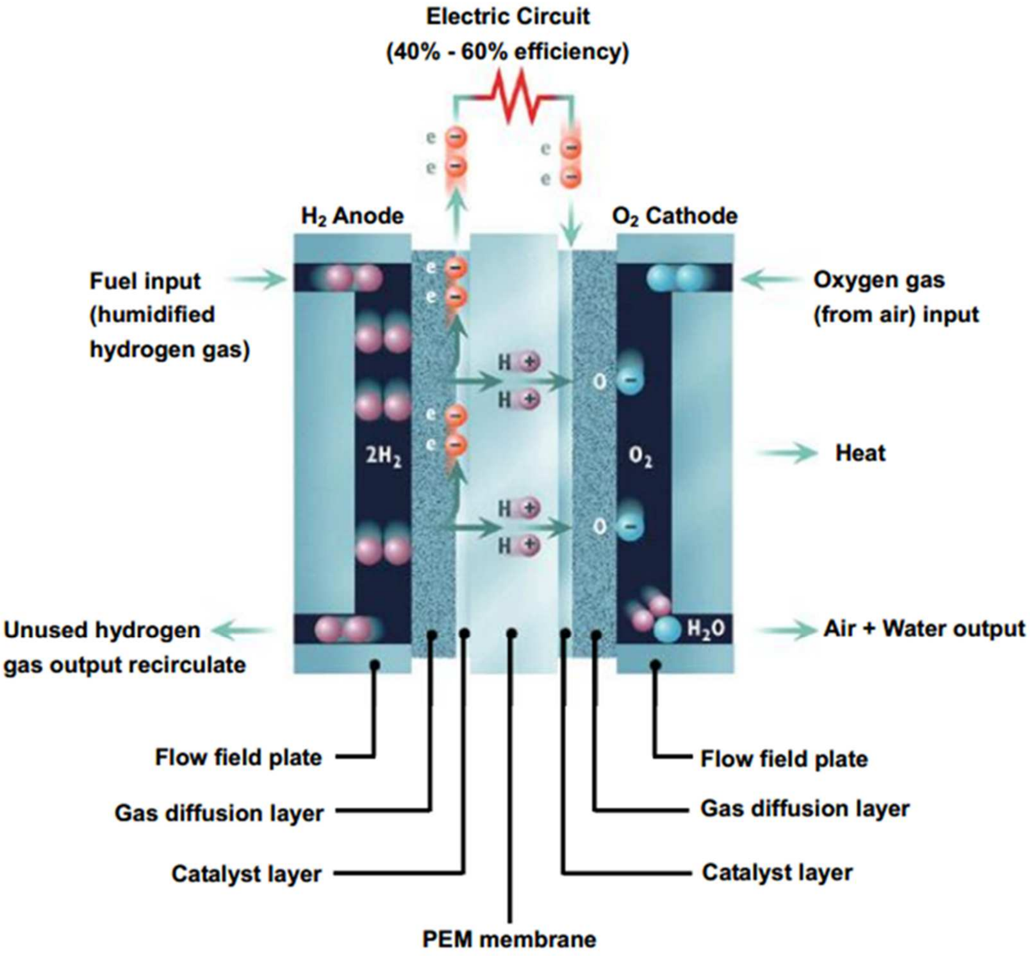


Figure.2.7 Schematic picture of the operating principle of a typical PEMFC (Mengbo and Zidong, 2009)

2.5.3. PEM Fuel Cell Components and Their Properties

A) Membrane

In a typical PEM fuel cell, the membrane is sandwiched between two catalyzed electrodes to transport the protons, support the anode and cathode catalyst layers, and more importantly, separate the oxidizing (air) and reducing (hydrogen) environments on the cathode and anode sides, respectively. Therefore, the requirements for an excellent membrane are manifold and stringent, including high protonic conductivity, flow reactant gas permeability, thermal and chemical stability, and so on. The most commonly used and promising membranes for PEM fuel cells are perfluorosulfonic acid (PFSA) membranes such as Nafion® (DupontTM), Gore-Select® (GoreTM), and Aciplex® and Flemion® (AsahiTM). Extensive studies have been carried out on the mechanisms of membrane degradation and failure in the fuel cell environment. At present, however, unsatisfactory durability and reliability of the membrane is still one of the critical issues impeding the commercialization of PEM fuel cells(FranoBarbir, 2012).

B) Electrode

A fuel cell electrode is essentially a thin catalyst layer pressed between the ionome membrane and a porous, electrically conductive substrate. It is the layer where the electrochemical reactions take place. More precisely, the electrochemical reactions take place on the catalyst surface. Since there are three kinds of species that participate in the electrochemical reactions, namely gases, electrons and protons, the reactions can take place on a portion of the catalyst surface where all three species have access to. The reaction zone may be enlarged by either “roughening” the surface of the membrane, and/or by reducing the catalyst particle size, and/or by incorporating ionomer in the catalyst layer.

The most common catalyst in PEM fuel cells for both oxygen reduction and hydrogen oxidation reactions is platinum. In the early days of PEMFC development large amounts of Pt catalyst were used (up to 28 mg cm-2). In the late 1990s with the use of supported catalyst structures this was reduced to 0.3–0.4 mg cm-2. It is the catalyst surface area that matters, not the weight, so it is important to have small platinum particles (4 nm or smaller) with large surface area finely dispersed on the surface of the catalyst support.

In order to minimize the cell potential losses due to the rate of proton transport and reactant gas permeation in the depth of the electro catalyst layer, this layer should be made reasonably thin. At the same time, the metal active surface area should be maximized(FranoBarbir, 2012).

C) Gas diffusion layer

The gas diffusion layer (GDL) is typically a dual-layer carbon-based porous material, including a macro porous carbon fiber paper or carbon cloth substrate covered by a thinner micro porous layer (MPL) consisting of carbon black powder and a hydrophobic agent.

The required properties of the gas diffusion layer follow from its functions:

- It must be sufficiently porous to allow flow of both reactant gases and product water (note that these fluxes are in opposite direction). Depending on the design of the flow field, diffusion in both through plane and in plane is important.
- It must be both electrically and thermally conductive, again both through plane and in plane. Interfacial or contact resistance is typically more important than bulk conductivity.
- Since the catalyst layer is made of discreet small particles the pores of the gas diffusion layer facing the catalyst layer must not be too big.
- It must be sufficiently rigid to support the “flimsy” MEA. However, it must have some flexibility to maintain good electrical contacts

These somewhat conflicting requirements are best met by carbon fiber based materials such as carbon-fiber papers and woven carbon fabrics or cloths. These diffusion media are generally made hydrophobic in order to avoid flooding in their bulk. Typically, both cathode and anode gas diffusion media are PTFE-treated. A wide range of PTFE loadings have been used in PEMFC diffusion media (5% to 30%), most typically by dipping the diffusion media into an PTFE solution followed by drying and sintering. In addition, the interface with the adjacent catalyst layer may also be fitted with a coating or a micro porous layer to ensure better electrical contacts as well as efficient water transport into and out of the diffusion layer. This layer (or layers) consists of carbon or graphite particles mixed with PTFE binder. The resulting pores are between 0.1 and 0.5 µm, thus much smaller than the pore size of the carbon fiber papers (20–50 µm).

D) Bipolar plates:

The bipolar plate is a multifunctional component of the fuel cell stack, acting as a separator between the fuel, oxidant gases, and coolant; homogeneously distributing reactant and product streams; and collecting the current generated by the electrochemical reaction.

In addition, they must be corrosion resistant in the fuel cell environment, yet they must not be made out of “exotic” and expensive materials. In order to keep the cost down not only must the material be inexpensive, but also the manufacturing process must be suitable for mass production.

In general, two families of materials have been used for PEM fuel cell bipolar plates, namely graphite-composite and metallic. The bipolar plates are exposed to a very corrosive environment inside a fuel cell (pH 2–3 and temperature 60– 80oC). The typical metals such as aluminum, steel, titanium or nickel would corrode in fuel cell environment, and dissolved metal ions would diffuse into the ionomer membrane, resulting in lowering of the ionic conductivity and reducing the fuel cell life.

In addition, a corrosion layer on the surface of a bipolar plate would increase electrical resistance. Because of these issues, metallic plates must be adequately coated with a non-corrosive yet electrically conductive layer, such as graphite, diamond-like carbon, conductive polymer, organic self-assembled polymers, noble metals, metal nitrides, metal carbides, indium doped tin oxide, etc.(Frano Barbir, 2012).

2.5.4. Fuel Cell Applications

Fuel cells can generate power from a fraction of a watt to hundreds of kilowatts. Because of this, they may be used in almost every application where local electricity generation is needed. Applications such as automobiles, buses, utility vehicles, scooters, bicycles, submarines have been already demonstrated. Fuel cells are ideal for distributed power generation, at a level of individual homes, buildings or a community, offering tremendous flexibility in power supply. In some cases both power and heat produced by a fuel cell may be utilized, resulting in very high overall efficiency. As a backup power generator, fuel cells offer several advantages over either internal combustion engine generators (noise, fuel, reliability, maintenance) or batteries (weight, lifetime, maintenance). Small fuel cells are attractive for portable power applications, either as replacement for batteries (in various electronic devices and gadgets) or as portable power generators.
Fuel cell and fuel cell system design are not necessarily the same for each of these applications. On the contrary, each application, besides power output, has its own specific requirements, such as efficiency, water balance, heat utilization, quick startup, long dormancy, size, weight, fuel supply, etc.(Frano Barbir, 2012).

A) Hydrogen for cooking

Fuel for cooking is an important sub-sector of energy consumption in which renewable energy use is largely ignored. Most of the world used known cooking, apparatus utilize liquefied petroleum gas (LPG) that is stored in a tank as fuel. Another disadvantage of using LPG as burner fuel is safety. Since leaks can happen in the LPG line and since the LPG is a heavy gas and highly combustible, the gas leak may settle in the environment and may explode with open flame. Scientific research has shown that renewable energy can be harnessed to power the process of splitting water by electrolyze to produce hydrogen gas. Hydrogen fuel cell can be used in future for cooking in the absence of LPG along with a modified stove (Akanksha&Chaurasia, 2014).

Table2.4 cost of different component of system hydrogen

Model of PEMFC	COST($)
HYFC-1KW	10000
HYFC-2KW	20000
HYFC-2KW	20000
HYFC-1KW	10000
PEMFC-500W	6225
PEMFC-500W	6225
PEMFC-500W	6225
PEMFC-500W	6225
PEMFC-500W	6225
PEMFC-500W	6225
HYFC-1KW	10000
HYFC-1KW	10000
HYFC-1KW	10000
PEMFC-500W	6225

Model of electrolysis	Cost($)	P(kw)
QL-7000	10000	3
QL-3000 SPE/PEM	5500	1-1.5
QL-3000 SPE/PEM	5500	1-1.5
QL-7000	10000	3
QL-3000 SPE/PEM	5500	1-1.5
QL-5000	7000	2
QL-1000P	6400	1.5
QL-5000	7000	2
QL-5000	7000	2
QL-7000	10000	3
QL-10000	20000	5
QL-7000	10000	3
QL-17000	30000	7.2
QL-34000	50000	13

Capacity(m^3)	COST($)
0.486535	2,545
0.934994	2,765
1.292599	3,895
1.385576	3,895
1.521728	3,895
1.729975	3,895
1.762001	3,895
1.780814	3,895
1.8206	4,110
2.195357	4,435
2.896438	5,000
3.060156	5,000
2.761297	4,770
1.884127	3,895

2.6. Conclusion

Hydrogen can be produced by miscellaneous methods. We focused in water electrolysis using fossil fuels, such as natural gas and coal, nuclear energy, and other renewable energy sources, such as biomass, wind, solar, geothermal, and hydro-electric power.

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (50-900 bar). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at 1atm is −252.8°C. Hydrogen can also be stored on the surfaces of solids by adsorption, or within solids by absorption.

The fuel cell stack generates electricity in the form of direct current (DC) from electro-chemical reactions.The amount of power produced by a fuel cell depends upon several factors, such as type, size, operatingtemperature andgases supplied pressure.It is expected; in near future plenty of H2 can be produced with the help of renewable source like solar energy and wind energy.

Chapter 03: Modeling and methods

The method developed for this type of systems is based on the average monthly values which calculated from the hourly values the contributions of each component (photovoltaic panel and wind turbine). Then, the size of the other component; storage system (battery or hydrogen), inverters are determined.

