Faculty of Electrical Engineering

DOCTORAL THESIS

For obtaining the degree of Doctor of Philosophy in the field of

Electric Power Engineering and Ecology

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Modelling of Electric Power Networks with Renewable Power Sources

Supervisor: doc.Ing.Emil Dvorský, CSc.

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Before all, thanks God.

Resume

This Ph.D. project “Modelling of Electric Power Networks with Renewable Power Source” has been started by the primary energy supply analysis in the world. It is necessary to have an idea about the world energy supply before to going throw the Libyan energy sources which one of the main parts in this project. The project should build-up the know-how about:

- Representation of existing energy sources in the world.
- Energy sources in Libya and the main income for this country.
- Electric machines and the wind power station generators.

Main subjects of the necessary work to reach work’s goal were to concentrated on:

- The local power network in Libya and its possibility to connect it with a large amount of wind power according to the real data from GECOL.
- Simulation and modelling the wind speeds data which I have received from GECOL

The main goal of this project has been to answer the following questions:

- What would happen in the Libya’s income if they had another possibility to produce the electricity other than from the oil and the natural gas?
- What would happen with Libyan’s power grid if it connected with a large wind power turbine?

Résumé

Ce projet de thèse "Modélisation des réseaux électriques avec une source d'énergie renouvelable» a été commencé par une analyse des approvisionnements d’énergie primaire dans le monde. Il est nécessaire d'avoir une idée sur l'approvisionnement énergétique mondial avant d'aller à travers les sources d'énergie libyennes qui l'une des parties principales de ce projet. Le projet devrait accumuler le savoir-faire sur:

- Représentation des sources d'énergie existantes dans le monde.
- Les sources d'énergie en Libye et le revenu principal de ce pays.
- Les machines électriques et les centraux des générateurs d'énergie éolienne. Principaux sujets des travaux nécessaires pour atteindre l'objectif de travail avait pour concentrer sur:
- Le réseau de distribution local en Libye et sa possibilité de le connecter à une source d'énergie éolienne de grande dimension selon les données réelles de GECOL.
- Simulation et modélisation des données des vitesses de vent de que je les ai reçues de GECOL. L'objectif principal de ce projet a consisté à répondre aux questions suivantes:
- Qu'est-ce que se passerait dans le revenu de la Libye s'ils avaient d’autres possibilités pour produire de l'électricité autre que de l'huile et le gaz naturel?
- Qu'est-ce que se passerait avec réseau électrique libyen si elle reliée à une turbine de puissance éolienne à grande échelle?

Keywords

Modelling of electric power network, renewable power sources in Libya, wind turbines, wind turbine regulation, Libya.

Mots-clés

Modélisation du réseau d'énergie électrique, les sources d'énergie renouvelables en Libye, les éoliennes, réglementation des éoliennes, la Libye.

I am sure that I have worked all this diploma work – Modelling of Electric Power Networks with Renewable Power Source with help of my scientific supervisor and literatures which is written in the references.

Je vous assure que j'ai travaillé tout cet ouvrage de diplôme - Modélisation des réseaux électriques avec une source d'énergie renouvelable avec l'aide de mon superviseur scientifique et littératures qui sont cités dans la référence

In Pilsen 31th January 2012. ....

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Tables

Symbols

PES	Primary Energy Sources
IEA	International Energy Agency
Mtoe	Million Tons of Oil Equivalent
TPES	Total Primary Energy Supply
GDP	Gross Domestic Product
PPP	Purchasing Power Parity
IAEA	International Atomic Energy Agency
RES	Renewable Energy Source
TFEC	Total Energy demand of the Final Power Consumption
GECOL	General Electric Company Of Libya
REAOL	Renewable Energy Authority of Libya
CDM	Clean Development Mechanism
MED-CSP	Concentrating Solar Power for the Mediterranean Region
PV	Photovoltaic
HVDC	High-voltage Direct Current
MENA	Middle East and North Africa
ENTSO	European network of transmission system operators for electricity
CIGRE	International council on large electric system
CENELEC	European Committee for Electro technical Standardization
IEC	International Electro technical Commission
EPS	Electric power system
EMC	Electromagnetic compatibility
AWTG	Asynchronous wind turbine generator
SCIG	Squirrel cage induction generator
PF	Power factor
RSC	Rotor side convertor
GSC	Grid side convertor
DFIG	Double fed induction generator
NEOS	Network enabled optimization
OPF	Optimal power flow

Values

f	Hz	Frequency
U	V	Voltage
I	A	Current
P	W	Active power
Q	VAr	Reactive power
S	VA	Total power or apparent power
E	J	Energy
A	m^2	Area
Z		Number of blades
m	kg/s	Mass flow
T	N/m	Torque
T	S	Time flow
V	m/s	Velocity
n	m/s	Rotation speed
Ω	rad/s	Rotation angle
δ	rad/s	Power angle
ρ	kg/m^2	Air density
Cp	-	Power coefficient
Ψ	T	Magnetic flux
Φ	%	Surface coefficient of the turbine
λ	-	Coefficient of high-speed
η	-	Efficiency

Specifications

L	Load
T	Turbine
n	Nominal value
max	Maximum value
m	Mechanical
r	Rotor
s	Stator
W	Wind
G	Generator
a	Upstream, admission value
e	Downstream, admission value
air	Air
d	direct axis
q	quadrate axis
K	Kinetic

The review of the present state of solved problem in the PhD thesis

Utilisation of RES as electric power sources is growing up very rapidly all over the world, this fact is conditioned by:

1- The exhausting of the fossil fuels
2- Environment protection
3- Electric level consumption

Therefore it is necessary to know for the economic utilisation:

1- The real potential of RES
2- Possibilities how to transform them to the electricity
3- How to deliver this electricity to the place of consumption
4- Performance characteristics of the transport ways

Anyway we can respect many outstanding factors which are also the limitations for the utilisation of RSE:

1- Transporting possibilities of the electric power networks
2- Distances of the RSE from the electric consumption
3- The behaviour of the electric power network in which will be connected the RSE

As the example of this problem should be presented unstable power flows from the existing offshore wind power stations in the Europe countries via UCTE electric power system. The great output of these power stations flows via the whole system and can make results of overloading power lines due to parallel power flow in the system.

The Libyan’s case it will have almost the same problems which is based on the replacing of the loads from the existing networks to the new system which should be feeded by RSE and use the old power stations just for picking the system.

Subjects of the PhD Thesis

The subjects are based on the problem how to estimate the best development of Libya's electric power network under the condition of the best utilisation of wind power stations connected to the systems.

It means to follow the next methodology:

1- To evaluate wind potential in the Libyan's area

2- To find the best locations for the wind power stations

3- To calculate the present power flows in the electric power network

4- To find suitable power machines for these purposes

5- To find the best development of wind power stations in the system

6- To make future plane for the RSE in Libya

1 Primary energy supplying in the world

One of the most critical problems in the world is how to ensure supplying with power sources all over the world with environment input reducing. This chapter deals with the primary energy supplying and consumption in the world, and the energy substitution, conservation and forecasting.

1.1 The Primary Energy Supplying in the World

The present situation in power supplying is characterized by increasing of the total consumption all over the world. Therefore, we have to know the trends and behaviour in the supplying to make good conclusions in the next PES utilization.

An analysis of the energy problems requires a comprehensive presentation of basic supply and demand data for all fuels type. This analysis should be conducted in such a way that allows the easy comparison of the contribution of each fuel types which makes to the economy and their interrelationships through the conversion of one fuel into another.

My analysis is based on the data base of International Energy Agency (IEA).Figure 1-1 explains the development of energy sources from 1973 to 2008.

The primary energy supply in the world by region in Mtoe and fuel shares of total primary energy supply.

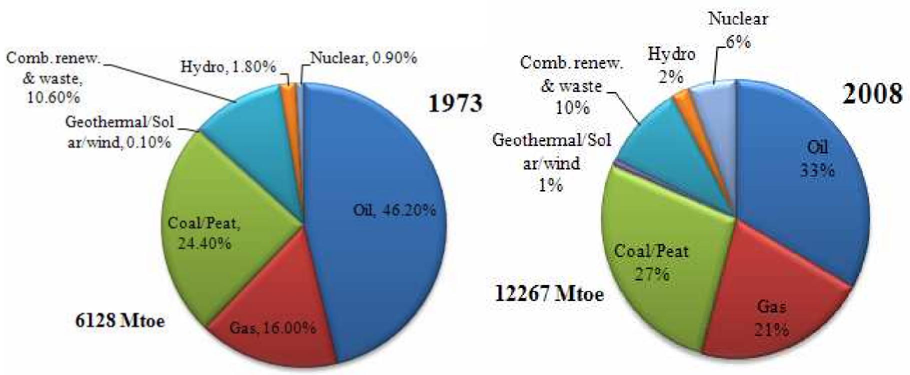

Figure 1-1: Fuel shares of TPES from 1973 to 2008

Most of the world's energy resources are from the sun's rays hitting the earth. Some of that energy has been preserved as fossil energy, some is directly or indirectly usable (e.g. via wind, hydro or wave power). Figure 1-2 represents the amount of the solar energy comparing with the other sources of energy.

For the whole Earth, with a cross-sectional area of 127,400,000 km², the total energy rate of the solar irradiation is approximately 174×10^{15} W and only half of the total rate of solar energy which received by the planet, reaches the earth's surface.

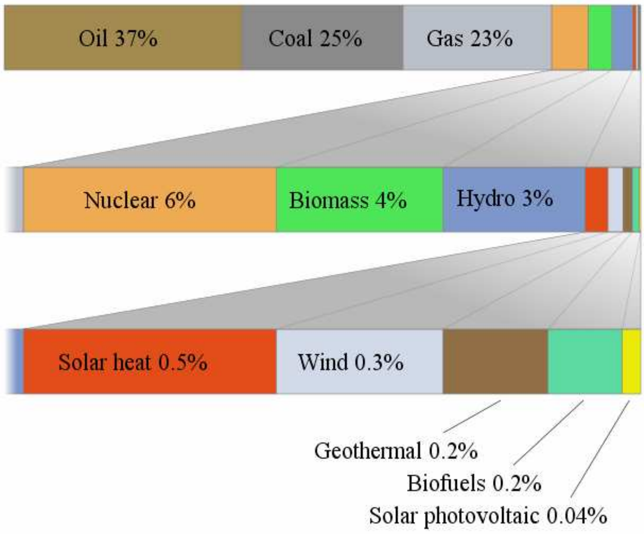

Figure 1-2: Global energy usage in successively increasing detail

The estimates of remaining worldwide energy resources vary with the remaining fossil fuels totalling an estimated 0.4×10^{24} J and the available nuclear fuel such as uranium exceeding 2.5×10^{24} J. The fossil fuels range from 0.6×10^{24} to 3×10^{24} J. If the estimation of the methane clathrates reserve (Methane clathrate, also called methane hydrate or methane ice) are accurate and become technically extractable. Mostly thanks to the Sun, the world also has a renewable usable energy flux that exceeds 1.2×10^{17} W or 3.8×10^{24} J/yr, dwarfing all non-renewable resources.

One of the most important parameters in PES is the parameter of the energy intensity level of the different economies in the world. The figure 1-3 plots the Gross Domestic Product (GDP) per capita and TPES for some countries with Libya as an example.

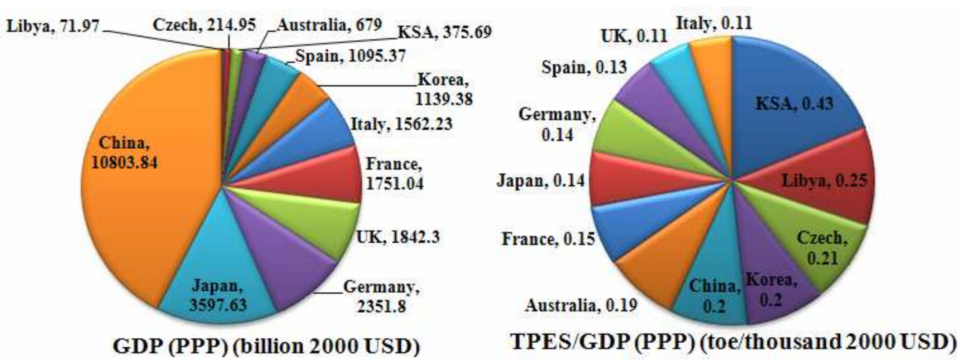

Figure 1-3: Energy consumption per capita versus the GDP per capita

1.2 Power Consumption

Since the advent of the industrial revolution, the worldwide energy consumption has been growing steadily. In 1890, the consumption of fossil fuels roughly equalled the amount of biomass fuel burned by households and industry. In 1900, the global energy consumption equalled 0.7×10^{12} W.