The optimization has been carried out, starting by the technical calculus taking into account the economic parameter that represents a criterion not to neglect in the operating systems with renewable sources. In order to select the optimum technico-economic configuration, several combinations of the PV/WT/Storage are considered and for which the total cost is determined to choose the optimal size.

3.1. Analysis of solar and wind potential energy in Ouargla

Ouargla has a strong potential of solar radiation, and the region is characterized by a very hot summer (June - September) with an average monthly temperature that exceeds 45°C. The average daily irradiation on inclined surface is very high during the period (April-August), compared to the other months, it can exceed 7.4kWh/m^2/day. It can be seen that the site of Ouargla has also a considerable annual wind speed which an average 5.9 m/s to a height of 10m This clearly proves that the site of Ouargla is well adapted for a production by hybrid system of Solar/wind energies.

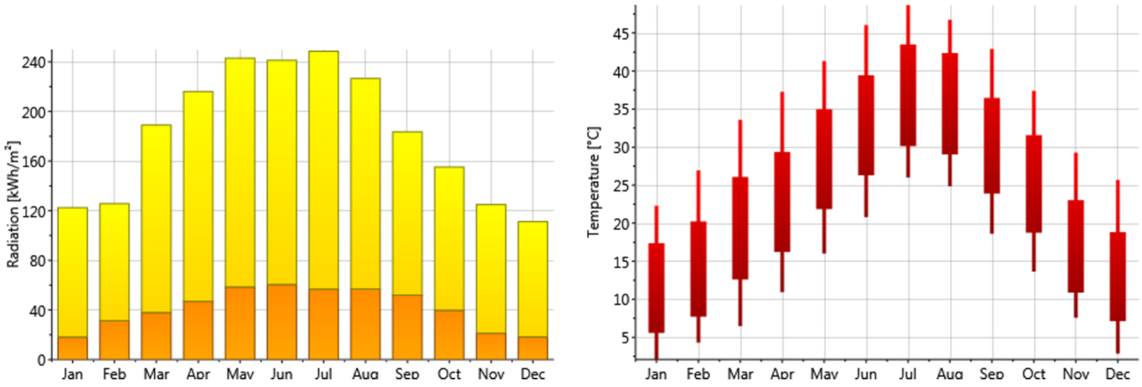


Figure 3.1: Average irradiation and temperature of Ouargla

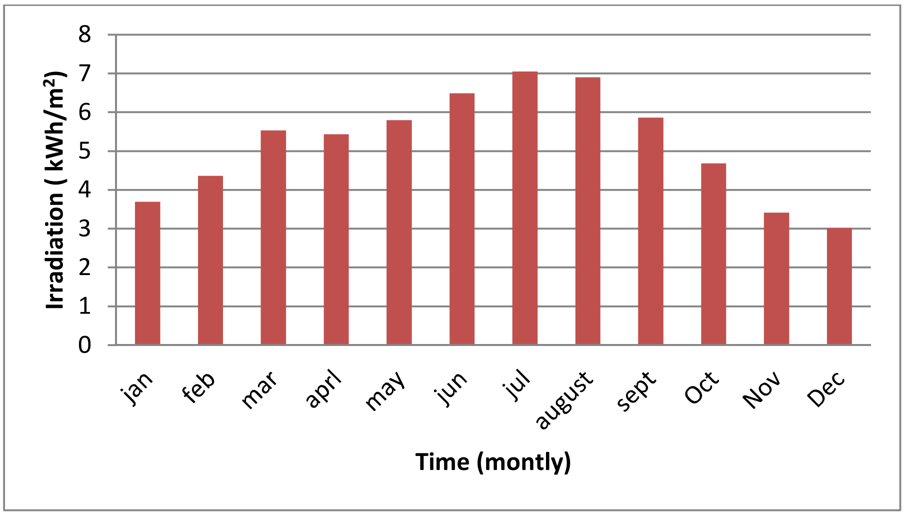


Figure 3.2: Average irradiation of 250W-polycrystalline panel inclined by 31.9°

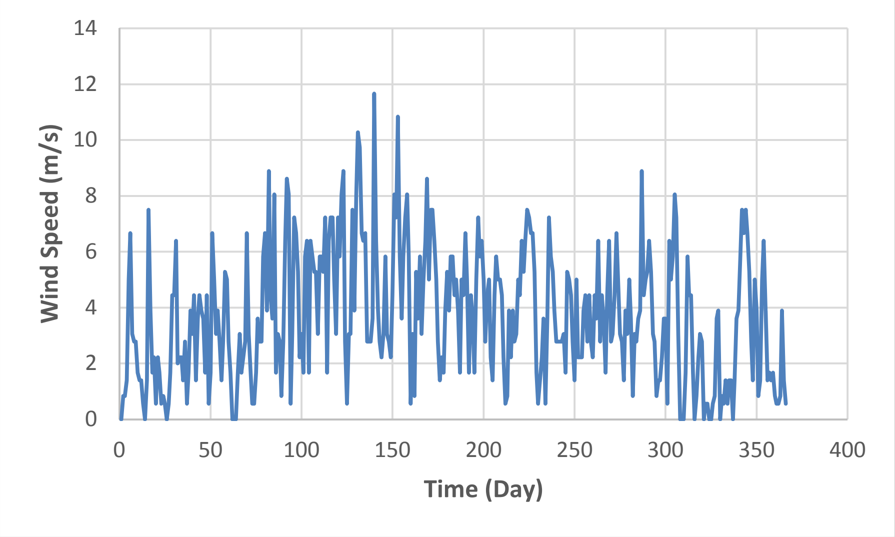


Figure 3.3: Average daily wind speed of Ouargla

3.2. Design of standalone house:

Based on the study of (R. Ghedamsi ET al.2016) the required energy for heating and cooling of the region of Ouargla is as follow: (see figure 3.4) Even though there are many different design options available, they all have several things in common: a tightly sealed thermal envelope; controlled ventilation; and lower than usual heating and cooling bills.

Recent technological improvements in building elements and construction techniques, and heating, ventilation, and cooling systems, allow most modern energy saving ideas to be seamlessly integrated into any type of house design without sacrificing comfort, health, or aesthetics. The following is a discussion of the major elements of energy-efficient home design and construction systems.

Table 3.2: Characteristics of house

• the wall consists of 5 layers : Plaster (1.5cm),Two layers Brick (10cm et 15cm) ,Air space (5cm),Cement (2cm)
• Area of house (150m^2) Consists of two floors
• Heating ,cooling and Controlled Ventilation well adapted

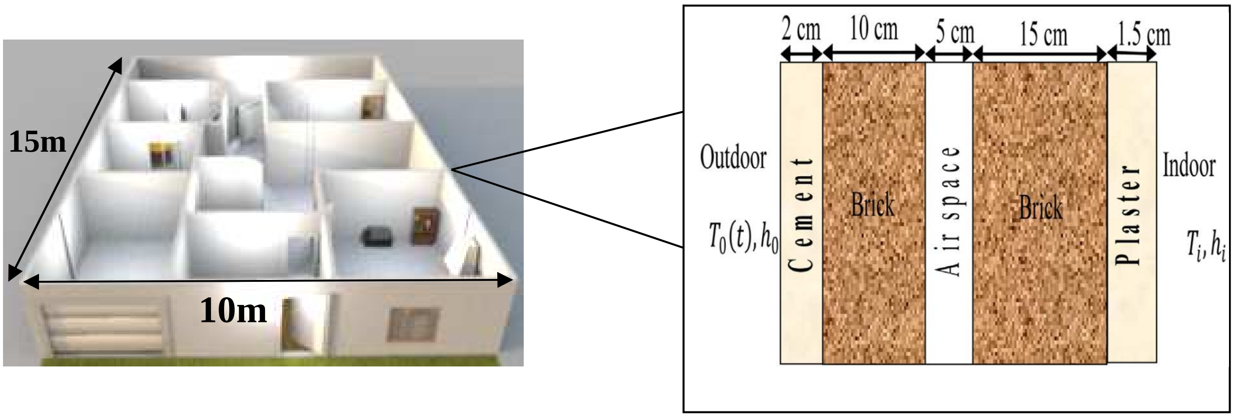


Figure 3.4: Typical house

3.3. Estimated loads of energy consumption:

As it is shown in (figure3.5) zone 1, the highest consumer of energy by consumer is nearly16000kWh yearly. A lot of factors influence the energy consumption of residential sector as the kind and the efficiency of the appliances. Between zone3 and zone 4 (Ouargla) Average yearly consumption nearly 14407, 04 kWh. (R. Ghedamsi et al. 2016)

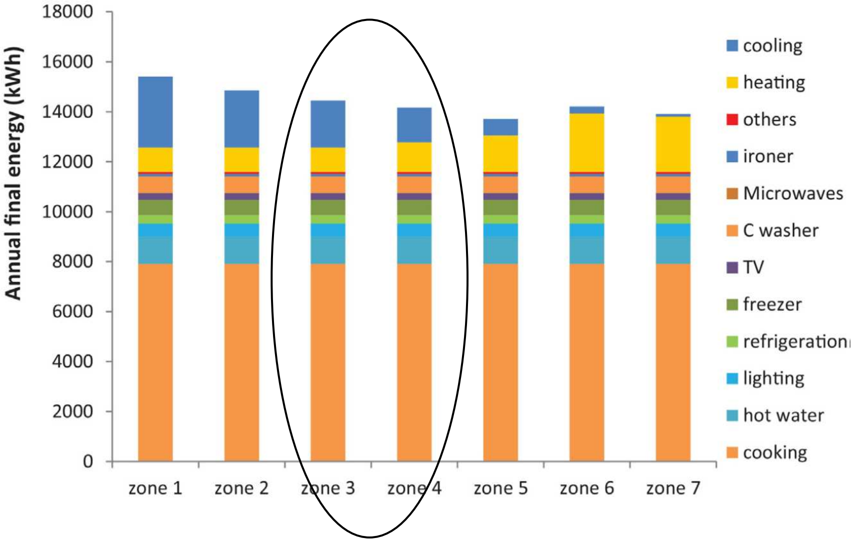


Figure 3.5: Energy consumption in different regions in Algeria

Table 3.3: Estimated loads of energy consumption from site Ouargla

Month	**Daily consumption (kWh)**	**Monthly consumption (kWh)**
Jan	45.04	1396.24
Feb	42.74	1196.72
Mar	39.04	1210.24
Apr	35.7	1071
May	36.18	1121.58
Jun	37.93	1137.9
Jul	40.18	1245.58
Aug	40.18	1245.58
Sep	37.91	1114.2
Oct	35.47	1099.57
Nov	39.91	1197.3
Dec	44.23	1371.13
Yearly consumption:		**14407.04**

3.4. Hybrid system PV/ WT/storage

The optimization of such system aims to generate energy satisfying the energy demands, which corresponds to real data of a household (of eight persons) in Ouargla city (latitude: 31.9N, longitude: 5.24'E) (R. Ghedamsi ET al.2016). To make this analysis, we combine two kinds of energies, which are then connected to storage (hydrogen or batteries) as shown in figure 3.6.