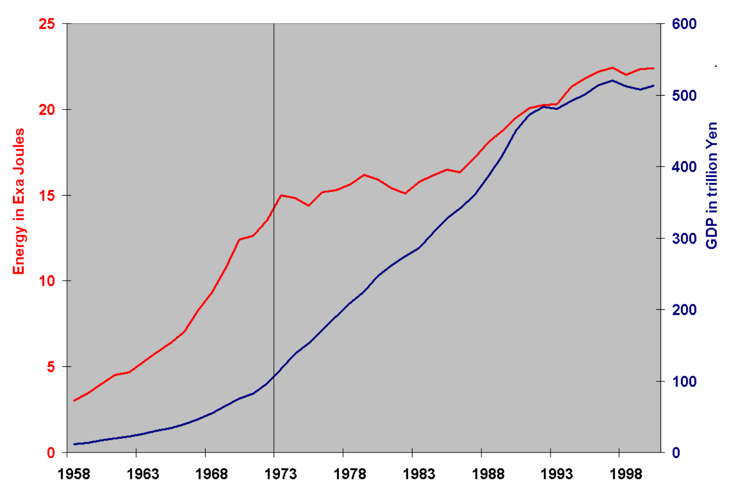

Figure 1-4: GDP and energy consumption in Japan from 1958 to 2000

There is a correlation between GDP and the energy use. The figure 1-4 shows the energy consumption in Japan after oil shocks the world between 1973 and 1979 as a clear and visible example for that. The energy use stagnated (red line) while Japan's GDP, cause they have special, strong and fast growing economy, the grow still continuing, (blue line) under the influence of the rapidly increase the prices and the expenses as well.

For that reason and for any success planner should have even small possibility for any unsuspected shock appears again in the system and maybe in different face but in the same affect.

1.3 Fossil Fuels

The twentieth century saw a rapid twenty-fold increase in the use of fossil fuels. Between 1980 and 2004, the worldwide annual growth rate was 2%. According to the US Energy Information Administration's, they estimated 1.5×10^{13} W total energy consumption of 2008 Figure 1-5 present the world fossil fuel share and the oil has the highest percentage in the world's energy than the gas and coal which they are in the second stage.

Coal fuelled the industrial revolution in the 18th and 19th century, with the advent of the automobile, airplanes and the spreading use of electricity, oil became the dominant fuel during the twentieth century.

The growth of oil as the largest fossil fuel was further enabled by steadily dropping prices from 1920 until 1973, and after the oil shocks, there was a shift away from oil to coal and nuclear, they became the fuels of choice for electricity generation and conservation measures increased energy efficiency. Over the last years, the use of fossil fuels has continued to grow and their share of the energy supply has increased, cause until know the oil has the cheapest processes for handling and less damage in the atmosphere.

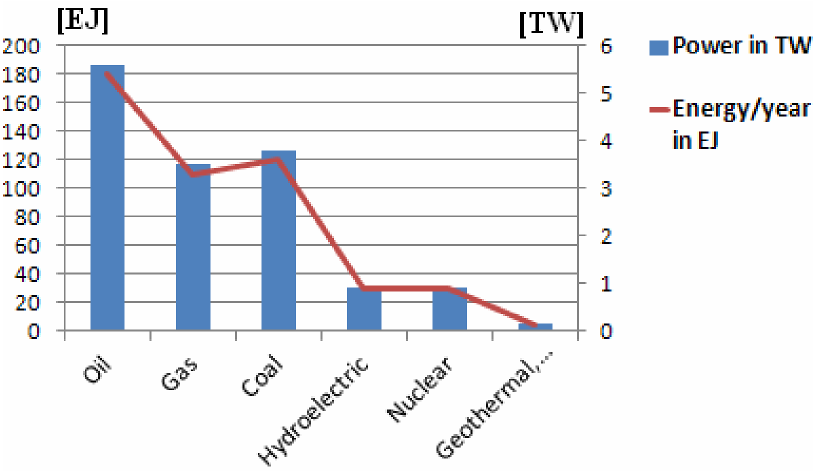

Figure 1-5: Percentage of fossil fuel share in the world consumption in 2008

The next figures show the world shares fossil fuels comparing between the year 1973 and 2008. These graphs are changing according to the industrials countries needs which the majority of them are oil-import. The oil price makes the coal still in use even it has the highest great for pollution and the carbon emission in the world.

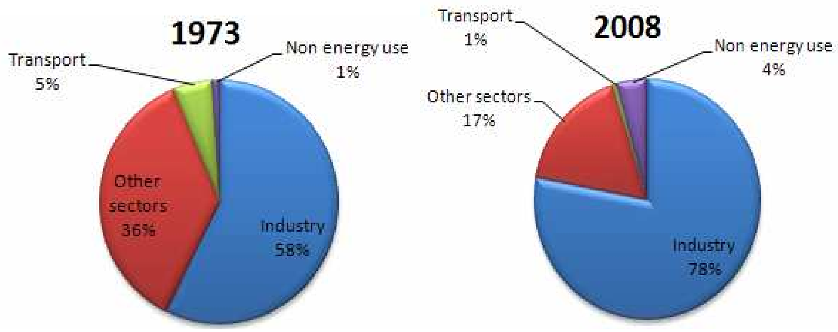

Figure 1-6: Shares of world coal consumption from1973 to 2008

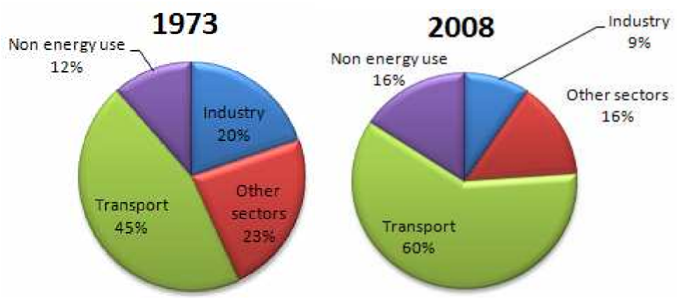

Figure 1-7: Shares of world oil consumption from1973 to 2008

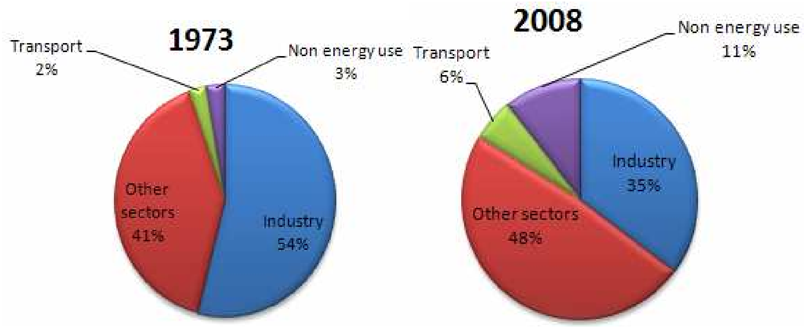

Figure 1-8: Shares of world gas consumption from1973 to 2008

1.4 Nuclear Power

In 2005, 2,626 TWh of electricity was generated by nuclear power, until December 2006, 442 nuclear power plants were in operation with a total installed capacity of about 370 GWe (WNA, 2006a). Six plants were in long-term shutdown and since 2000; the construction of 21 new reactors has begun (IAEA, 2006). The US has the largest number of reactors and France the highest percentage hare of total electricity generation. Many more reactors are either planned or proposed, in whole over the world. Nuclear power capacity forecasts out to 2030 (IAEA, 2005c; WNA, 2005a; Maeda, 2005; Nuclear News, 2005) between 279 and 740 GWe

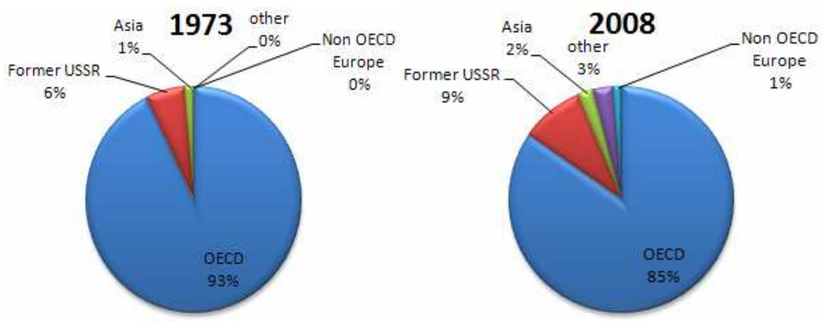

Figure 1-9: Regional shares of nuclear production from 1973 to 2008

1.5 Renewable Energy Sources

Renewable energy offers our planet a chance to reduce carbon emissions, clean air, and put our civilization on a more sustainable footing. It also offers countries around the world the chance to improve their energy security and drive economic development. So much has happened in the renewable energy sector during the past five years that our perceptions lag far behind the reality of where the industry is today. More than 65 countries now have goals for their own renewable energy, future, and are enacting a far-reaching range of policies to meet those goals. Moreover, many renewable technologies and industries have been growing at rates of 20 to 60 percent, year after year, capturing the interest of the largest global companies. In 2007, more than 100 billion US dollars were invested in renewable energy production assets manufacturing research and development a true global milestone. Growth trends mean this figure will only continue to increase. In the figure 1-10 we can see the percentage of the RES.

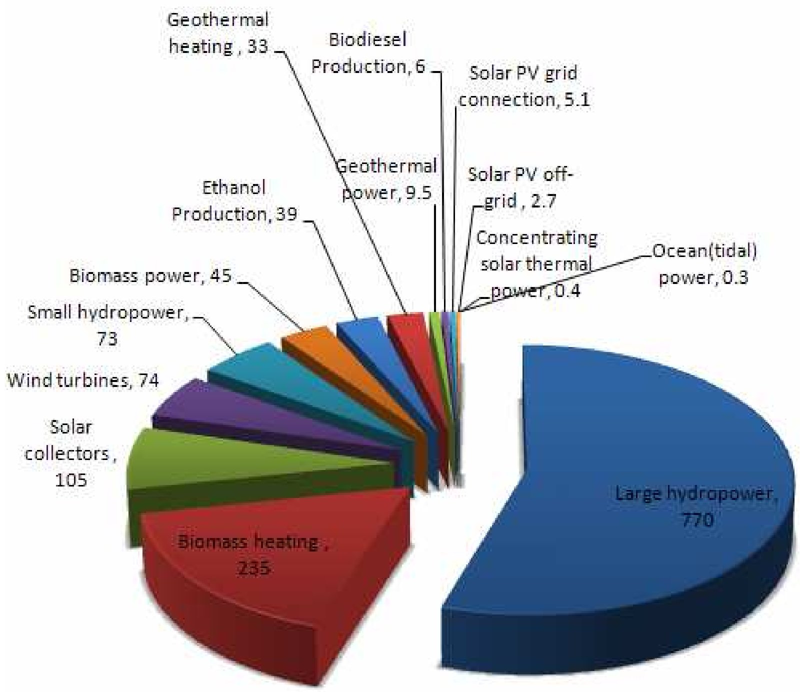

Figure 1-10: Renewable energy sources worldwide at the end of 2008 [GW]

2 Energy and Sustainable Development in Libya

Libya is an oil exporting country located in the middle of North Africa, with 6 million inhabitants distributed over an area of 1 750 000 km^2. Figure 2-1 shows the main part of country which is located in the Sahara desert and northern part is situated on the Mediterranean Sea cost. All these areas have a great potential of solar and wind energy and the big percentage from that area is free it makes from Libya a very good location for the purpose of renewable power sources.