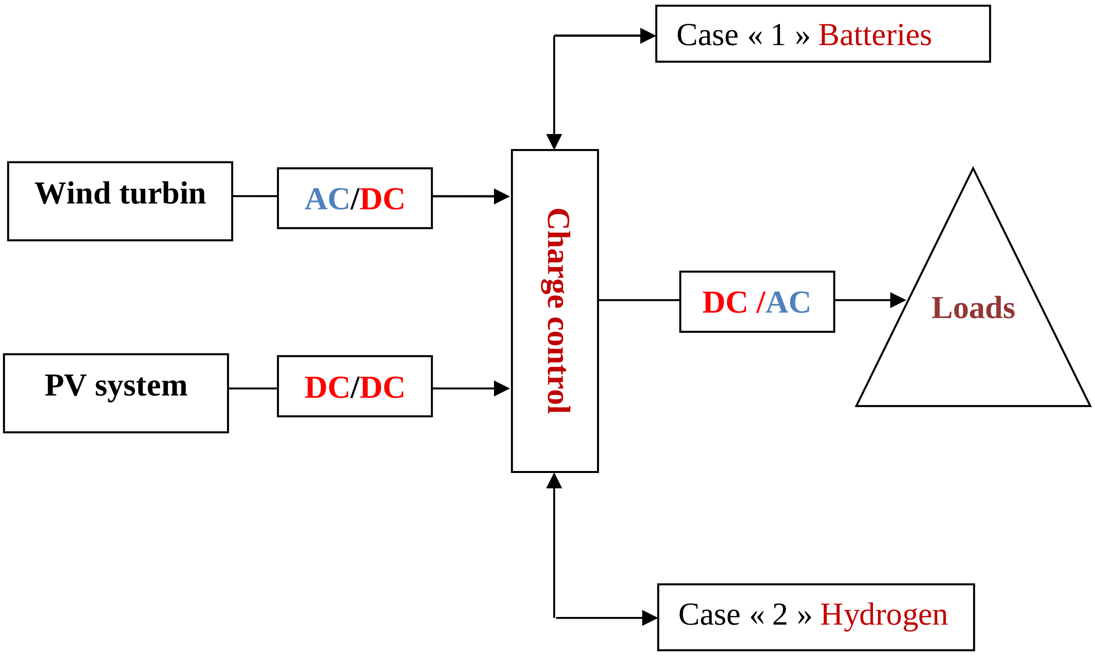


Figure 3.6: Schematic illustrates system PV/WT storage by batteries or hydrogen

3.5. Mathematical modeling of the hybrid system

3.5.1. Photovoltaic generator

The energy produced by a photovoltaic generator is estimated from the data of the overall irradiation on inclined plane, the ambient temperature and the data of the manufacturer for the photovoltaic module used. The electrical energy produced by a photovoltaic generator is given by (R. Ghedamsi ET al.2016).

$$P_{pv}^{t} = \eta_{pv} S_{pv} G^{t} \qquad t=0,\ldots\ldots T-1 \qquad (1)$$

Where η_{pv} represents the PV generator efficiency, S_{pv} is the solar cell array area, and G^{t} is the forecasted hourly irradiance, that is predicted by some meteorological model.

The efficiency of the photovoltaic generator is represented by the following equation :

$$\eta_{pv} = \eta_{r} \eta_{pc} [1 - \beta (T_{c} - T_{cref})] \qquad (2)$$

Where η_{r} is the reference module efficiency, η_{pc} is the power conditioning efficiency which is equal to 1 if a perfect maximum power tracker is used. β is the generator efficiency temperature coefficient, it is assumed to be a constant and for silicon cells the range of β is 0.004-0.006 per (°C),T_{cref} is the reference cell temperature (°C) and T_{c} is the cell temperature (°C) and can be calculated as follows (R. Ghedamsi ET al.2016).

$$T_{c} = T_{a} + \left[\frac{(NOCT-20)}{800}\right] G^{t} \qquad (3)$$

Where T_{a} is the ambient temperature (°C) and NOCT is the nominal cell operating temperature (°C). η_{pc}, β, NOCT and S_{pv}, are parameters that depend upon the type of module used. Thus,

$$E_{pv}^{t} = P_{pv}^{t}.\Delta t \qquad t=0\ldots\ t-1 \qquad (4)$$

3.5.2. Wind generator

The power contained in the form of kinetic energy, P (W), in the wind is expressed by (Kaabeche et al., 2011):

$$p_{WT}(t) = \begin{cases} 0 & V^{t} \prec V_{cut-in} \\ P_{r} \dfrac{V^{2}(t) - V_{cut-in}^{2}}{V_{r}^{2} - V_{cut-out}^{2}} & V_{cut-in} \le V^{t} \le V_{r} \\ P_{r} & V_{r} \le V^{t} \le V_{cut-out} \\ 0 & V^{t} \succ V_{cut-out} \end{cases} \qquad t = 1, 2, \ldots, T \qquad (5)$$

With:

Pr: is the rated power of wind turbine generator,

Vcut-in: Starting speed for which the wind turbine begins to produce energy.

Vr: is the nominal speed of the wind turbine

Vcut-out: represents the maximum speed for which the production is stopped by reason of security and the turbine is put in flag.

For applications in engineering wind energy, the estimate of the average power produced by a wind turbine, necessarily passes through the knowledge of the wind speed at the height of its hub. To obtain data for wind speeds at a desired height, we must proceed to a vertical extrapolation of wind speeds measured generally to the standardized height of 10 meters above the ground, using the model of power (Justus and Mikhail 1976), often used in the existing literature

$$\frac{V}{V_{data}} = \left(\frac{Z}{Z_{data}}\right)^{\alpha} \tag{6}$$

As α is given by the power law Justus C.G. and Mikhail 1976 [6]

$$\alpha = \frac{0.37 - 0.088\ln(V_{data})}{1 - 0.088\ln\left(\frac{Z_{data}}{10}\right)} \tag{7}$$

$$\mathrm{E}_{\mathrm{wt}}^{\mathrm{t}} = \mathrm{P}_{\mathrm{wt}}^{\mathrm{t}}.\Delta\mathrm{t} \qquad \mathrm{t=0,\ldots..,T-1} \tag{8}$$

The power produced is overall:

$$Eg(t) = Npv.Epv(t) +.Ew(t) \tag{9}$$

3.5.3 Case Battery bank Model

Battery is defined as a combination of individual cells. A cell is the elemental combination of materials and electrolyte constituting the basic electro-chemical energy store. A storage cell is recharged after discharge by passing a direct current through the cell in the opposite direction to the discharge current. In other words, battery is used as a backup for long run applications means it stores the excess energy generated by hybrid energy system and supply that energy during low generation period (M.K. Deshmukh.2008).

a). Total Power Generation (solar + wind) > load demand

If total power generation; (combination of solar and wind) of hybrid system is greater than load demand then load will be supplied and excess power is used to charge the battery

Battery charging:

$$E(t) = E(t-1) \times (1 - \sigma) + \left(Egen(t) - \frac{El(t)}{\eta inv}\right) \times \eta B \qquad (10)$$

b). Total power generation (solar + wind) < load demand

Load will be supplied + Battery discharging

If total power generation (combination of solar and wind) of hybrid system is less than load demand Battery discharging:

$$E(t) = E(t-1) \times (1 - \sigma) - \left(\frac{El(t)}{\eta inv} - Egen(t)\right) \qquad (11)$$

Where:

E (t) and E (t-1) charge of battery bank (Wh) at the time (t) and (t – 1) respectively; σ is hourly self-discharge rate; Egen (t) is the total energy generated by PV array and wind generators after energy loss of controller;

El (t) is load demand at the time t; η_{inv} and η_B are the efficiency of inverter and charge efficiency of battery bank, respectively.

The storage capacity of the battery (Wh) is calculated using Eq (Khatib, 2011):

$$Cb = \frac{EL \times AD}{(\eta V \times \eta B \times DOD)} \qquad (12)$$

Where:

DOD is allowable depth of discharge of the battery,

AD is number of autonomy days

Number of battery: $$Nb = \frac{Cb}{CB} \qquad (13)$$

Where:

CB: is the storage capacity of a single battery ;(nominal), Cb is the sizing storage capacity of the battery en Wh.

3.5.4 Case Hydrogen Model

A- PEM Fuel Cell (PC)

A simplified model of fuel cell is used in this chapter. We assume that the fuel cell works to a fixed point of operation, (Victor M.2014) so that the produced power (P_{PC} (t)) is defined by:

$$P_{PC}(t)=\left(\frac{P_{ch}(t)}{\eta_{inv}}-P_g(t)\right)\Big/\eta_{PC} \tag{14}$$

Where ηPC ηinv and are the effectiveness of the PEM and the inverter, respectively; Pg (t) is the power developed by the wind generator and the PV during each hour.

$$P_g(t)=P_{PV}(t)+P_{WT}(t) \tag{15}$$

A time step of an hour is used. As well, the powers products are equivalent to the energies produced at a particular time, as it is indicated to the equations (16) and (17).

$$P_g(t)=E_g(t) \tag{16}$$

$$P_{ch}(t)=E_{ch}(t) \tag{17}$$

B- Electrolyze

The power transferred of electrolyze to the hydrogen Tank can be defined as follows (Victor M, 2014)

$$E_{elect}(t)=\left[E_g-E_{ch}(t)/\eta_{inv}\right].\eta_{elect} \tag{18}$$

C- Reservoir of hydrogen

We assume that the electrolyze operates at a constant point, so that the hydrogen produced by the electrolyze is proportional to its effectiveness. The energy equivalent of hydrogen is taken of the electrolyze and it is stored in the tanks of hydrogen.

If the power developed the system is greater than the load demand at time t, electrolyze will be employee to fill the tank of hydrogen, which is described by the equation (AK. Maleki.2014)

$$E_{stok}(t)=E_{stok}(t-1)+\left[E_g(t)-E_{ch}(t)/\eta_{inv}\right].\eta_{elect} \tag{19}$$

Where E_{Stok} (t) and E_{Stok} (t -1) are the energy stored in the tank of hydrogen to hours (t) and (t -1), respectively, the ηinv is the inverter efficiency, η_{Elect} is the electrolyze efficiency.

When the application of the load is greater than the energy produced by the system, the PEM is used to provide the load. In this case, the amount of hydrogen in the tank to the time t is obtained by:

$$E_{stok}(t)=E_{stok}(t-1)-\left[E_{ch}(t)/\eta_{inv}-E_g(t)\right]/\eta_{pC} \tag{20}$$

Where: the η_{PC} is the PEM efficiency

The mass of the hydrogen stored at any time t is calculated as follows (A. Kashefi, 2009):

$$m_{stok}(t) = \frac{E_{stok}(t)}{HHV_{H_2}} \quad (21)$$

Where: ($HHVH_2$), the calorific value higher of hydrogen is equal to 39.7 kWh/kg. It should be noted that there are lower and upper limits for the quantity of the hydrogen stored. It is not possible that the mass of the hydrogen stored exceeds the estimated capacity of the tank. On the other hand, due to some problems, for example, drop in pressure of hydrogen, a small fraction of the hydrogen (here, 5%) cannot be extracted. This fraction is the lower limit of the stored energy, therefore.

3.6.3. Hydrogen fuel cell for cooking

Using H2 as fuel cell for cooking and heating and fed directly the stove to burning H2

Low heating=120Mj/kg

High heating=142Mj/kg

In condition 700 bar (30 Kg----1m3)

Average heating= 130Mj/kg

1Mj=0.2777kWh

130Mj/kg*0.2777kWh=36.1 KWh/kg

(Energy*0.9)/ 36.1 KWh/kg = Mass H2 (kg)   (22)

3.7. Analysis of the System Cost

A-The initial cost:

The analysis of cost is necessary to utilize the renewable energy resources efficiently and economically. There are many ways to calculate the system cost. Here the concept of life cycle cost of system, consisting of the initial capital cost, the operation and maintenance cost and the components replacement cost, is adopted in this paper, which is expressed by the following equations (Ak Maleki.2014) :

Battery bank

$$Ci = Nwt*Cwt + Npv*Cpv+Nb*Cb+ Cinv \quad (23)$$

Hydrogen

$$Ci = Nwt*Cwt + Npv*Cpv + Cstok +Cele+Cpem+Cinv+Ccomp \quad (24)$$

With:

Cb: The initial cost of battery bank ($)

Cwt: The initial cost of the wind turbine system ($).

Cpv: The initial cost of the photovoltaic system ($).

Cstok: The initial cost of the system of storage ($).

Cele: The initial cost of electrolyze ($).

Cinv: The initial cost of the inverter ($).

Cpem: The initial cost of fuel cell ($).

B-Operation and maintenance cost

Assessment of operation and maintenance cost of the hybrid system describe by the equation:

Battery bank

$$\mathrm{Cm} = (\mathrm{Nwt} * \mathrm{Cwt} * \mathrm{Mw} + \mathrm{Npv} * \mathrm{Cpv} * \mathrm{Mpv} + \mathrm{Cinv} * \mathrm{Minv})\mathrm{dvsys} \qquad (25)$$

Hydrogen

$$\mathrm{Cm} = (\mathrm{Nwt} * \mathrm{Cwt} * \mathrm{Mwt} + \mathrm{Npv} * \mathrm{Cpv} * \mathrm{Mpv} + \mathrm{Cstok} * \mathrm{Mstok} + \mathrm{Cele} * \mathrm{Mele} + \mathrm{Cpem} * \mathrm{Mele} + \mathrm{Cinv} * \mathrm{Minv} + \mathrm{Ccomp} * \mathrm{Mcomp})\mathrm{dvsys} \qquad (26)$$

M: Percentage of each component [%]

dvsys: Life of the system [years]

C- Replacement cost:

Each component of the system has time; it must then be replaced on the duration of operation of the system.

Battery bank

$$\mathrm{Cr}=(\mathrm{Nwt}*\mathrm{Cwt}).\frac{dvsys-dwt}{dvwt} + (\mathrm{Npv}*\mathrm{Cpv}).\frac{dvsys-dvpv}{dvpv} + \mathrm{Cinv} * \frac{dvsys-dvinv}{dvinv} + (\mathrm{Nb} * \mathrm{Cb}).\frac{dvsys-dvb}{dvb} \qquad (27)$$

Hydrogen

$$\mathrm{Cr}=(\mathrm{Nwt}.\mathrm{Cwt}).\frac{dvsys-dwt}{dvwt} + (\mathrm{Npv}.\mathrm{Cpv}).\frac{dvsys-dvpv}{dvpv} + (\mathrm{Nstok}.\mathrm{Cstok}).\frac{dvsys-dvstok}{dvstok} \qquad (28)$$

dvwt , dvpv , dvinv,dvb , dvstok , it is the life time respectively of the wind system, the photovoltaic system, of the storage system and the inverter. Usually the wind generator and the photovoltaic generator have life time close to the life of the system therefore a cost of replacing zero. The overall cost for the duration of operation is given by:

$$\mathrm{Cg} = \mathrm{Ci} + \mathrm{Cm} + \mathrm{Cr} \qquad (29)$$

A Matlab computer program developed based on the above methodology. Fig. 3 shows the flowchart of this program.

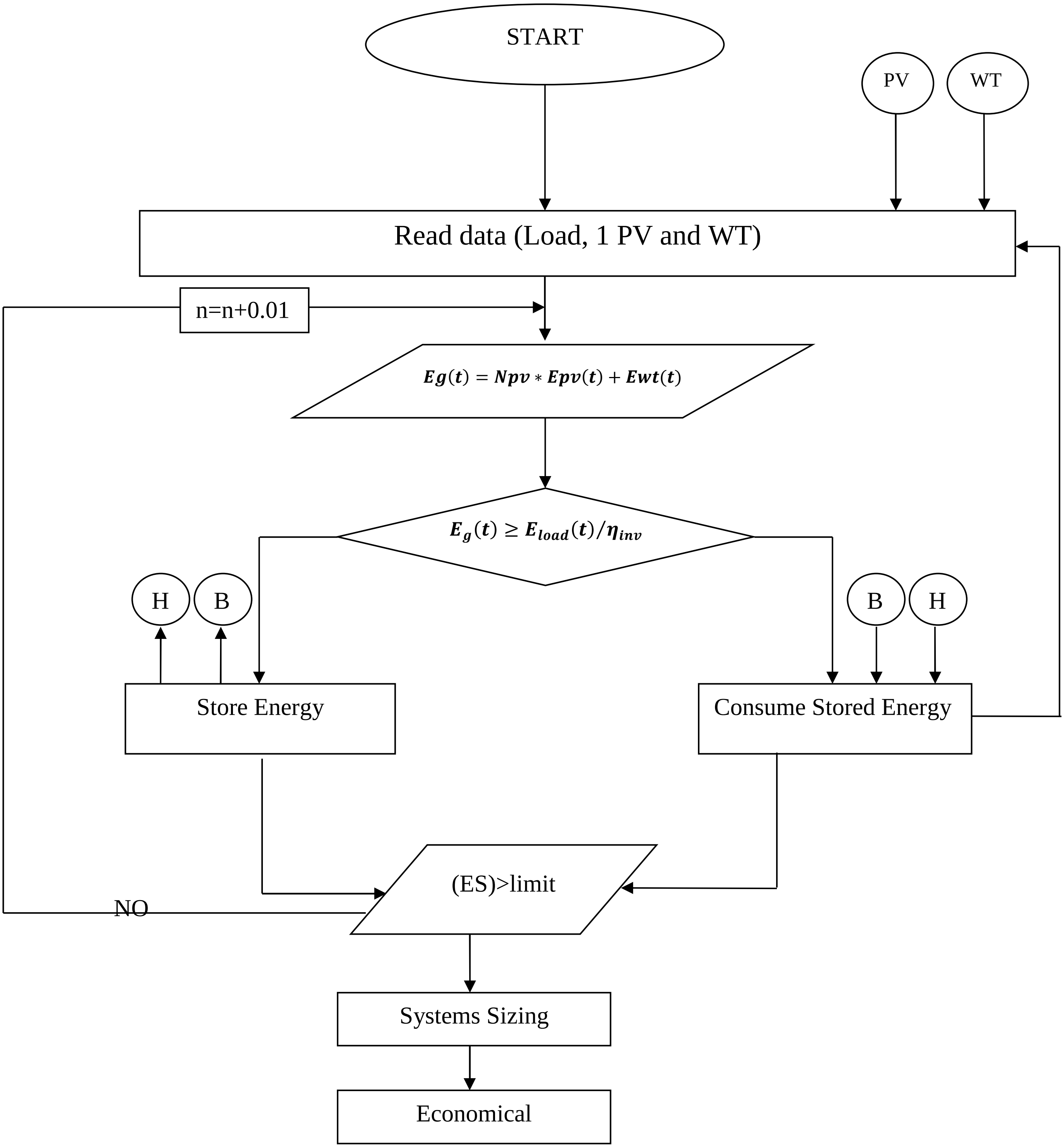
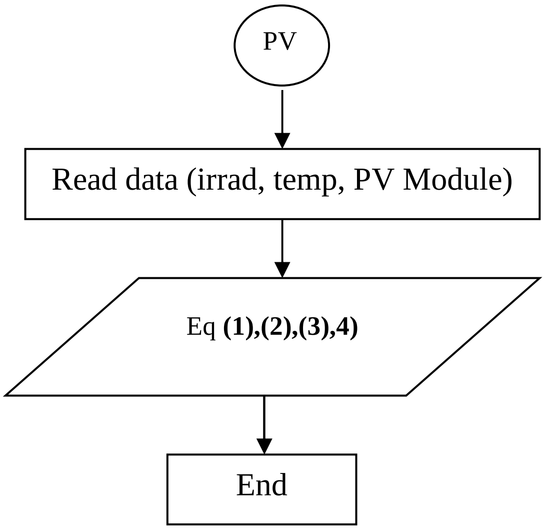
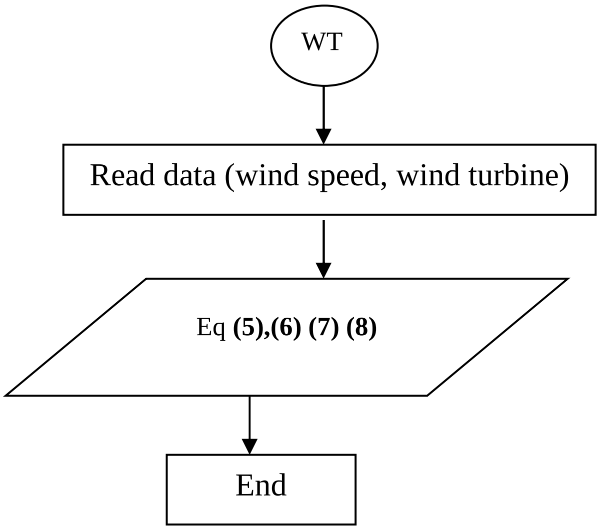
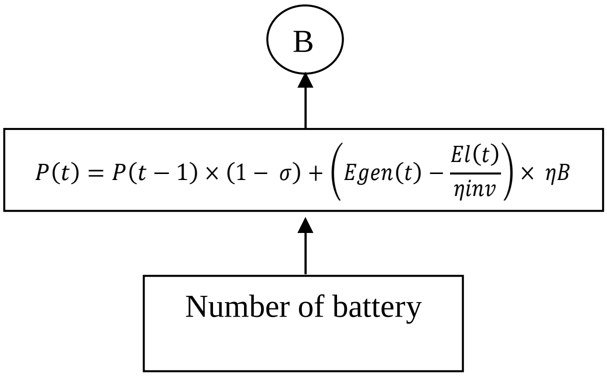
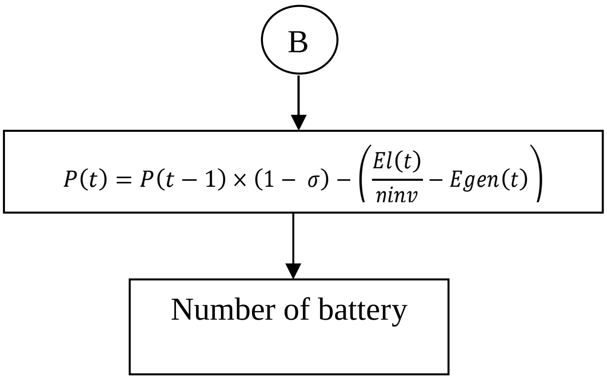


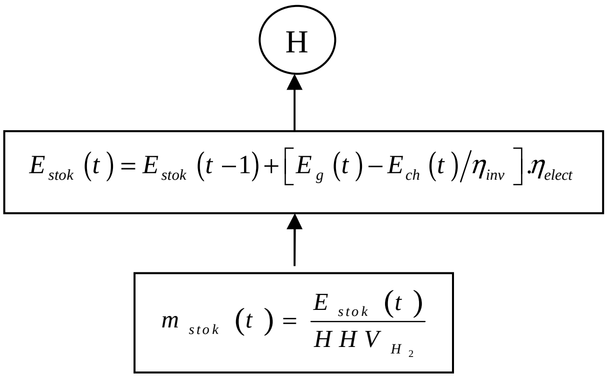
Fig. 3 shows the flowchart of this program.

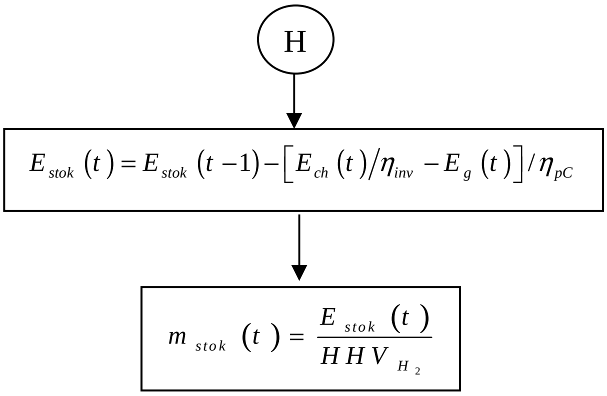












Conclusion:

In recent years, the use of renewable energies such as photovoltaic and wind power is in strong growth for the production of electricity. But these systems must be hybrid combine with other sources of energy such as Batteries and hydrogen which can be produced by electrolysis, then stored and finally, reused by a fuel cell to produce electrical energy. In this chapter we show weather data of solar and wind, and calculate loads of stand-alone house based on the work of (R. Ghedamsi ET al.2016). from cite of Ouargla then, we present the mathematical models of the different electric components.

Chapter 04:Results and discussins

In this chapter, we present and discuss the main results of the three scenarios

A simulation program has been developed by Matlab predict the behavior of the entire system. The framework of a preliminary study aimed to assess the interest of the implementation of a hybrid PV/wind system in a given place. Then ,the simulation has been applied to a defined Algerian site (in Ouargla region), where the data of 12 months (a typical day of each month) have been taken, solar irradiation, ambient temperature and wind speed. The input data contains the characteristic of PV, WT, inverter, controller, and tow storage options (batteries or hydrogen tank, electrolyze and PEMFC). The load needed to be covered was taken differently, in the first and second scenarios when cooking, heating and hot water appliances are supplied by electricity, however, in the third scenario, and they are fed directly by burning H_2.

As previously mentioned, the area of this study is considered in the site of Ouargla, which is located in the South East of Algeria. Ouargla has a hot desert climate, long hot summers and short cold winters. Averages high temperatures in summer are consistently over 40 °C for nearly 4 months (June, July, August and September) and reach a maximum of around 45 °C in July. Averages low temperatures in summer are also very high, and are above 27 °C and routinely above 30 °C during the hottest month.