The daily average of the solar radiation on a horizontal plane in the coast region is 7.1 kWh/m^2/day and in the southern region is 8.1 kWh/m^2/day. The daily average of the sun duration is more than 3500 hours per year.

However, the present Libyan industry is based on two conventional energy sources – oil, natural gas.

Figure 2-1: Libya satellite image

2.1 The Country Energy Situation

The situation of the Libya energy industry can be described by the table 2-1 which presents the main primary power sources used in Libya.

The electricity production, which only covers the domestic consumption, is based just mainly on these two primary sources.

Type	***Unit***	***Production***	***Consumption***	***Export***
Natural gas	[Trillion.m^3/year]	12	3	9
Oil	[Trillion.bbl/year]	0.6	0.1	0.5
Electricity	[Trillion.W/year]	20	20	0

Table 2-1 Energy production by the 2005 in Libya

Libya is the great oil and gas supplier for the many neighbour countries in the North Africa, south and middle Europe.

It had total proven oil reserve of 35 Trillion barrels at the end of 2005 and 1.5 Trillion m^3 proven natural gas reserves, figure 2-2 shows the regions where the oil and natural gas are produce. Libya's export revenues have increased sharply in recent years to 34 Trillion US dollars by the end of 2006 up from only 5.3 Trillion US dollars in 2001.

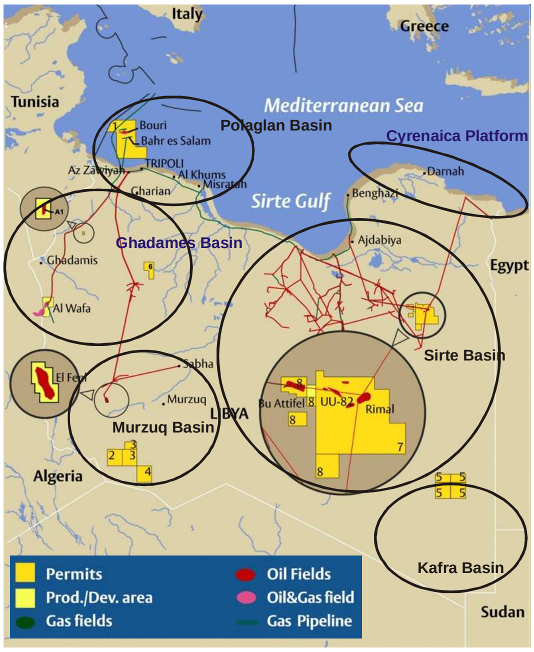

Figure 2-2: Libya oil and gas basins

Oil export revenues are extremely important to the economic development of the country as they represent 90% of the total GDP. Due to Libya oil export income, Libya experienced strong economic growth, which shows figure 2-3, with the real GDP of 46 billion US dollars in 2005, which made Libya one of the highest per capita GDP in Africa.

Libya is hoping to reduce its dependency on oil and natural gas on the country source of income, and to increase investment in tourism, fisheries and mining.

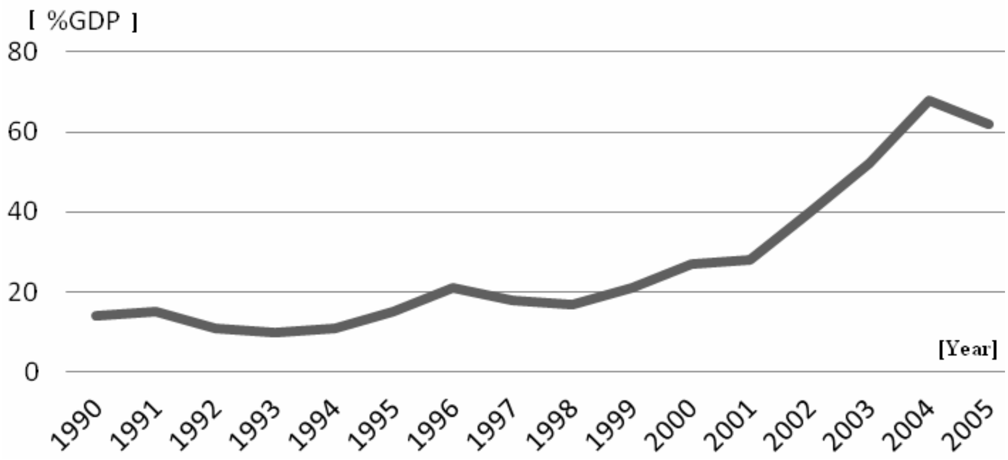

Figure 2-3: Total income from oil and gas as percentage of GDP

However, we can realize that the main part of Libyan income, even in the close future, will come from power industries. It will be better than before for sure in the future that the country income since when we will use the oil and the gas revenues for a good deals and active investments and decries the dependency on the oil and make multi sources income for the country, and open the gats to the neighbours countries to share projects, information and knowledge.

2.2 Power Supplying and Consumption

The TPES in Libya has increased from 9.7 Mtoe in 1990 to 17.7 Mtoe in 2005 with an average annual growth of 4.7 %. Figure 2-4 shows that the oil has the largest share of TPES (57-66%) during 1990-2000 with a little decrease in last year's because of using natural gas more than oil in electrical power generation.

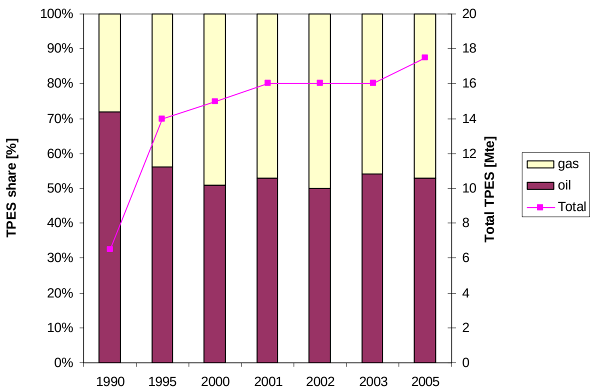

Figure 2-4: Share of single PES on total consumption

The total energy demand of the final power consumption (TFEC) has increased from 5.4 Mtoe in 1990 to 9.1 Mtoe in 2003 with growth of 60 % which shows figure 2-5. This figure also shows that the oil sector has the highest consumption with 61 % of total consumption in 2003. Primary studies show that the future energy demand in 2015 will be 12.5 Mtoe. The share of electricity is close to level of 10 %.

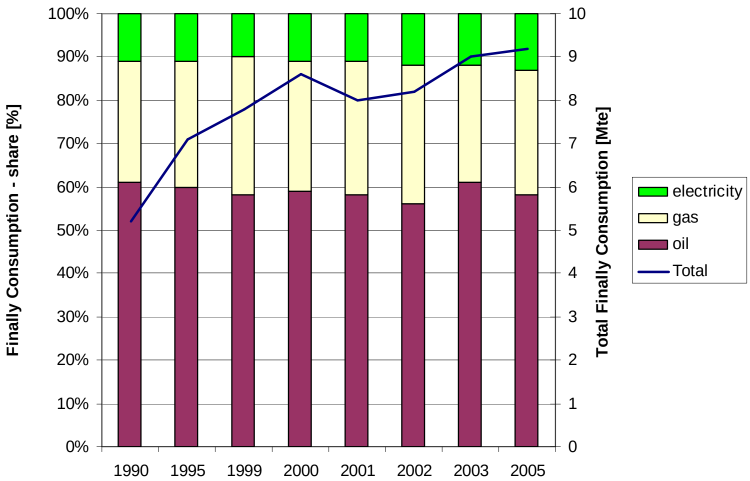

Figure 2-5: Shares of single final power sources

2.3 Electricity in Libya

As presented in the previous part, the share of the electricity in TFEC is going up. The electric energy sector has been developed during the last decade; becoming an economic and social development. The peak load has increased from 1595 MW in 1990 to 3875 MW in 2005 while the total installed capacity has increased from 3352 MW in 1990 to 5120 MW in 2005 and the generated electric energy from 9851 GWh in 1990 to 22500 GWh in 2005. The contribution of steam power plants is 65 %. Natural gas represents 32 % of the fuel supply for electric power plants, 33 % heavy oil fuel, and 35 % light oil. Figure 2-6 shows the growth of peak load during the period from 1992 to 2006, and its forecast until 2020.

The energy consumption per capita has increased from 1493 kWh/c in 1990 to 3119 kwh/c in 2005. The national electric network is accessible to 99 % of the population.

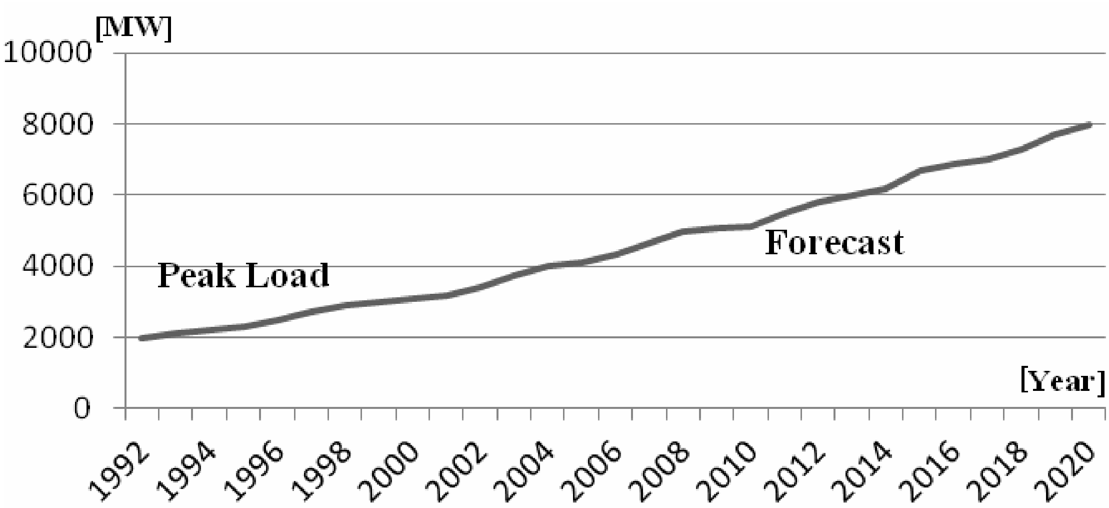

Figure 2-6: The growth of peak load

Most of electric network is concentrated on the coast, where the most of the inhabitants are living. Figure 2-7 shows the locations of the majority of the electrical power plants in Libya.

Figure 2-7: Locations of the electrical power plants

The electric energy demand is expected to grow very rapidly. It is expected that electrical energy will be double by the year 2014 and it will be more than two-and-half by the end of year 2020, as shown in figure 2-6. The total number of customers in electric system in Libya is about one million distributed among seven categories. Residential sector represents 39 % of the total consumption followed by commercial with 14 % as shown in figure 2-8.

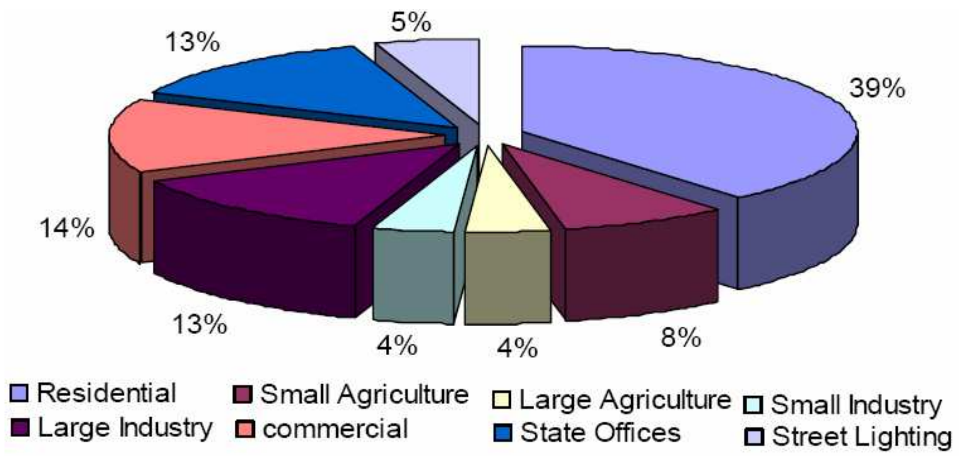

Figure 2-8: Total numbers of customers in electric system

The residential sector represents the highest share in electrical energy demand in Libya. The share of residential load is about 40 % of the overall peak load of electrical power system in Libya.