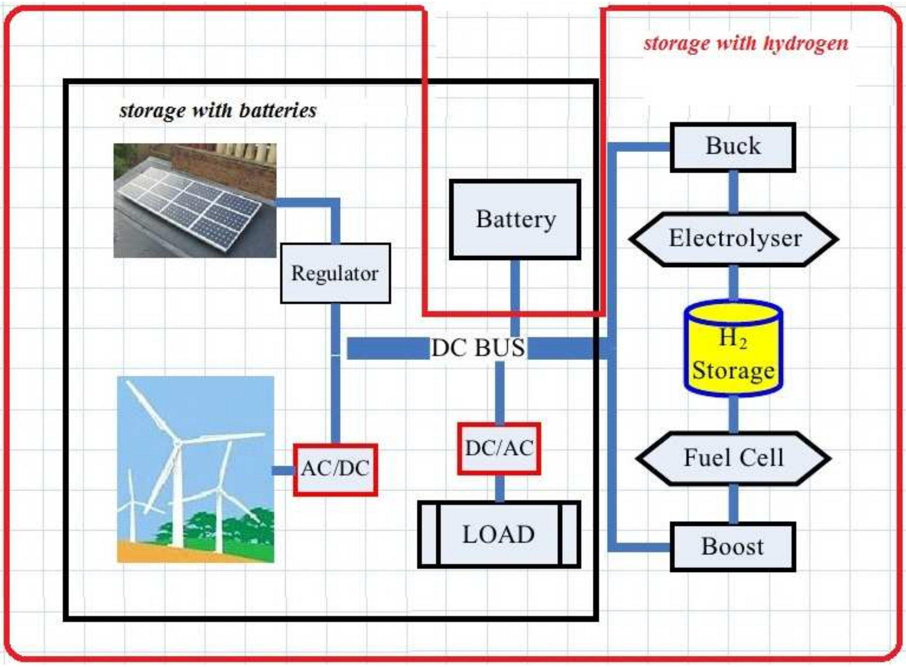


Figure. 4.1: Schematic of hybrid system with storage

The optimization of the system aims to generate energy satisfying the dynamic demands, which corresponds to real data of a household (of eight persons) in the region of Ouargla.

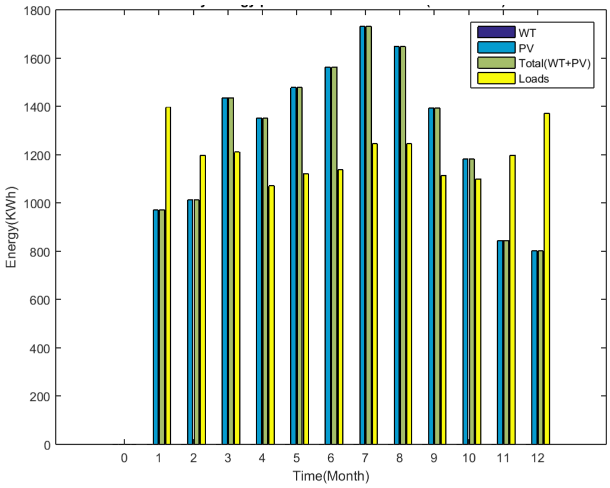
The energy produced by WT or PV modules can be directly used to satisfy a part of the electrical demand. The surplus energy can be stored to the storage system. In other words, the storage system supplying electricity when the production of electricity by RE resources is less than electricity load (R. Ghedamsi ET al.2016).In the following chapter, we present the results of three scenarios;

- hybrid system with battery storage option
- hybrid system with hydrogen storage option
- hybrid system with hydrogen for cooking, heating and hot water

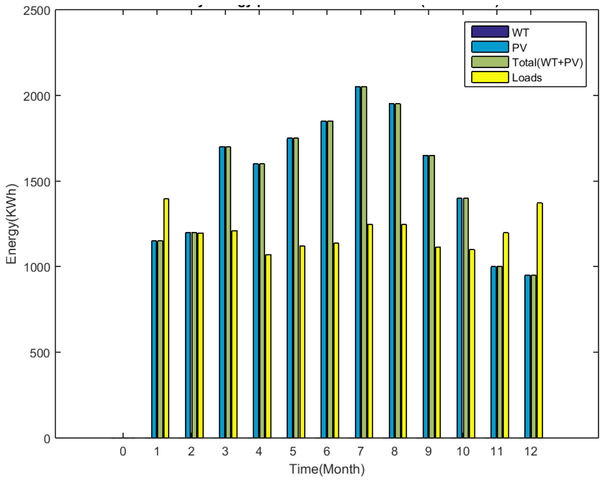
Noting, for all economic analysis, the costs are given in Algerian Dinar (1 $= 108.32 DZD) and the year 2017 is considered as a reference of estimation starting.

4.1. Case of hybrid system with battery storage

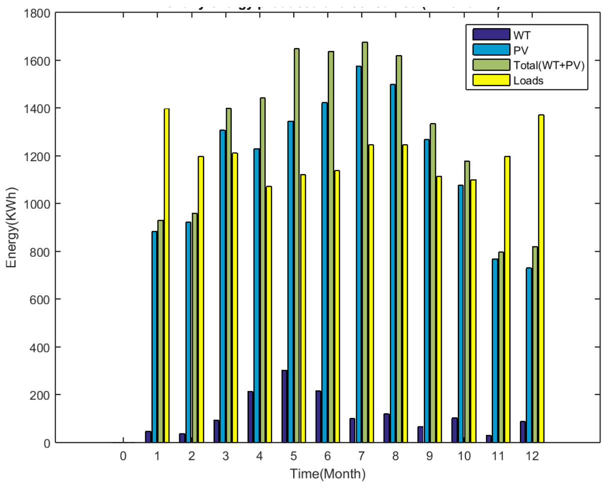
The graphs in figures4.2 represent the profiles of energy consumption (load) and energy production by PV and WT during 2016 (12 months). The storage provides by batteries.

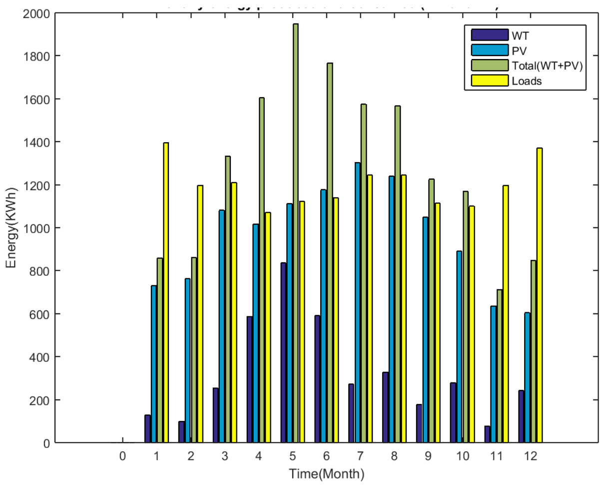


0kW-WT/42-PV/322-B

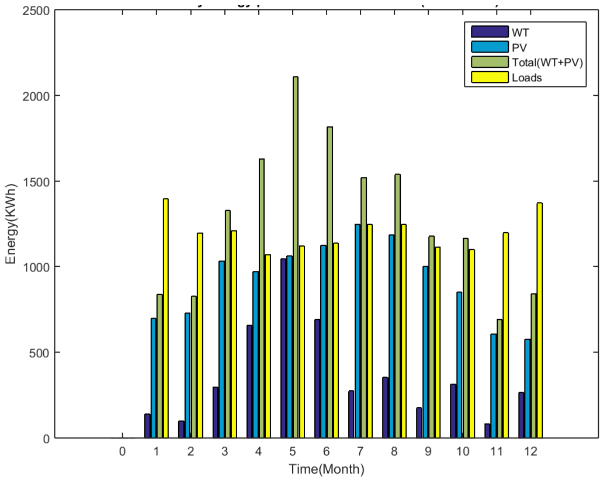


0kW-WT/50-PV/161-B

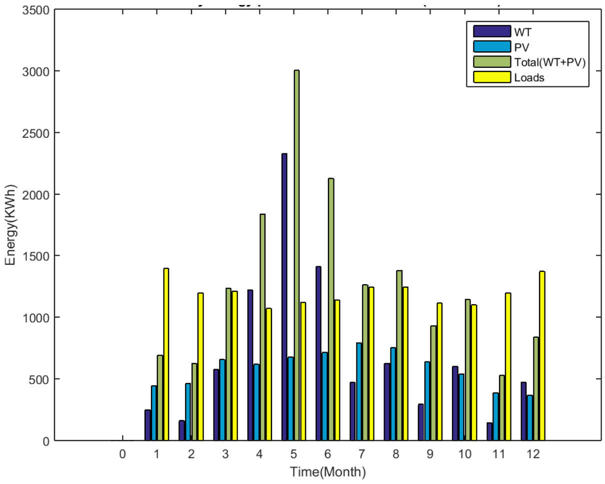




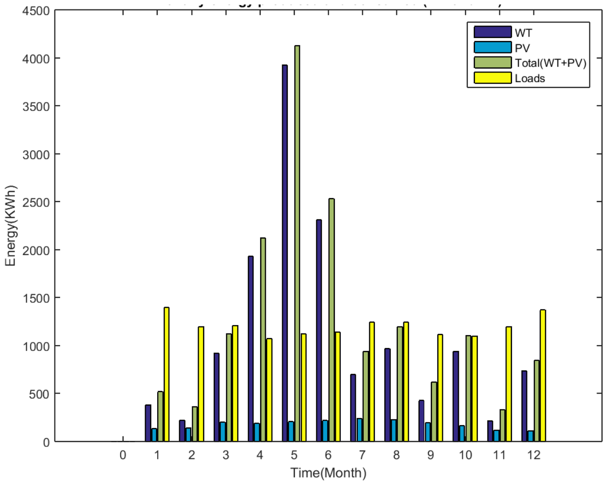
0.6kW-WT/38-PV/363-B



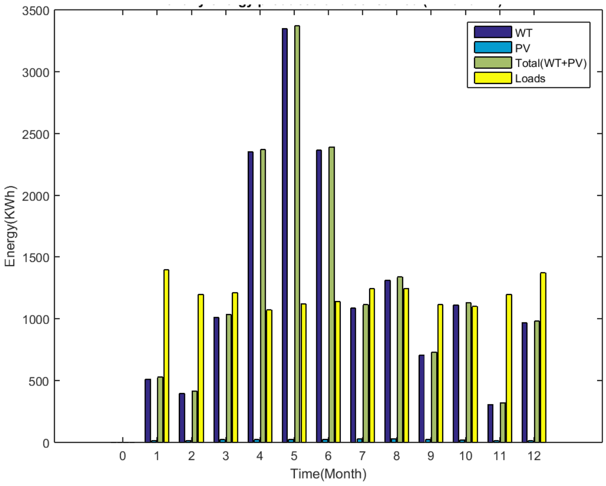
1kW-WT/33-PV/417-B



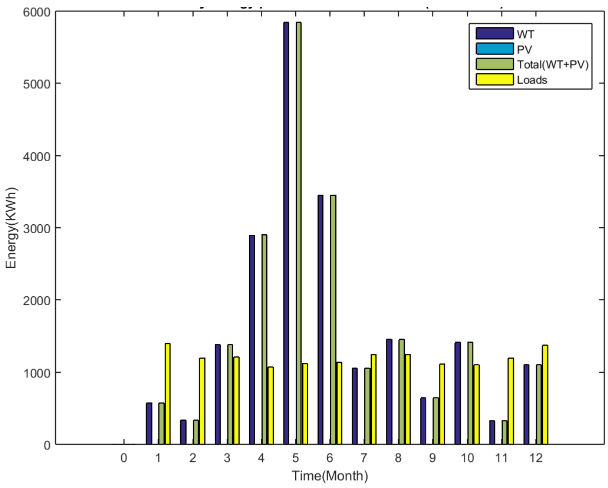
2kW-WT/29-PV/461-B



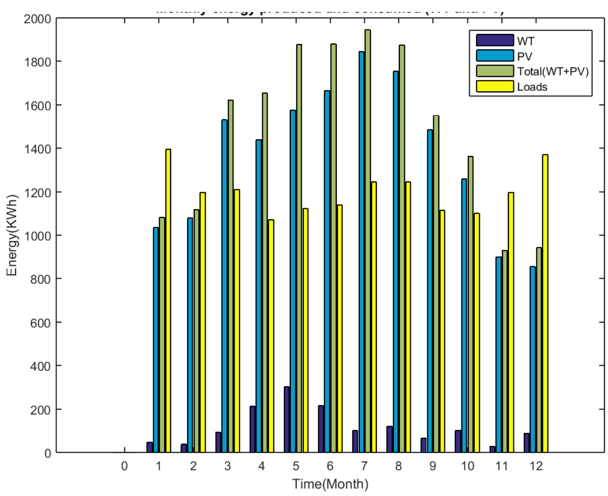
3kW-WT/19-PV/617-B



5kW-WT/6-PV/853-B



6kW-WT/01-PV/866-B



10kW-WT/0-PV/790-B **0.6kW-WT/45-PV/227-B**

Figure4.2: Monthly energy production (wind and PV) and consumption

The monthly mean electric production from PV array and wind turbine is presented in figure4.2. The PV output was extremely high in the summer and spring months, particularly, from Jun to September. This is a favorable characteristic for summer due to high cooling load. In other hand, electricity demand is stronger in winter because of using electric cooker and heater (consume high energy). The wind energy contribution was found to be significant in April, May and Jun but less in other months. Solar energy is typically available during the middle of the day. But the wind is related to weather condition. As you see from the graphs, energies produced from both WT and PV in winter is insufficient, therefore, the storage system is highly required. The excess electricity was used to charge the battery bank and reuse it when needed.

Figure4.3 shows the variation of batteries number as function of PV panels and WT model.

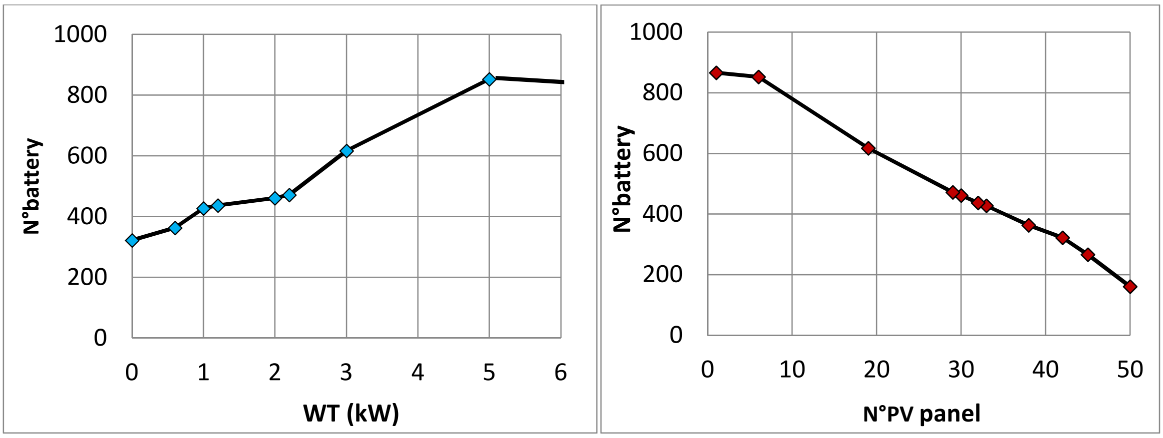


Figure4.3: N° battery as function of WT &PV panels

From the profiles of energy demand and energy production, we can deduce that, in general, when augment the share of photovoltaic, the number of required batteries decreases due to the continuous availability of solar in all months comparing to wind. When, augment the size of turbine so add photovoltaic modules, also the number of batteries decreases due to the surplus energy production. However, we should carefully take care to the minimum number of batteries, taking into consideration the energy needed when the absence of production (i.e. daylight and weather conditions). As an example, we found that in December (which has the lowest production and one of the most consumption) the energy is not enough to cover the load (consume44kWh and produce 44kWh by 72 PV in one day, min of 10batteries).Furthermore, the weather condition such as, cloudy days with low wind speed, therefore, the total absence of production for several days, makes the minimum number of batteries (for 5 days in December, min of 91 batteries).

Table 4.1 presents the cost of different configurations of hybrid system with initial and maintenance costs in order to choose the most suitable configurations of WT/PV/batteries for a stand-alone house in the region of Ouargla sites. The prices of the components were taken from the most popular companies in this domain; finally the costs were compared and averaged to reach the most reasonable total cost.

Table4.1: Cost of different configurations (hybrid: WT/PV/Batteries)

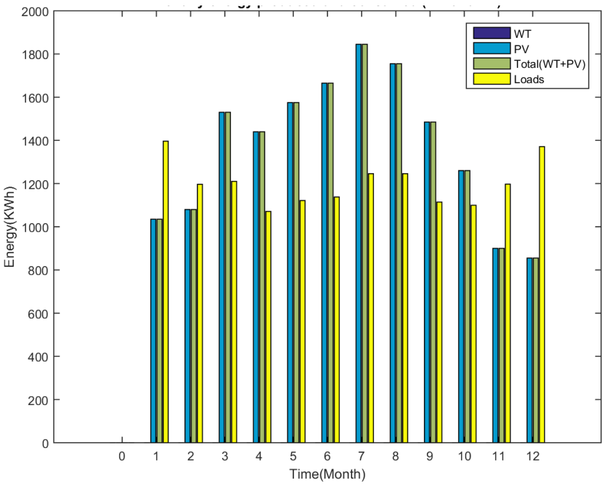
N° WT (kW)	N° PV	N° Batteries	Initial cost ($)	R & M COST for 20 years ($)	Total cost
0	50	161	18250	6896,5	46640
0	45	266	22500	8229	66240
0	42	322	24700	8913	76600
0.6	38	363	26310	9485,5	84256
1-Ur8	33	428	29470	10856	97464
1-Ur10	32	437	29620	10904,5	98864
2-Ur8	30	461	30530	11206,5	103280
2-Ur10	29	472	30920	11332	105264
3	19	617	37150	13560,5	133080
5	6	853	48150	17614,5	179640
6	1	866	48300	17729	181640
10	0	790	49500	19635	174600
15	0	540	41200	18150	131440
0,6	45	227	21220	38484	59704

Cost evaluation helps designers and users to choose the most suitable configuration WT/PV/batteries for an isolated house. The choice of these elements is very important parameter to achieve economic viability. The table above shows an increase in total cost when using a higher number of batteries (maintenance and changing batteries every 5 years), so adding PV panels for production electricity gives many benefits to reduce this increase.

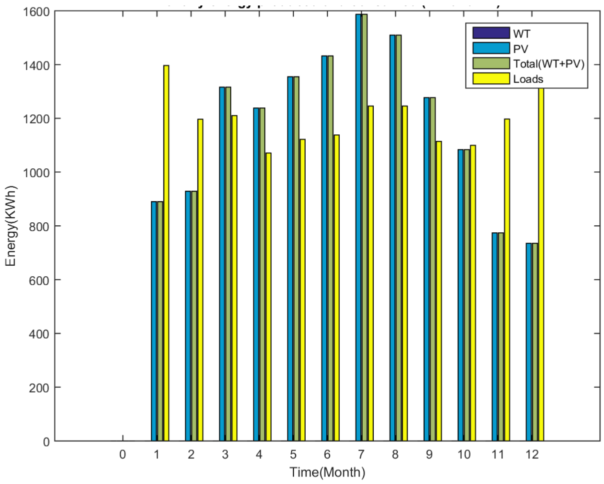
Even with using higher power WT, number of batteries remains almost the same and the total cost augments due to the increase in WT initial and maintenance costs.

4.2. Case of hybrid system with hydrogen storage

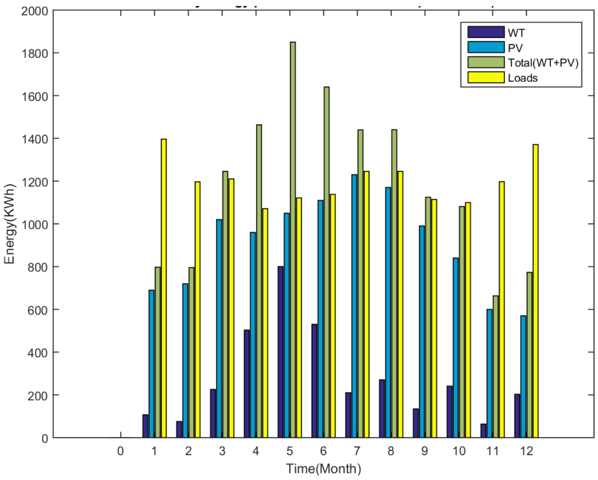
The graphs in figures4.4 represent the profiles of energy consumption (load) and energy production by PV and WT during 2016 (12 months). The storage provides by hydrogen system.