2.4 Environment

Libya is a country under the United Nations Framework Convention on Climate Change (ratified June 14, 1999) and it is a signatory to the Kyoto Protocol. Thus, Libya currently is eligible to the Clean Development Mechanism (CDM). GECOL has already started contacts with international agencies and investors to use CDM for renewable energy development; the Libyan government has already issued a law to encourage foreign investors for all sectors. The main emitter of CO_2 in 2003 in Libya, as shown in figure 2-9, are fuel combustion in the power generation sector (38 %), in the transport sector (20 %) and in industry (8 %). Other sectors represent 34 %. In total, energy-related emissions are responsible for almost 100 % of CO_2 emissions in the country.

In 2003, petroleum accounts for more than 60 % of carbon emissions in Libya and natural gas is responsible for around 40 %. The increasing reliance on natural gas should work to lower carbon emissions. Libya's energy-related CO_2 emissions increased by more than 78 %, from less than 18.7 Mtoe in 1980 to around 50 Mtoe in 2003 the average annual growth is 8 % between 2001 to 2003, mostly due to increased energy supply.

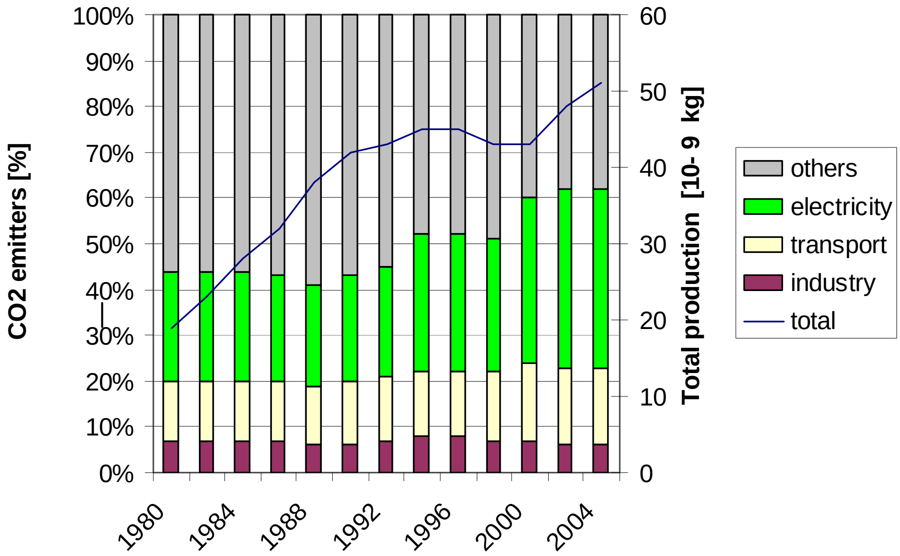

Figure 2-9: CO_2 production by sectors

2.5 Renewable energy in Libya

Libya has, good condition for the renewable energy sources as it was mentioned in paragraph 2-1, mainly the solar and wind energy are the most useful RES in Libya. In this part; I will discuss the potential of these sources.

2.5.1 Solar Radiation

The solar radiation in Libya considered being very high. The maximal energy received on horizontal plan reach up to 7.1 KWh/m^2 per day as indicated in the figure 2-10, and it is over 3 KWh/m^2 during the whole year. The possible total year solar power intensity is shown on figure 2-11 and clearly indicates the importance of the Libyan's location in the distribution map of the solar energy.

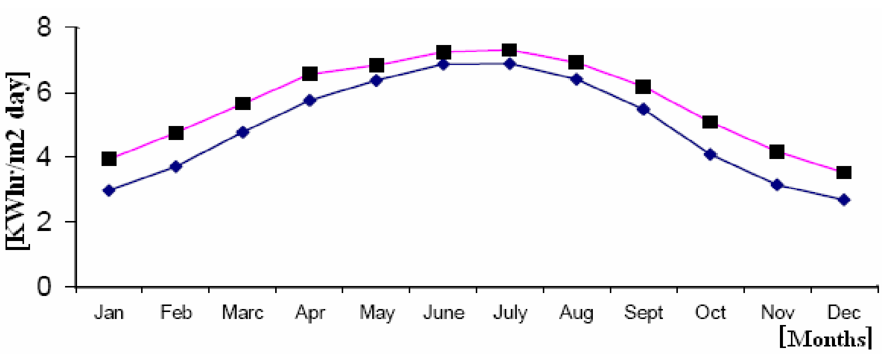

Figure 2-10: The average monthly daily global radiation on the horizontal surface

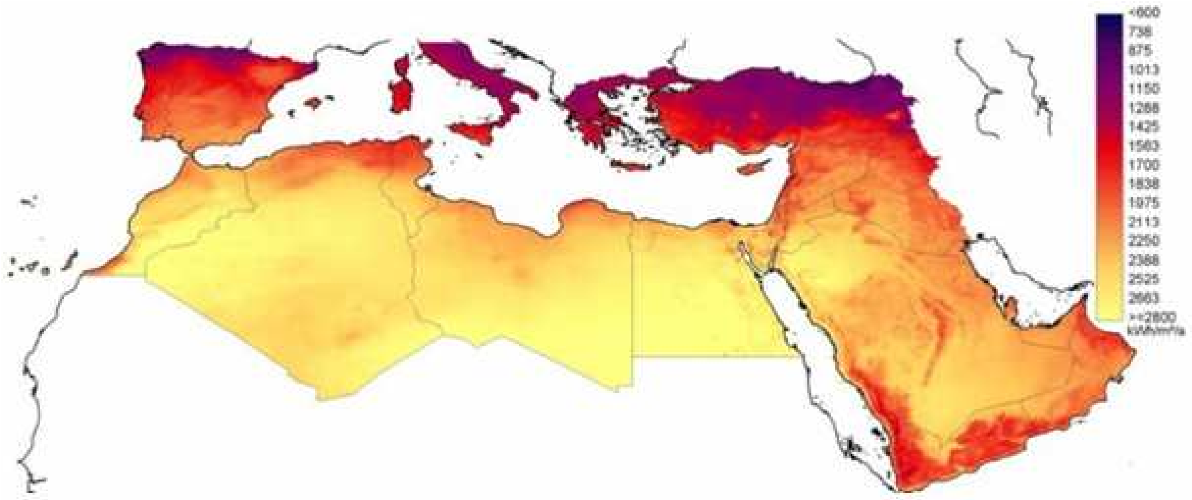

Figure 2-11: Annual global irradiations on region's surfaces

2.5.2 Wind Potential

The measurements show a high potential of wind energy in Libya, figure 2-12 presents the potential of wind energy data measured at 80 m above the ground in the north of Libya.

The potential can be also divided in to two parts:

- Coast area, where the population is concentrated.
- Sahara desert.

Like in many other African countries, wind data in Libya are limited to just an evaluation of meteorological data.

The coastal wind speeds in Libya and identified three sections of the coast with different levels of annual average wind speeds in 50 m above ground are:

- at the west coast between 4.7 to 9.1 m/s,
- at the central coast between 5.4 and 8.9 m/s,
- at the east coast between 5.6 and 10.4 m/s.

In 2003/2004 measurement of the wind speed for wind potential has been conducted. The measurements showed that there is a high potential for wind energy in Libya and the average wind speed at a height of 40 meters is between 6-7.5 m/s.

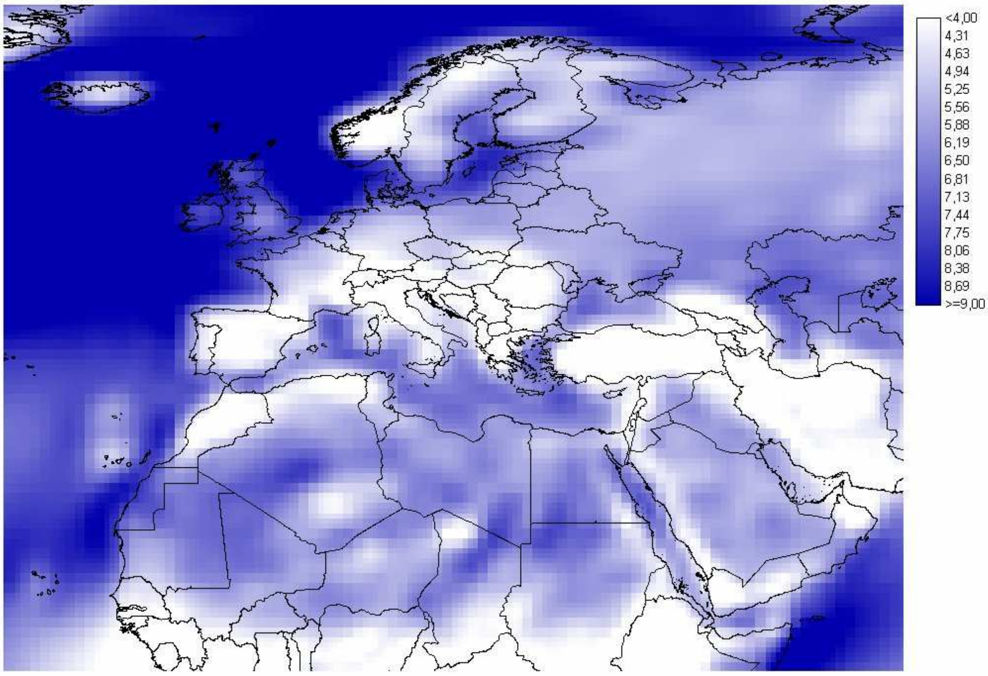

Figure 2-12: Annual average wind speed at 80 m above ground level in m/s

2.5.3 Resources Estimation for Libya

The estimated renewable energy sources in Libya according to the MED-CSP (concentrating solar plants scenario) is shown in Table 2-2, while the electric consumption and its sources in year 2050 are shown in figure 2-13.

Type	***Potential [TWh/yr]***
Solar electricity	140 000
Wind electricity	15 000
Biomass	2 000
Total	157 000

Table 2-2: Renewable energy sources for Libya

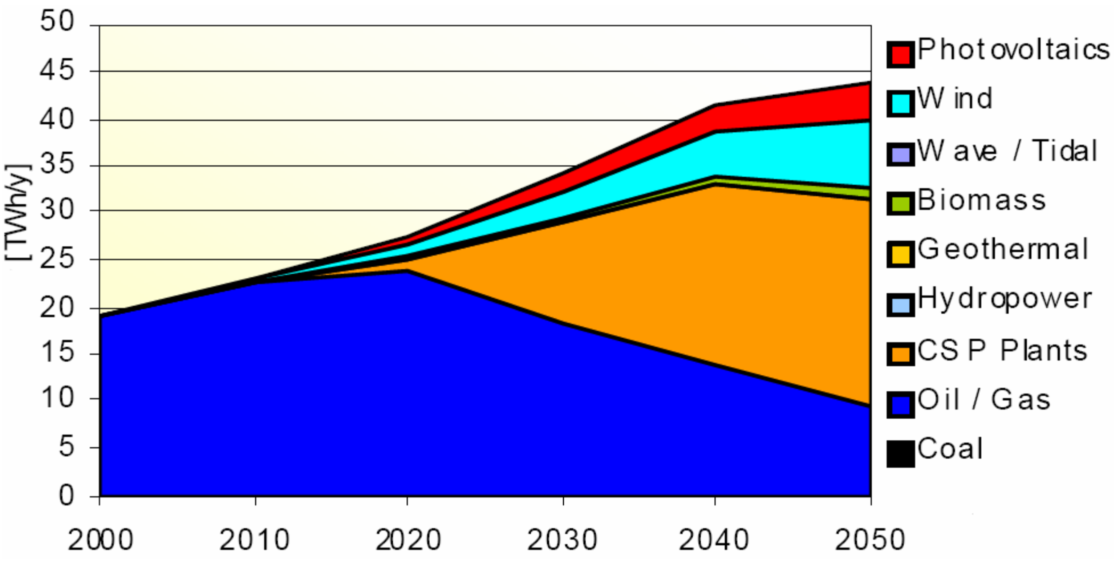

Figure 2-13: Electricity consumption in Libya and supply resources

2.6 The Possibilities of Renewable Energy Applications

Now there are already many RES applications, which have been introduced in wide scale due to its convenience use and being economy effective. Present RES applications and future possibilities are discussed in this paragraph.

2.6.1 Solar Applications

Solar applications can be used mainly for the electric production which can be connected to the electricity grid or operate in stand-alone operation. They are two solar technologies concentrating solar plants and photovoltaic cells. CSP stations should be used as the power generating points for the electric production. They can be combined with the high energy consumption industry as for example the water desolation.

The photovoltaic generators are used in grid off applications as systems for industry supplying and the rural use.

In industrial sector, there are possibilities to supply a cathodic protection to protect the oil pipe lines, in the field of communications to supply energy to microwave repeater stations, the use of PV systems for rural electrification and lighting was started in 2003 which indicate in the figure 2-14. The water pumping possibility, presented by figure 2-15 showing the water pumping projects erected in the beginning of 1984. The role of PV application was grown in size and type of application.

Figure 2-14: PV isolated system in countryside.

Figure 2-15: PV Water pumping for livestock

These PV systems proved to be reliable and justified economically for these types of applications.

The electrification of rural areas and villages is one of the problems facing electric company in all countries, it is a known fact that it is very costly to extend local electric network to the places that fare away. The use such type's electric generators as the diesel generators will not be the best solution as it has a high running cost and need special handling. Thus it will be more practical to use other possible sources of energy, as renewable sources.

2.6.2 Wind Applications

Wind energy is now utilized especially for water pumping and electricity production. A demonstration project of one unit of size 10 KW was installed 1993. The use of wind energy for electricity production has not started yet in Libya, but a project was contracted for installing 25 MW as a pilot project to be erected in two years time. A project to present two

Atlases that provide fact access to reliable solar and wind data throughout Libya is also been contracted for. The Atlases allow for accurate analysis of the available wind and solar resources anywhere in Libya, and it is therefore very valuable for planning profitable wind farms and solar projects.

Libyan electricity utility GECOL began seeking the country's wind energy potential and build the first commercial wind farm to generate electricity from a renewable energy source on economically reasonable terms requirements and start to wind farm development.

2.7 National Renewable Energy Strategy

From the experience gained in utilizing PV systems, a proposed national Renewable Energy plan that aims toward bringing RE into the main stream of the national energy supply system with a target contribution of 10% of the electric energy demand by the year 2020.

A long-term plane for 2006-2020 will make use of all possible renewable power sources; the table 2-3 shows the contribution of each source for the years 2006-2020.

Technology	***Total***
PV	10 MWp
Wind	150 MW
Thermal Water heating	20 000 m^2
Thermal electricity	20 MW
Thermal Desalination	20 000 m^3
Hydrogen	20 KW

Table 2-3: proposed plan of RES 2006-2020

The objectives of implementing this strategy are summarized as follow:

- To improve energy efficiency and energy conservation.
- Capacity building.
- Electricity export to Europe.
- Save oil and gas basins.
- CO_2 reduction.
- Coordination of national efforts towards the achievement of the strategy target for renewable energy.
- Support of renewable energy market penetration.
- Support of renewable energy Technology transfer.

- Support of research and development (R&D), education and training in the field of renewable energy.

2.8 Future Development and Problems with RES

The future development and the technical problems, which should be solved in electricity production from RES in Libya, are discussed in this paragraph, especially problems with interconnected technologies to the electric transmission a distribution systems.

2.8.1 Grid Connected Solar Systems

GECOL is now planning a PV project of 1 MW capacity grid connected system. The site of the plant is already decided. This pilot PV project is intended to accommodate know how on PV technology and on the operation, maintenance and management of a large PV system, in preparation for larger scale installations in the future.

In future, there is a vision to transport electricity from Middle East and North Africa (MENA) countries to Europe figure 2-16.

There are problems which can be solved and based on:

- How to interconnect these huge power generating systems to the local electric systems?
- What are the problems with the regulation?
- How to transport of this energy to Europe over a distance of e.g. 3000 km?

There is in principle possibilities to transport or storage this energy into another form.

The technical options of solar electricity transfer from MENA to Europe via hydrogen, through the conventional alternating current (AC) grid and by a possible future high voltage direct current (HVDC) infrastructure. The transfer capacities of the conventional AC grid are rather limited, and even considering that the MENA countries would empower their regional electricity grid to Central European standards and would create additional interconnections all around the Mediterranean Sea, the transfer would still be limited to about 3.5 % of the European electricity demand. Over a distance of 3000 km, about 45 % of the generated solar electricity would be lost by such a transfer. HVDC technology is becoming increasingly important for the stabilization of large electricity grids, especially if more and more fluctuating resources are incorporated. HVDC over long distances contributes considerably to increase the compensational effects between distant and local energy sources and allows compensating blackouts of large power stations through distant backup capacity. It can be expected that in the long term, a HVDC backbone will be established to support the conventional European electricity grid and increase the redundancy and stability of the future power supply system technology as "Electricity Highways" to complement the conventional AC electricity grid.

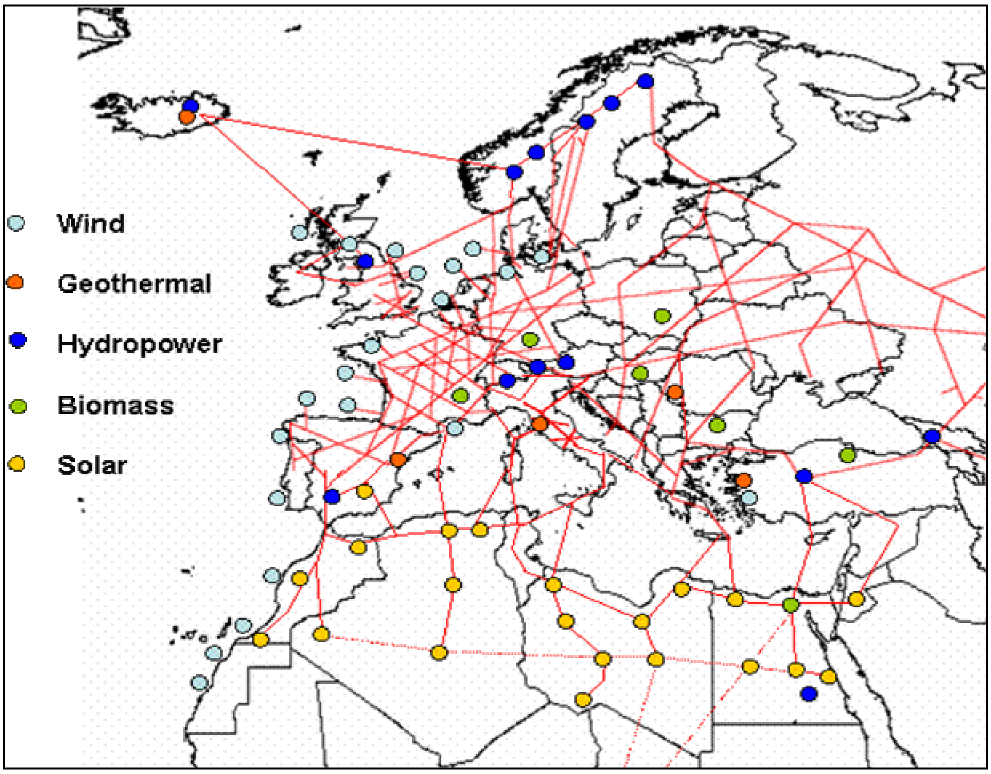

Figure 2-16: Vision of a EUMENA backbone grid using HVDC power transmission

2.8.2 Grid Connected Wind Systems

Under the GECOL´s provided data about the grid connection nodes, which were used to calculate key figures indicating the stability of the grid and its potential of integrating wind generated electricity. It was found that at all sites the capability of the grid is sufficient from a network operator's point of view. Though, at some sites the capacity is limited to take the wind power.

The values of wind velocity range from 6.4 m/s to 8.3 m/s in 50 m above ground level, meaning good to excellent wind conditions and therefore the possibilities of power outputs from wind farms should be 5 MW, 15 MW and 25 MW with and three wind turbine sizes (< 1,000 kW, < 1,500 kW, > 1,500 kW).

The entire project aims to prepare and create a sustainable development of utilizing wind energy in Libya. This success promising strategy allows Libya to gather experience in planning and operating in a safe environment and further develop the potential of wind energy in Libya. A calculated net capacity factor of 35 % means approximately 80.000.000 kWh for a 25 MW winds farm and a corresponding saving of 80.000 tons of CO^2 emission per year, the wind farm and its potential extension can significantly contribute to Libya's measures to fulfil its Kyoto goals.

3 Ways of wind transformation to electricity

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes in this chapter and these are the problems of the RES conversion to electricity will be discussed. Each of single RES has its own possibilities for transmission to electricity. The main important transformation chains of RES to electricity are presented.

The terms wind energy or wind power describes the process by which the wind is used to generate power to electricity – the upper part of the figure 3-1, the transformations process goes indirectly ways via mechanical power trough wind turbines. This mechanical power is converted into electricity – as shown in the lower part of the figure 3-1.

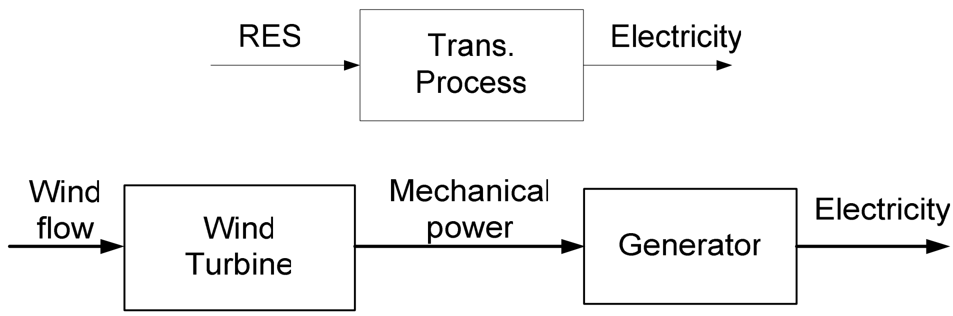

Figure 3-1: Block diagram how is produce the electricity by wind turbine

The wind turbine captures the wind’s kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over the year.

The wind farms effect the landscape values While the physical characteristics and design constraints of a wind energy facility which potentially impact on a landscape can be clearly documented, how a wind farm affects what is valued in a landscape is less easily defined.

There is positive impacts can wind farms have on a landscape and negative impacts as well according to the people mentality, cultures and knowledge about this type of power plants and how friendly to the nature are .