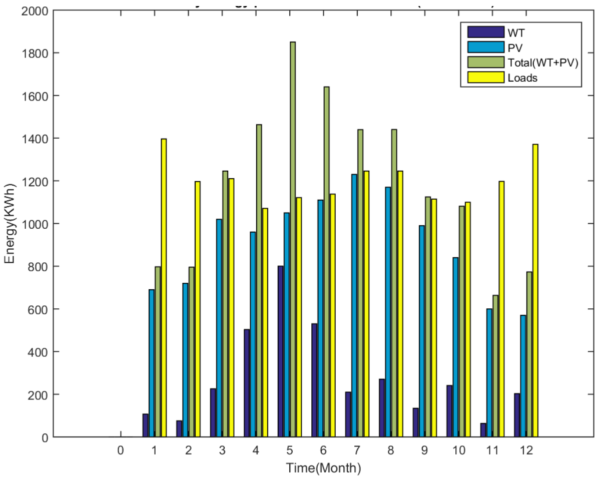
0kW-WT/45-PV/28- kg



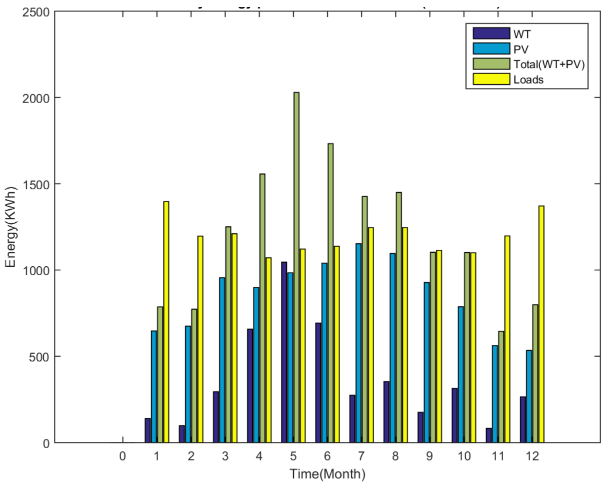
0kW-WT/39-PV/42- kg



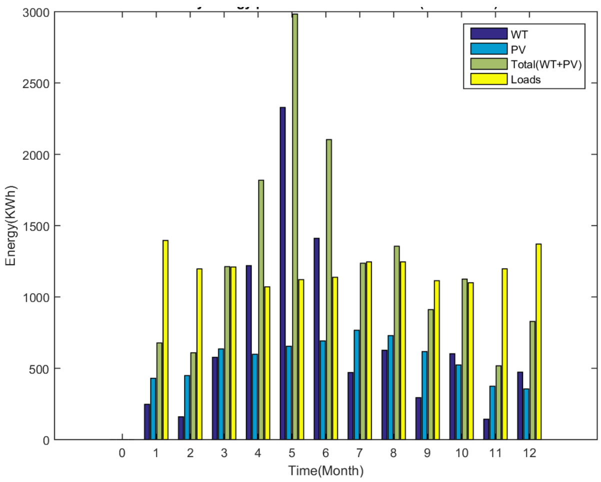
1kW-WT/30PV/52-kg



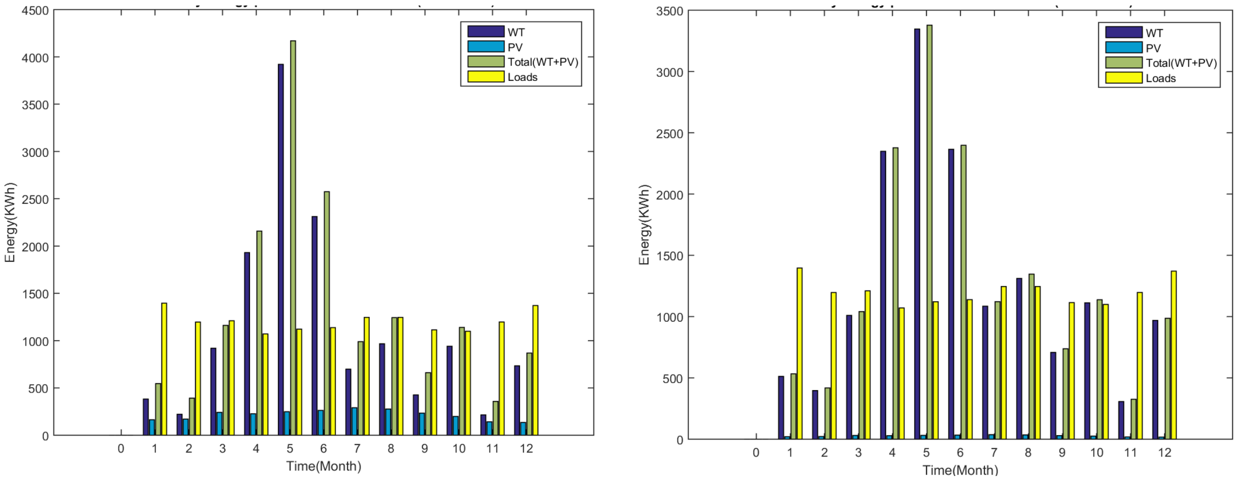
0.6kW-WT/35-PV/46-kg



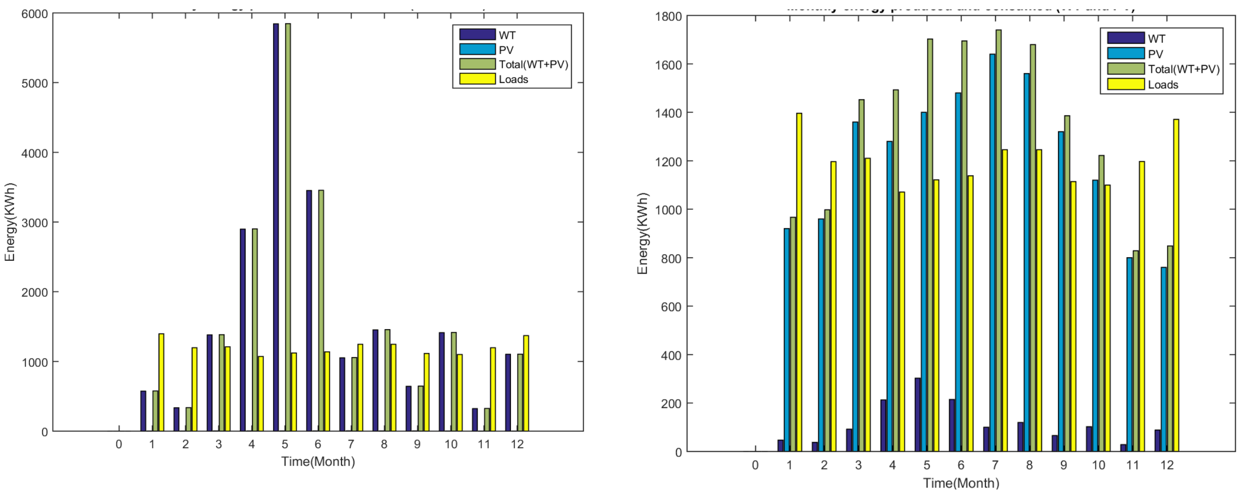
2kW-WT/28-PV/54-kg



3kW-WT/19-PV/66-kg



5kW-WT/7-PV/87-kg **6kW-WT/0-PV/92-kg**



10kW-WT0-PV/83-kg **0.6kW-WT40-PV/35-kg**

Figure4.4: Monthly energy production (wind and PV) and consumption

We can notice that the PV output was high in summer and spring months and the wind energy contribution is significant in April, May and Jun (as the first case). Electricity demand is high in winter (also the same reason, cooking, heating, and hot water by electricity). As you see from the graphs, energy produced from both WT and PV in winter is insufficient; therefore, the storage system is highly required. The excess electricity was used to produce hydrogen and reuse it when required.

We can also notice that there was a slight reduction in PV and WT, which is mainly due to differences in storage systems (batteries have a self discharge rate may reach 3% per month.

The distribution of hydrogen storage produced by the generators; PV and WT at the site of Ouargla is illustrated below in figures 4.5.

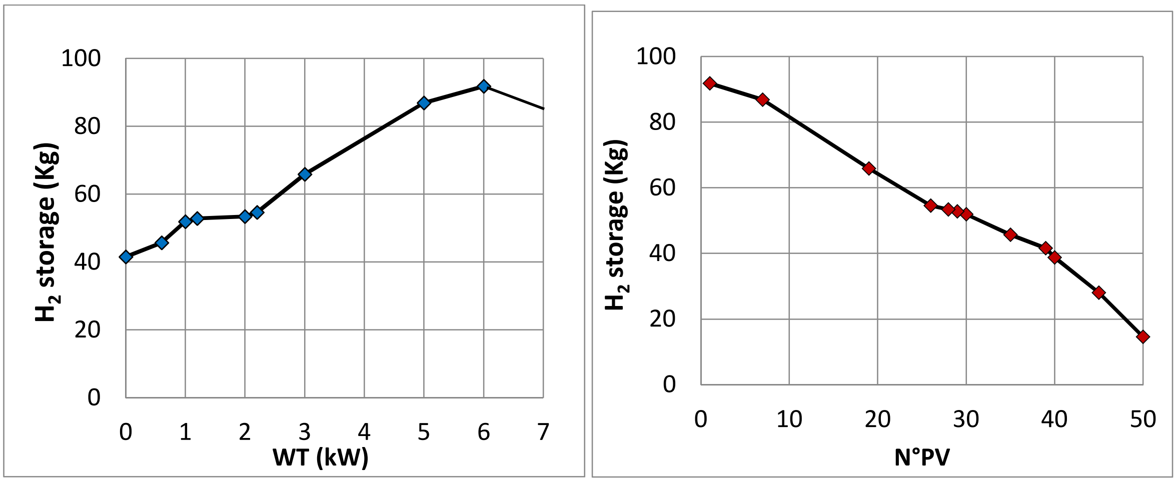


Figure4.5: Amount of hydrogen as function of WT &PV panels

When augment the size of turbines or add photovoltaic modules, the amount of hydrogen stored decreases due to the surplus energy production. There is a minimum hydrogen storage, taking into consideration the energy needed when the absence of production (i.e. daylight and weather conditions). This minimum is for one day in December, consume 44kWh and produce 44kWh by 72 PV in one day, min of 0.5kg). Also if cloudy days with low wind speed so, the total absence of production for several days, makes the minimum hydrogen storage (for 5 days in December, min of 7Kg).Whenever add panels the mass of hydrogen decrease.

The Table 4.2 shows the possible cost of the hybrid system studied which meet the needs of the load during one year.

Table 4.2: Cost of different configurations (hybrid: WT/PV/ Hydrogen)

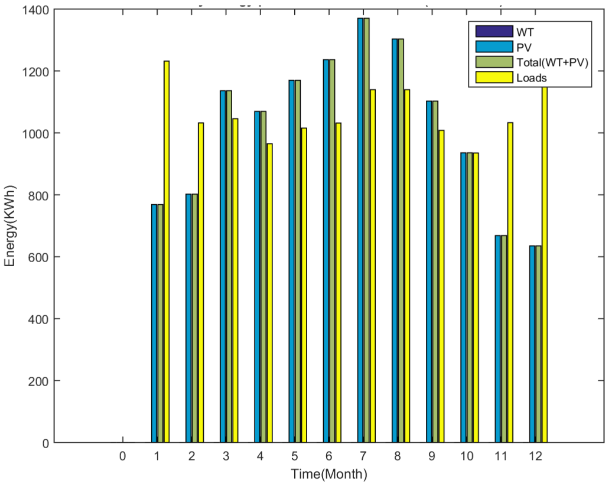
PV Panel		WT				Cost of component		Cost($)		Total cost ($)
Number	Cost($)	Model	Cost($)	DC/AC DC/DC	Tank($)	PEMF C($)	Ele ($)	I c	M	
50	10000	0	0	300	2545	10000	10000	43665	53271	96936
45	9000	0	0	260	2765	20000	5500	39255	44959	84214
40	8000	0	0	260	3895	20000	5500	38255	44501	82756
39	7800	0	0	100	3895	10000	10000	32395	37475	69870
40	8000	0.6kw	360	100	3900	6225	5500	24100	23467	47567
35	7000	0.6kw	360	100	3895	6225	5500	23885	23604	47489
30	6000	1kw/10	750	260	3895	6225	7000	25270	26195	51465
29	5800	1kw/8	850	260	3895	6225	6400	24570	25083	49653
28	5600	2kw/10	960	260	3895	6225	7000	24415	26214	50629
26	5200	2kw/8	1000	260	4110	6225	7000	25055	26054	51109
19	3800	3kw	1900	300	4435	6225	10000	27595	31362	58957
7	1400	5kw	3500	400	5000	10000	20000	40900	54959	95859
1	200	6kw	4000	400	5000	10000	10000	30200	36710	66910
0	0	10kw	9000	500	4770	10000	30000	55100	75640	130740

0	0	15kw	13000	600	3895	6225	50000	75195	108350	183545

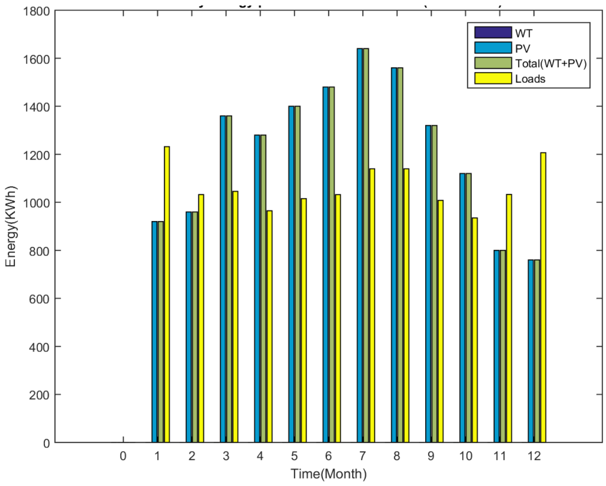
The choice of suitable configuration WT/PV/hydrogen storage for an isolated house is very important in order to achieve economic viability. The table above shows a preferable cost for hybrid system against single PV or WT. The total cost increases when using more PV panels or high WT model (different components of hydrogen storage remain almost with the same except hydrogen storage tank), so adding PV panels for production electricity cannot give the same benefits contrary to the first scenario.

4.3. Case of hybrid system with hydrogen for cooking, heating and hot water

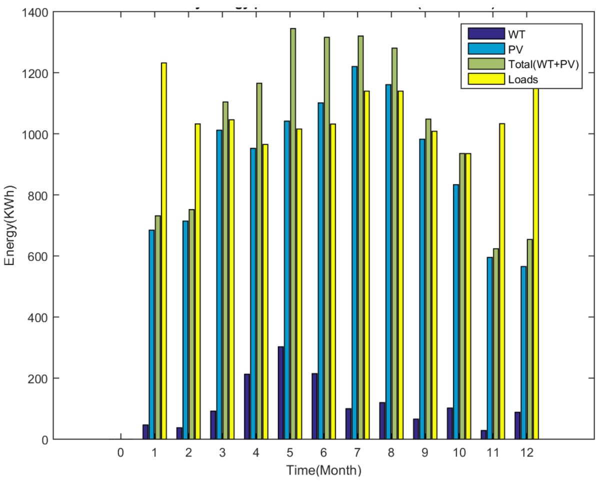
The graphs in figures4.4 present the profiles of energy consumption (load) and energy production by PV and WT during 2016 (12 months). The storage provides by hydrogen system. In this case cooking, heating and hot water are provided by direct burning of hydrogen.

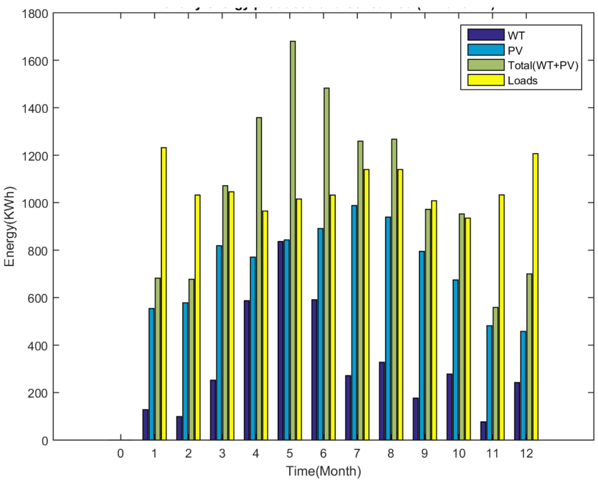


0kW-WT/33-PV/37- kg

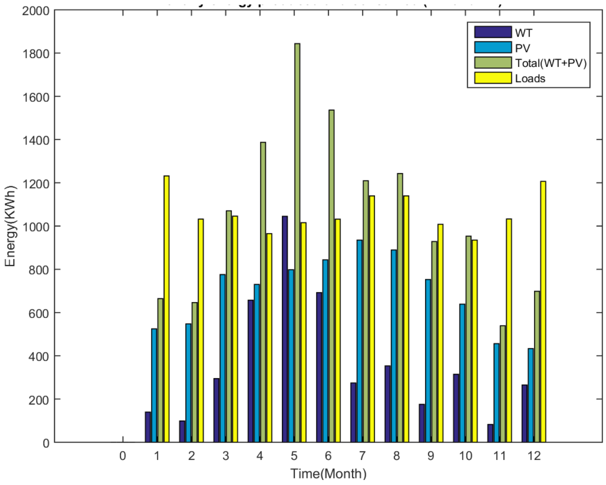


0kW-WT/40-PV/23- kg

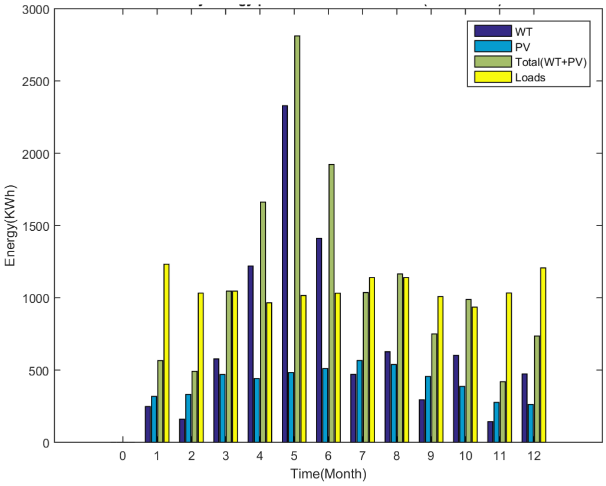




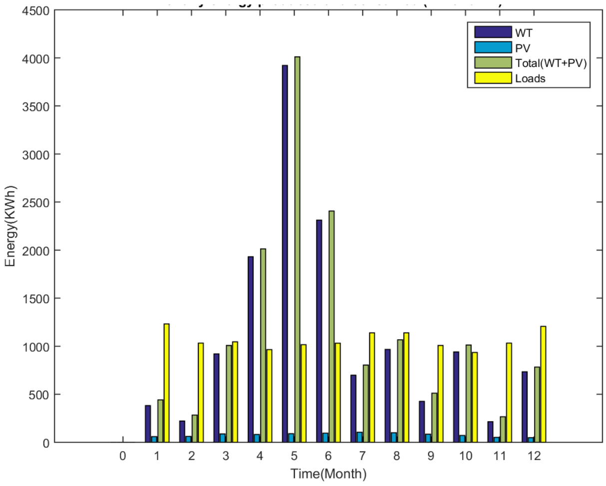
0.6kW-WT/30-PV/41- kg



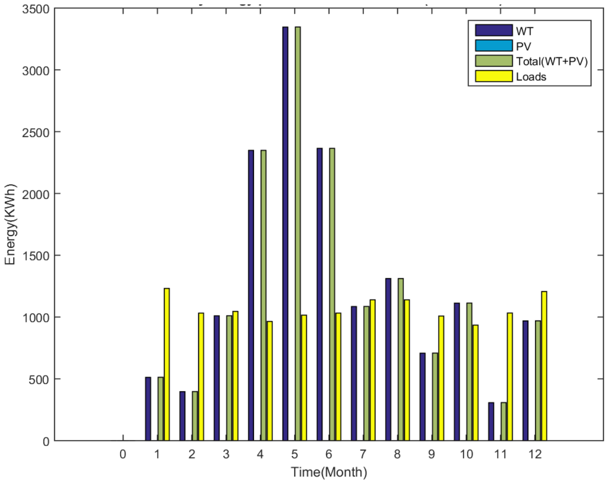
1kW-WT/24-PV/47- kg



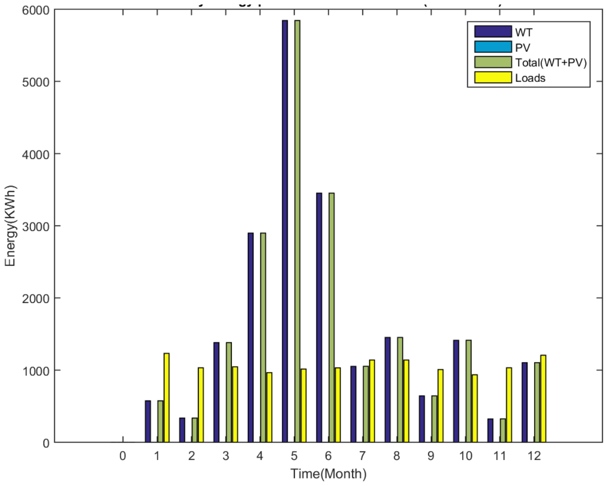
2kW-WT/23-PV/49- kg



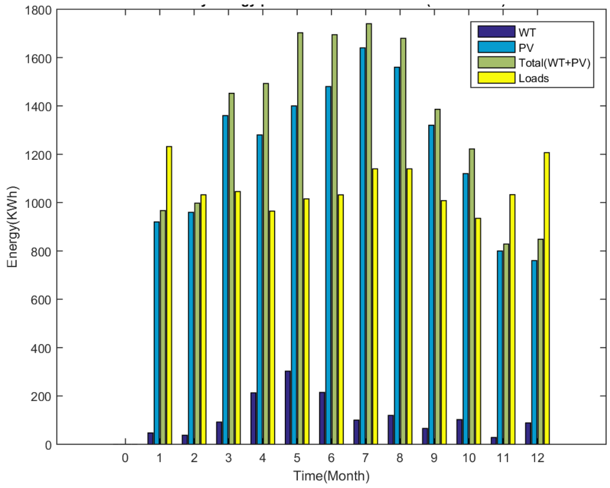
3kW-WT/14-PV/61- kg



5kW-WT/3-PV/80- kg



6kW-WT/0-PV/71- kg



10kW-WT/0-PV/67- kg **0.6kW-WT/40-PV/19- kg**

Figure4.5: Monthly energy produced and consumed (wind and PV)

We notice a considerable reduction in electricity demand because in this case, cooking, heating, and hot water by direct burning of hydrogen. As you see from the graphs, energy produced from both WT and PV in winter is insufficient; so, the storage system is highly required for electricity production by PEM and direct burning of hydrogen.

We can also notice that there was a remarkable reduction in PV and WT, which is mainly due to reduction in electricity demand.

The distribution of hydrogen storage produced by the generators; PV and WT at the site of Ouargla is illustrated below in figures 4.6

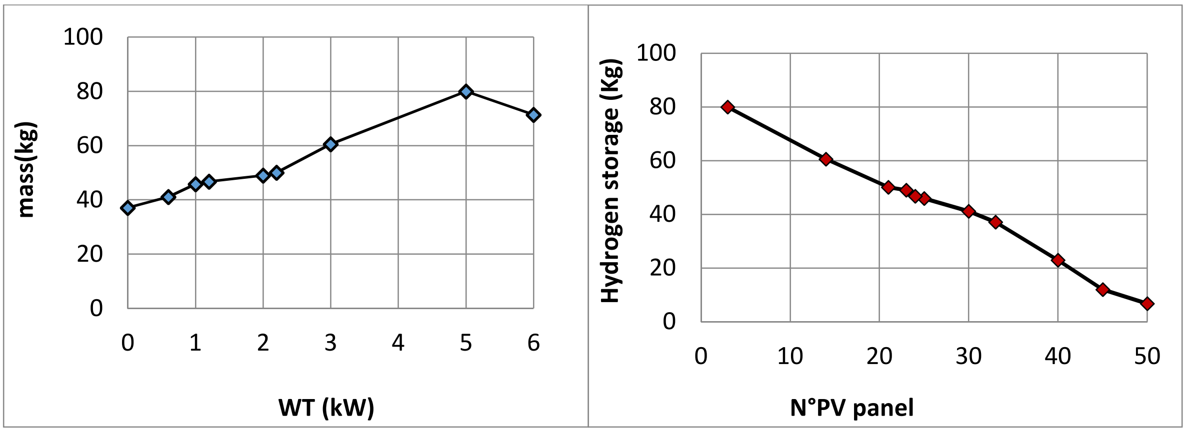


Figure 4.6: Amount of hydrogen as function of WT &PV panels

Table 4.3 shows the possible cost of the hybrid system studied which meet the needs of the load during the year.

Table 4.3: the cost of each component and case using hydrogen for cooking and heating

PV Panel		WT		Cost of component				Cost($)		
Number	Cost($)	Model	Cost($)	DC/AC DC/DC	Tank($)	PEMFC ($)	Ele ($)	Initial cost	reparation (20 year)	Total ($)
45	9000	0	0	260	2000	2000	7000	21405	20354	41759
40	8000	0	0	260	2545	3000	5500	20116	18744	38860
33	6600	0	0	100	3895	6225	5500	22920	23163	46083
35	8000	0.6kw	360	100	2845	4000	5500	20000	19860	39860
30	6000	0.6kw	360	100	3895	4000	5500	20445	19760	40205
25	5000	1kw/10	750	260	3895	4000	6400	21120	21246	42366
24	4800	1kw/8	850	260	3895	4000	6400	21020	21214	42234
23	4600	2kw/10	960	260	3895	6225	7000	23755	25606	49361
21	4200	2kw/8	1000	260	3895	6225	7000	23395	25447	48842
14	2800	3kw	1900	300	4110	6225	10000	26595	30904	57499
3	600	5kw	3500	400	4770	10000	20000	40100	54593	94693
0	0	6kw	4000	400	4770	10000	10000	30000	36618	66618
0	0	10kw	9000	500	4770	10000	30000	54870	75588	130458

0	0	15kw	13000	600	3895	4000	50000	72095	104810	176905

The table above illustrates the different prices of PV and WT in various configurations, from lowest to the highest. We can see that cost ranges from 20000 to $72000 initial cost and maintenance from 19000 to $105000. The case where PV and WT together is the most economical, whereas it is low economical in PV or wind alone. The differences are not very height.

As results, the comparison indicates that batteries are preferred in short storage period, but in long period hydrogen is better.

But, the cost analysis helped us to decide on, the most preferable case which is the third one "cooking by hydrogen" with the configuration 0.6 kW wind & augmented PV 40

For all scenarios, adding PV can decrease storage and cost. WT decreases storage, but the total cost augment.

Conclusion and recommendations

Millions of people live in off grid areas, because of the high investment costs to connect to the public grids. Therfore, variable Distributed Generation (DG) such as hybrid system with PV and WT is a recommanded solution to supply these areas.

The chosen hybrid design exploits the two most abundant energy sources in the South of Algeria. We utilize solar and wind energy sources to supply a standalone house by electric power. Battery and hydrogen systems incorporated in the design to show the best storage system. The optimization of the system aims to generate energy satisfying the dynamic demands, which corresponds to real data of a household (of 8 persons) in the region of Ouargla. The energy produced by WT or PV modules can be directly used to satisfy a part of the electrical demand. The surplus energy can be stored to the storage system. In other words, the storage system starts working when the production of electricity by RE resources is less than the load. In this study we focused on both technical and economical sides to reach the optimal sizing of the energy system (i.e. maximize the ability to respond to energy demand and minimize the investment cost).

We present the results of the three scenarios, the first scenario (hybrid system with battery storage option) shows that even with using high power WT, the number of batteries remains almost the same and the total cost augments due to the increase in WT initial and maintenance costs, however, adding more PV panels decreases the total cost. In the second scenario (hybrid system with hydrogen storage option), the total cost increases when using more PV panels or high WT model (different components of hydrogen storage remain almost the same, except hydrogen storage tank), so adding PV panels for producing electricity cannot give the same benefits as the first case. The third scenario (hybrid system with hydrogen for cooking, heating and hot water) shows the same global behavior as second scenario, but with lower cost.

As results, for short storage period batteries are preferred, but in long period hydrogen is better. However, from the cost analysis, the most preferable case is the third one, when using hydrogen for cooking, heating and hot water, with the configuration 0.6 kW wind & augmented PV to 35 panels "about $40000" (from the technical side 0.6 kW with only 30 panels "about $40000"). Therefore, we can replace the traditional electric cooker, heater with flexible hydrogen appliances (we consider the cost of old cooker and heater the same as the new ones).

Finally, we recommend farther studies to choose better PV with higher efficiency and WT with low rated speed to have best results.

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