3.1 Wind Power

The most important part of each energy transformation system is the efficiency therefore we are able to evaluate it and also necessary to know the power possibility of inputting power sources, it means to evaluate wind energy or power input to the system

The kinetic energy in air can be described by basic equation of kinetic energy:

$$E_k = \frac{1}{2}.m.v_w^2 \quad [J]\cdot \tag{3-1}$$

Where:

m – Mass flow [kg/s]

v_w – Wind velocity [m/s]

Then kinetic wind power is:

$$P_K = \frac{E_K}{t} \quad [W] \tag{3-2}$$

Where:

t – Time of the flow [s]

Mass flow which goes through A_r swept area is:

$$m = A_r v_w \rho_{air} \quad [m/s] \tag{3-3}$$

Where:

A_r - Area swept by the rotor blades [m^2]

ρ_{air} – Air density [kg/m^2]

Two potential wind sites are compared in terms of the specific wind power expressed in watts per square meter of area swept by the rotating blades. It is also referred to as the power density of the site, and is given for (input-admission) by the following expression:

$$p_A = \frac{P_k}{A_r} = \frac{1}{2}\rho_{air}.v_w{}^3 \left[\frac{W}{m^2}\right]\cdot \tag{3-4}$$

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades, and with the cube of the wind speed. All of the upstream wind power cannot be extracted by the blades, as some power is left in the downstream air which continues to move with reduced speed.

Therefore there is necessary to know wind velocity in the place of transformation which the most important parameter for every power evaluation

3.2 Power Extracted from the Wind

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers. Figure 3-2 presents the impact of the wind direction on the rotation of the wind turbine. The equation 3-5 shows the relation between the mechanical power and the different between upstream and downstream wind speed:

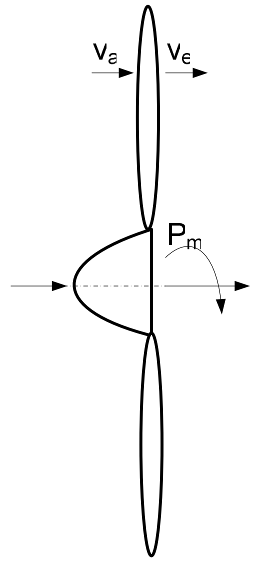

Figure 3-2: Impact on the rotation direction of the wind turbine

$$P_m = \frac{1}{2} m.\left[v_a^{\,2} - v_e^{\,2}\right] \ \ [W]. \qquad (3\text{-}5)$$

Where:

v_a - Upstream wind velocity at the entrance of the rotor blades [m/s]

v_e - Downstream wind velocity at the exit of the rotor blades.[m/s]

The air velocity is discontinuous from v_a to v_e at the “plane” of the rotor blades in the macroscopic sense. The mass flow rate of air through the rotating blades is, therefore, derived by multiplying the density with the average velocity; equation 3-6 presents the mass flow value.

$$m = \rho_{air}.A_r.\frac{v_a + v_e}{2} \ \ [kg/.s] \qquad (3\text{-}6)$$

Where:

A_r - value of the rotor swept area [m^2]

The mechanical power extracted by the rotor, which is driving the electrical generator, is:

$$P_m = \frac{1}{2}[\rho_{air}.A_r.\frac{(v_a + v_e)}{2}].(v_a^{\,2} - v_e^{\,2}) \ \ [W] \qquad (3\text{-}7)$$

The above expression can be algebraically rearranged:

$$P_m = \frac{1}{2}[\rho_{air} . A_r . v_a^3 . \frac{(1+\frac{v_e}{v_a})\left[1-\left(\frac{v_e}{v_a}\right)^2\right]}{2}] \; [W] \qquad (3\text{-}8)$$

The power extracted by the blades is usually expressed as a fraction of the upstream wind power as follows:

$$P_m = \frac{1}{2}\rho_{air} . A_r . v_a^{\;3} . C_p \; [W] \qquad (3\text{-}9)$$

Where:

C_p - The fraction of the upstream wind power, which is captured by the rotor blades

This coefficient is:

$$C_p = \frac{(1+\frac{v_e}{v_a})[1-(\frac{v_e}{v_a})^2]}{2} \qquad (3\text{-}10)$$

The remaining power is discharged or wasted in the downstream wind. The factor C_p is called the ***power coefficient*** of the rotor or the ***rotor efficiency -*** η_r.

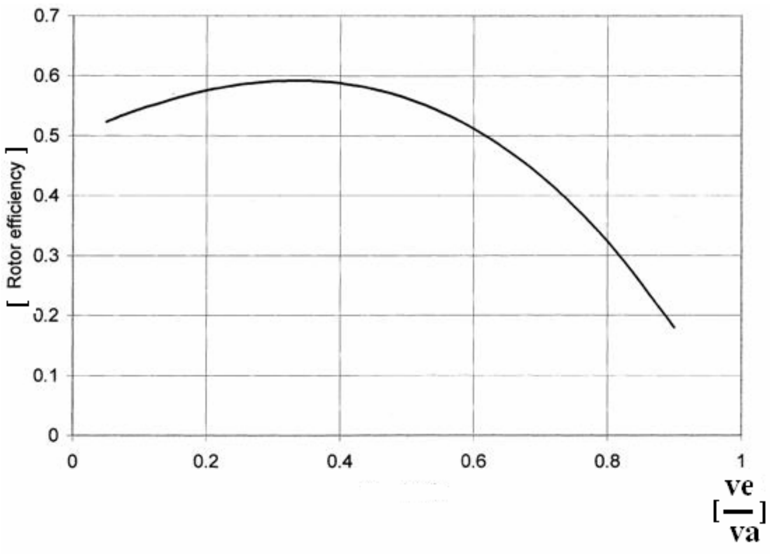

Figure 3-3: Rotor efficiency versus v_o/v ratio has single maximum.

For a given upstream wind speed, the value of C_p depends on the ratio of the downstream to the upstream wind speeds, that is (v_e/v_a). The plot of power coefficient versus (v_e/v_a) shows that C_p is a single, maximum-value function Figure 3-2. It has the maximum value of 0.59 when the (v_e/v_a) is one-third. The maximum power is extracted from the wind at that speed ratio, when the downstream wind speed equals one-third of the upstream speed. Under this condition rotor efficiency is the fraction of available wind power extracted by the rotor and fed to the electrical generator.

$$P_{max} = \frac{1}{2}\rho_{air}.A_r.V_w^3.0.59\,[W] \qquad [3\text{-}11)$$

The theoretical maximum value of C_p is 0.59. In practical designs, the maximum achievable C_p is below 0.5 for high-speed, highest efficiency two-blade turbines, and between 0.2 and 0.4 for slow speed turbines with more blades Figure 3-3. If we take 0.5 as the practical maximum rotor efficiency, the maximum power output of the wind turbine becomes a simple expression:

$$P_{max} = \frac{1}{4}.\rho_{air}.v_a^3\left[\frac{W}{m^2}\right]. \qquad (3\text{-}12)$$

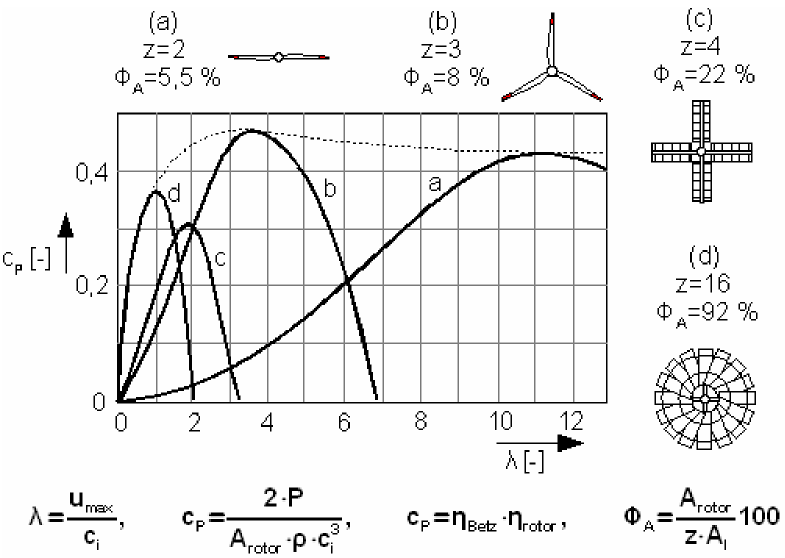

Figure 3-4: Efficiency versus tip speed ratio for rotors with different numbers of blades.

3.3 Type of Wind Turbine

The equation for the maximum available power is very important since it tells us that power increases with the cube of the wind speed and only linearly with density and area. The available wind speed at a given site is therefore often first measured over a period of time before a project is initiated.

In practice one cannot reduce the wind speed to zero, so a power coefficient Cp is defined as the ratio between the actual power obtained and the maximum available power as given by the equation 3-12. A theoretical maximum for Cp exists, C_{Pmax}=16/27 = 0.593. Modern wind turbines operate close to this limit, with Cp up to 0.5, and are therefore optimized

Techniques capable of capturing the large amounts of wind energy will be investigated with emphasis on costs and safety factors. The selection of an ideal location for a wind turbine installation is very important and the process must consider factors such as wind speed and direction, desirable terrain features, nearby residential areas, and annual energy capture. Note that the ratio for actual energy captured by a wind turbine to that which could be captured is very critical. Furthermore, the wind speeds must be within the optimum range throughout the year at the designated location to enable the turbine to operate at its maximum power coefficient.

To meet this operational criterion, wind speeds from 20 to 30 m/min are recommended by installers this is the most important site selection requirement.

Turbine blade area A_T [m^2]	***Mass flow rate m [kg/s]***	***Pressure drop at turbine P_a-P_e [Pa]***	***Power delivered P_T [W]***	***Power coefficient Cp [-]***
Small	High	Small	Low	<0.59
Large	Low	Large	Low	<0.59
Optimum	Optimum	Optimum	Optimum	0.59

Table 3-1: Impact of wind turbine performs on C_p

Other selection parameters include installation height, blade parameters, airfoil characteristics, and aerodynamic requirements; they all play important roles in efficient capture of wind energy by a wind turbine Power coefficient is dependent on several factors such as installation site features, rotor blade areas, angle of attack, flow rate, pressure drop at turbine, and other issues. Impact on power coefficient and power delivered due to rotor blade area, flow rate, and pressure drop at the turbine can be seen in the table 3-1.

Note that large blade areas yield both greater power outputs and improved power coefficients but over a narrow range of tip speed ratios as illustrated in Figure 3-4. Turbine blades with smaller areas provide lower power coefficients over a wider range of tip speed ratios.

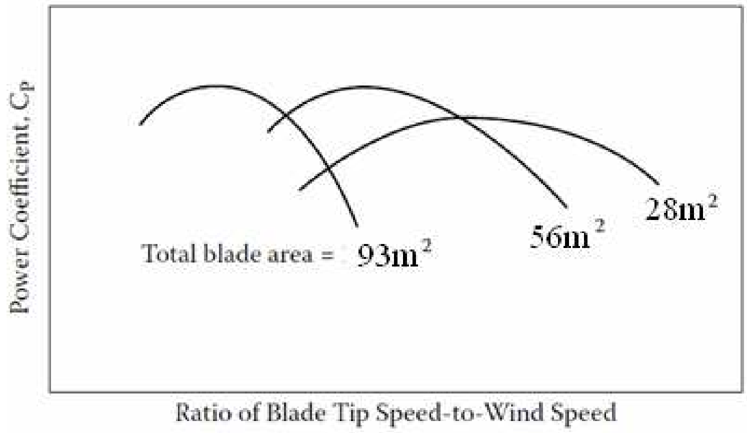

Figure 3-5: Power coefficient as functionof total blade area tip speed

Sailors discovered very early on that it is more efficient to use the lift force than simple drag as the main source of propulsion. Lift and drag are the components of the force perpendicular and parallel to the direction of the relative wind respectively. It is easy to show theoretically that it is much more efficient to use lift rather than drag when extracting power from the wind. All modern wind turbines therefore consist of a number of rotating blades looking like propeller blades. If the blades are connected to a vertical shaft, the turbine is called a vertical-axis machine,

- Vertical VAWT
- Horizontal HAWT

For commercial wind turbines the mainstream mostly consists of HAWTs; the following text therefore focuses on this type of machine as sketched in figure 3-5 is described in terms of the rotor diameter(D) the number of blades(Z) the tower height(H), the rated power and the control strategy.

The tower height is important since wind speed increases with height above the ground and the rotor diameter is important since this gives the area (A) in the formula for the available power. The ratio between the rotor diameter and the hub height is often approximately one. The rated power is the maximum power allowed for the installed generator and the control system must ensure that this power is not exceeded in high winds.

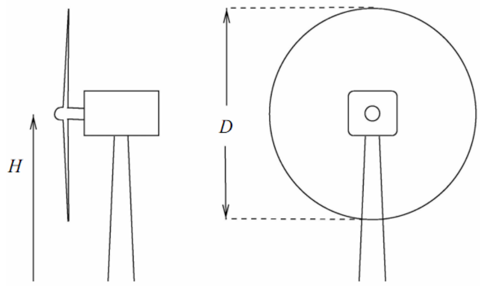

Figure 3-6: Horizontal-axis wind turbines (HAWT)

The number of blades is usually two or three. Two-bladed wind turbines are cheaper since they have one blade fewer, but they rotate faster and appear more flickering to the eyes, whereas three-bladed wind turbines seem calmer and therefore less disturbing in a landscape. The aerodynamic efficiency is (the difference between the upstream wind speed and downstream wind speed) which shown in the previous figure 3-2 is lower on a two bladed than on a three-bladed wind turbine. a two-bladed wind turbine is often, but not always, a downwind machine; in other words the rotor is downwind of the tower. Furthermore, the connection to the shaft is flexible, the rotor being mounted on the shaft through a hinge. This is called a teeter mechanism and the effect is that no bending moments are transferred from the rotor to the mechanical shaft. Such a construction is more flexible than the stiff three-bladed rotor and some components can be built lighter and smaller, which thus reduces the price of the wind turbine. The stability of the more flexible rotor must, however, be ensured. Downwind turbines are noisier than upstream turbines, since the once-per-revolution tower passage of each blade is heard as a low frequency noise. The rotational speed of a wind turbine rotor is approximately 20 to 50 rpm and the rotational speed of most generator shafts is approximately 1000 to 3000 rpm. Therefore a gearbox must be placed between the low-speed rotor shaft and the high-speed generator shaft. The layout of a typical wind turbine can be seen in Figure 3-5, showing a Siemens wind turbine designed for offshore use. The main shaft has two bearings to facilitate a possible replacement of the gearbox. This layout is by no means the only option; for example, some turbines are equipped with multiple generators, which rotate so slowly that no gearbox is needed. Ideally a wind turbine rotor should always be perpendicular to the wind. On most wind turbines a wind vane is therefore mounted somewhere on the turbine to measure the direction of the wind. This signal is coupled with a yaw motor, which continuously turns the nacelle into the wind. The rotor is the wind turbine component that has undergone the greatest development in recent years. The aerofoil's used on the first modern wind turbine blades were developed for aircraft and were not optimized for the much higher angles of attack frequently employed by a wind turbine blade.

3.4 Rotor Swept Area

As seen in the power equation, the output power of the wind turbine varies linearly with the rotor swept area. For the horizontal axis turbine, the rotor swept area is given by :

$$A_r = \frac{\pi}{4} D_r^{\,2} \; [m^2] \qquad (3\text{-}13)$$

Where:

D_r - The rotor diameter [m]

For the Darrieus vertical axis machine, determination of the swept area is complex, as it involves elliptical integrals. However, approximating the blade shape as a parabola leads to the following simple expression for the swept area:

$$A = \frac{2}{3} D \, x \, H \; [m^2]. \qquad (3\text{-}14)$$

The wind turbine efficiently intercepts the wind energy flowing through the entire swept area even though it has only two or three thin blades with solidity between to 5 to 10 percent. The solidity is defined as the ratio of the solid area to the swept area of the blades. The modern tow-blades turbine has low solidity ratio. Hence, it requires little blade material sweep large areas.

3.5 Air Density

The wind power varies linearly with the air density sweeping the blades. The air density ρ varies with pressure and temperature in accordance with the gas law:

$$\rho_{air} = \frac{p}{R.T} \; [kg/m^3] \qquad (3\text{-}15)$$

Where:

p - Air pressure [Pa]

T - Temperature on the absolute scale [K]

R - Gas constant.[287.05J/(kg.K)]

The air density at sea level, one atmospheric pressure (14.7 psi) and 15.5556°C is 1.225 kg/m^3. Using this as the reference, ρ is corrected for the site specific temperature and pressure. The temperature and the pressure both in turn vary with the altitude. Their combined effect on the air density is given by the following equation, which is valid up to 6,000 meters of site elevation above the sea level:

$$\rho = \rho_0 . e^{-\{\frac{0.297 H_m}{3048}\}} \quad [kg/m^3]. \qquad (3\text{-}16)$$

Where:

H_m - The site elevation [m]

ρ_0 - Air density on 0 level [kg/m^3]

Equation (3-16) is often written in a simple form:

$$\rho = \rho_0 - 1.194 . 10^{-4} . H_m \; [kg/m^3]. \qquad (3\text{-}17)$$

The air density correction at high elevations can be significant. For example, the air density at 2,000-meter elevation would be 0.986 kg/m^3, 20 percent lower than the 1.225 kg/m^3 value at sea level. For ready reference, the temperature varies with the elevation:

$$T = 15.5 - \frac{19.83 H_m}{3048} \; [K]. \qquad (3\text{-}18)$$

3.6 Wind speed distribution

Having the cubic relation with the power, the wind speed is the most critical data needed to appraise the power potential of a candidate site. The wind is never steady at any site. It is influenced by the weather system, the local land terrain, and the height above the ground surface. The wind speed varies by the minute, hour, day, season, and year. Therefore, the annual mean speed needs to be averaged over 10 or more years. Such a long term average raises the confidence in assessing the energy-capture potential of a site. However, long-term measurements are expensive, and most projects cannot wait that long. In such situations, the short term, say one year, data is compared with a nearby site having a long term data to expect the long term annual wind speed at the site under consideration. This is known as the "measure, correlate and predict (MCP)" technique.

4 Wind generators

Introduction

Before addressing more technical aspects of wind generators technology, an attempt is made to give a short general introduction to the principal of the electric generators which are transforming the mechanical energy of wind turbine to the electricity according to the parameters and the specifications of the electric system and the power networks standard. Basically the electric generators selection depends on the level of the power output from the wind turbine and interconnections to the electric networks, they produce:

- Alternate current – AC generators.
- Direct current – DC generator.

Each of these from two basic groups has many variations. AC generator can be divided into:

- Asynchronous generator.
- Synchronous generator.

Asynchronous generators, called induction generators, they don’t need their own exciting system; they are very simple and cheap. The main problem for this type how to insure in transformation system the same mechanical rotation of the generator (frequency) as the wind turbine as the power network has.

This can be done in the side of the wind turbine mechanically by the gear box or in the electric side of the generator by the electrical conditioner.

Synchronous generators need an exciting system therefore they are more complicated regarding to the electric side of the transformation process of the wind energy to the electricity.

Direct current generators must always have an electric conditioner.

Basically the transformation system wind turbine generators (WTG) must have two subsystems:

- System for wind transformation to the mechanical power – wind turbine (WT).
- System of transformation of mechanical power to the electricity.

The figure 4-1 presents clearly the parameters of these two subsystems, the mechanical parameters of WT and the electric parameters of the conditioning.

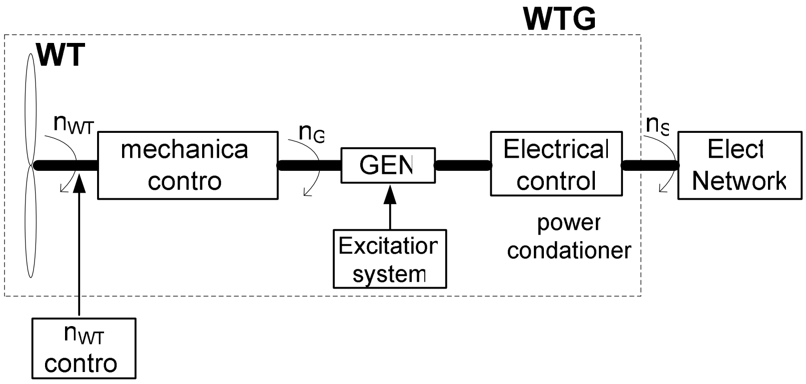

Figure 4-1: Possibility of wind transformation to the electric parameters

4.1 Asynchronous Wind Turbine Generator

From the main principle of this group of AWTG, I present the characteristics of chosen four types from them, regarding to their characteristics it is suitable to choose the generator for the wind turbine as an electric machine transform.

4.1.1 Direct connected asynchronous

The asynchronous wind turbine generator generates alternating current with a synchronous frequency against supplying power system. The existing system of the generator goes from the electric power system seen in the figure 4-2 , in order to eliminate inductive power goes to the existing system there is necessary to corrected by power flow corrector (PF)- capacitor.

The characteristics of the induction generator connected direct to the line are:

- The fixed speed is (1-2%) above synchronous.
- They don't need power converter.
- Voltage control capability in this type of wind turbine is affected by voltage, frequency disturbances and absorbs VAr while generating a real power.
- The PF correction is through low voltage capacitors.
- This is the typical of the older style generators.

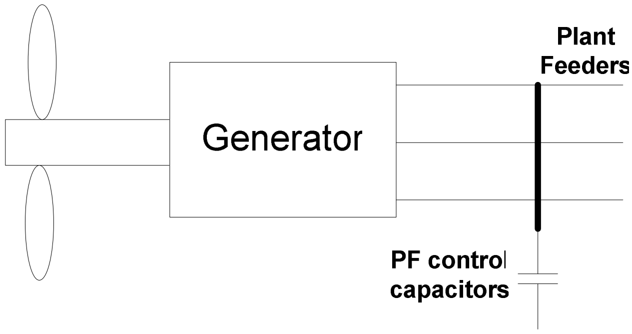

Figure 4-2: Direct connected synchronous turbine

4.1.2 Direct connected AWTG with Variable Resistance Rotor

These types of the generator also generate alternating current with asynchronous frequency, but this frequency can be change with variable resistance control of the rotor winding seen in the figure 4-3.

The characteristics of this type of turbine are:

- Variable slip with speed = (0-10%) above synchronous - n_{as} = (0.9 – 1) $n_{s.}$
- Slip power converter.
- No voltage control capability just PF control.
- Improved voltage and frequency disturbances.
- Absorbs VARs while generating real power.
- PF correction is through low voltage capacitors in Nacelle.

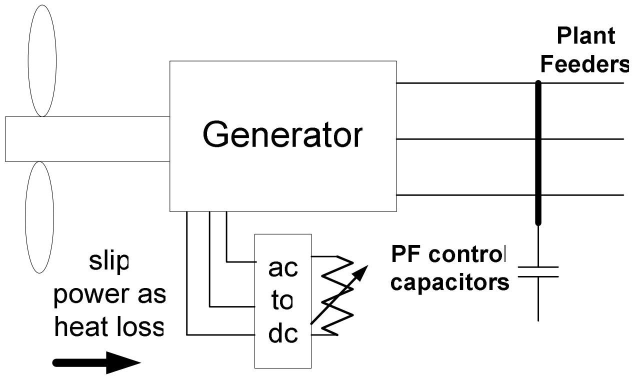

Figure 4-3: Direct connected variable resistance rotor

4.1.3 AWTG with Power Conditioner

The connection of the generator to the power system is via power conditioner which correct asynchronous rotation to a synchronous via AC =DC=AC convertor. Therefore this type of generator does not need power factor corrector.

The characteristics of this type are:

- Variable speed is up to 100% of synchronous.
- Full rated back-to back four quadrant power converters.
- Reactive control through inverters is independent of real power.
- Requires full sized inverters as all power passes through both inverters.
- Mechanical drive train isolated from electrical grid.
- Good voltage and frequency disturbance ride through capability.
- Full voltage regulating capability without use of shunt capacitor.
- PF control also available.

The figure 4-4 below represents the equivalent circuit of this type of turbine.

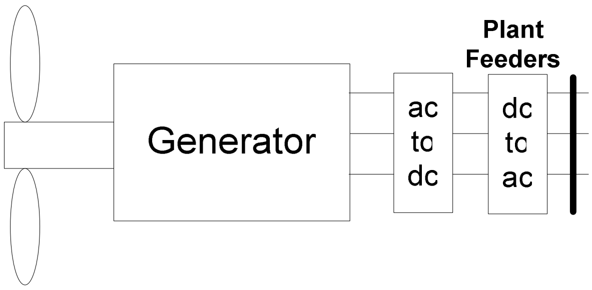

Figure 4-4: AC-DC-AC convertor connected

4.1.4 Double-fed induction generator (DFIG)

The part of the existing voltage can go across the rotor windings supplied by the PF conditioner which transform AC power of power network to DC and back to AC seen in the figure 4-5.

The characteristics of this type of turbines are:

- Induction Generator connected across the line with variable frequency and voltage control of rotor windings.
- Variable speed is (±30%) of synchronous.
- Partially rated power converters with reactive control through converters.

- Requires smaller (≈30% rated) converters but adds slip rings to generator.
- Good voltage and frequency disturbance ride through capability.
- Full voltage regulating capability without use of shunt capacitors.

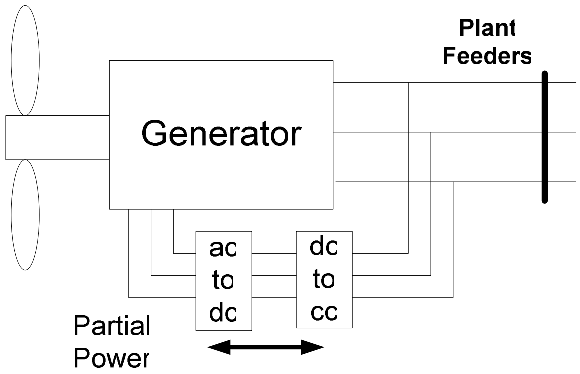

Figure 4-5: Double fed induction generator

4.2 Synchronous Wind Turbine Generator

This kind of the generators need it is own exciting system which has to have possibility to control it. The rotation of the generator has the same rotation as power network, it means $n_G = n_s$. The figure 4-6 shows the Synchronous Generator equivalent circuit.

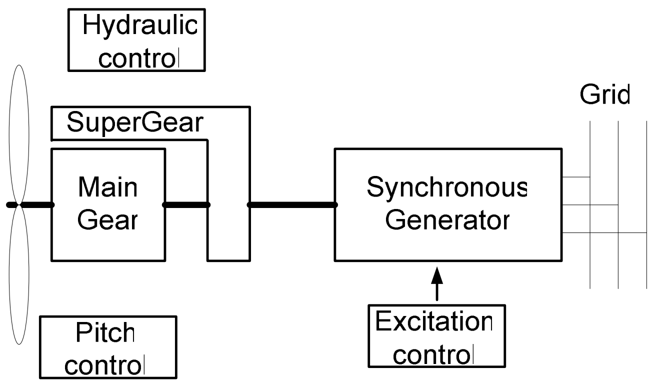

Figure 4-6: Synchronous generator

The characteristics of this type of turbines are:

- No power electronics.
- Good voltage and frequency disturbance ride through capability.
- Reactive control by changing the field voltage.
- Full voltage regulating capability without use of shunt capacitors.

4.3 AWTG Modelling

For modelling of the transformation process from the wind side to the electricity network via WTG there is necessary to know mathematically description of this process this description usually respect energy ratio in the system. Then each type of subsystems in the whole system of WTG is possible to express it as equation systems with necessary inputting parameters in order to calculate outputting values going to the fallowing subsystem see the figure 4-7.

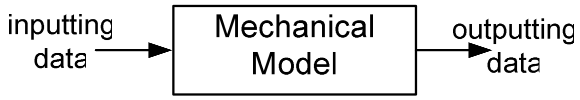

Figure 4-7: Basic principle of WTG modelling

We can make a mathematical model like close boxes with predefined inputs and outputs I would to present two mathematical models of WATG:

4.3.1 Squirrel Cage Induction Generator (SCIG)

The electrical machine in the wind turbine is modelled as close boxes with predefined inputs and outputs. This illustrated in the Figure 4-8 which symbolize as blocks, with the most relevant input and output signals for squirrel cage induction generator (SCIG).

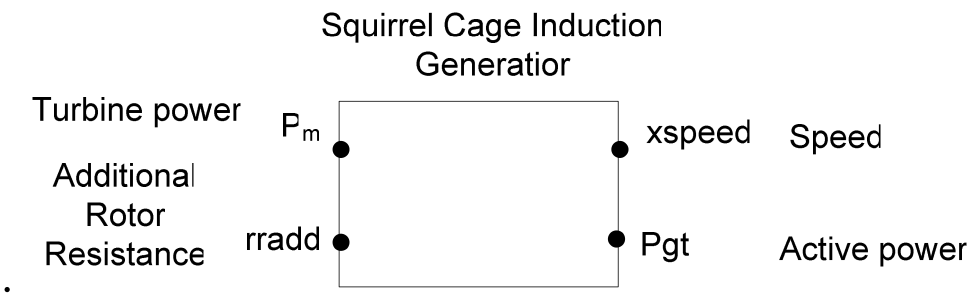

Figure 4-8: Squirrel cage induction generator (SCIG)

Squirrel cage induction generator model has the mechanical power of the wind turbine as prime mover input. An additional rotor resistance can be inserted if it is necessary. The outputs are the generator speed and the electrical power. In the load flow calculation, used in the initialization process of the system, the information on the generators active power has to be specified.

Squirrel-cage generators for wind turbines are rugged, reliable, require little maintenance, are efficient, quiet and have a long lifetime. The equivalent circuits which illustrated in

Figure 4-9 defines the parameters in the induction generator model; it consists of a general model for the stator, which can be combined with three different rotor models, depending on the type of the generator**.**

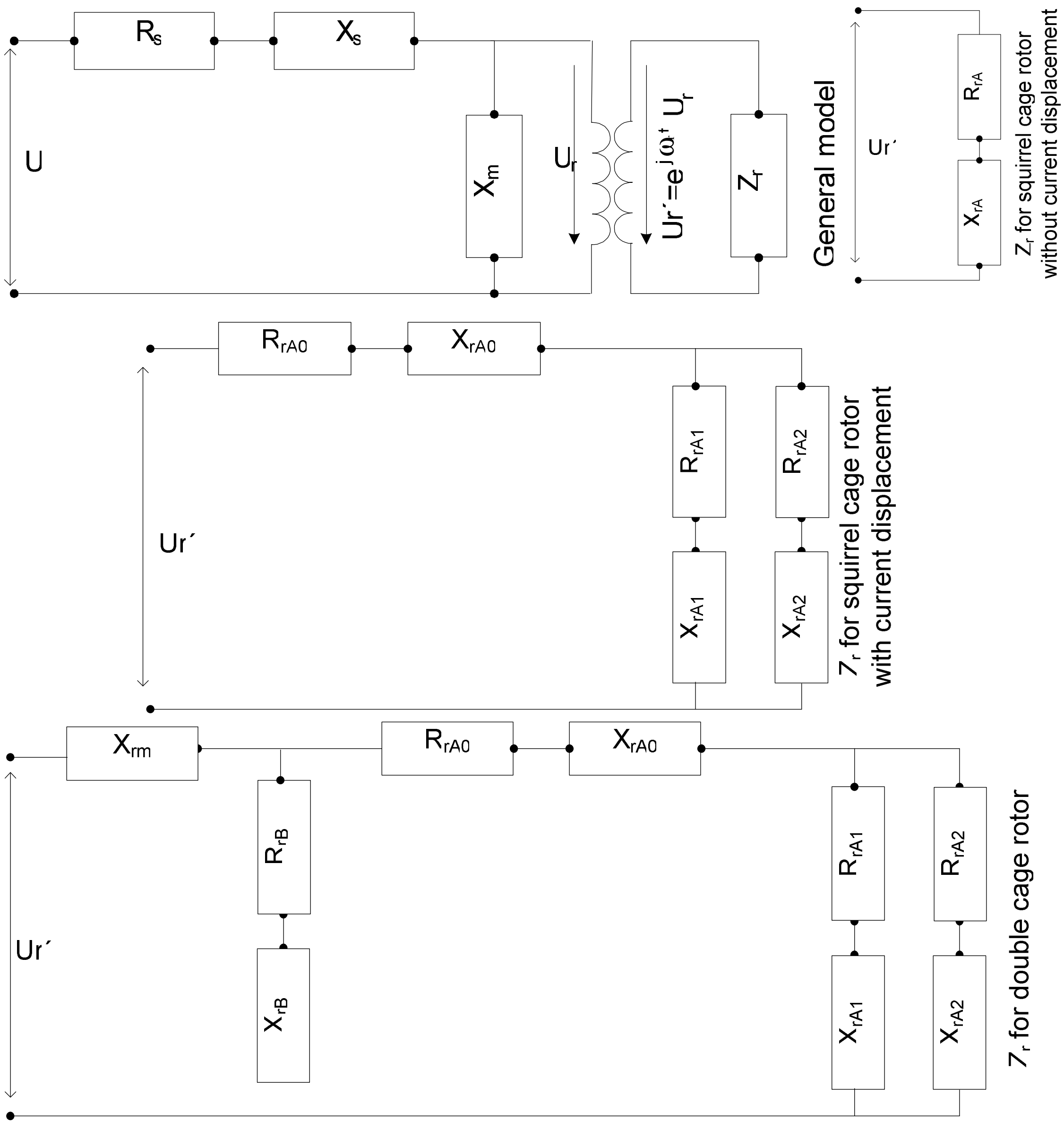

Figure 4-9: Squirrel cage induction generator diagram with the different definition for the rotor impedance Zr

Where:

Rs - Stator winding resistance [Ω].

Xs - Stator leakage reactance.[Ω]

Xm - Magnetizing reactance.[Ω]

Zr - Rotor impedance. [Ω]

The dynamic model of the induction generator uses the steady state parameters defined in the equivalent circuit diagram which characterized in the previous figure.

$$u_s = R_s i_s + j\varpi_{syn}\psi_s + \frac{d\psi_s}{dt}. \qquad (4\text{-}1)$$

$$0 = R_s i_s + j(\varpi_{syn} - \varpi_r)\psi_s + \frac{d\psi_s}{dt}. \qquad (4\text{-}2)$$

Where:

u, i, and ψ - Are space vectors for the voltage, current and flux, respectively.

ϖ_{syn} - The synchronous speed, [rad/s]

ϖ_r - The rotor angular speed.[rad/s]

The voltage equations in per unit are:

$$u_s = R_s i_s + j\frac{\omega_{syn}}{\omega_n}\psi_s + \frac{1}{\omega_n}\frac{d\psi_s}{dt}. \qquad (4\text{-}3)$$

$$0 = R_r i_r + j\frac{(\omega_{syn} - \omega_r)}{\omega_n}\psi_r + \frac{1}{\omega_n}\frac{d\psi_r}{dt}. \qquad (4\text{-}4)$$

Where:

ω_n - The nominal electrical frequency of the network.[rad/s]

The generator inertia is modelled inside the built-in induction machine model. The generator inertia is specified in the form of an acceleration time constant in the induction generator type.

The dynamic model of the induction generator is completed by the mechanical equation:

$$J\omega_r = T_e - T_m. \qquad (4\text{-}5)$$

Where:

J - The generator inertia.[kg.m^2]

T_e - The electrical torque.[N/m]

T_m - The mechanical torque.[N/m]

The nominal torque equation related to the nominal values parameters is:

$$T_n = \frac{P_n}{[\omega_n(1-s_n)]}\ [N/m]. \qquad (4\text{-}6)$$

And as a result the acceleration time constant T_{ag} can be expressed as:

$$T_{ag} = \frac{J(1-s_n)\omega_n^2}{P_n}\ [N/m]. \qquad (4\text{-}7)$$

Where:

s_n - The nominal slip.

4.3.2 Double-Fed Induction Generator (DFIG)

The doubly-fed induction generator (DFIG) symbolize as block shown in the figure 4-10.

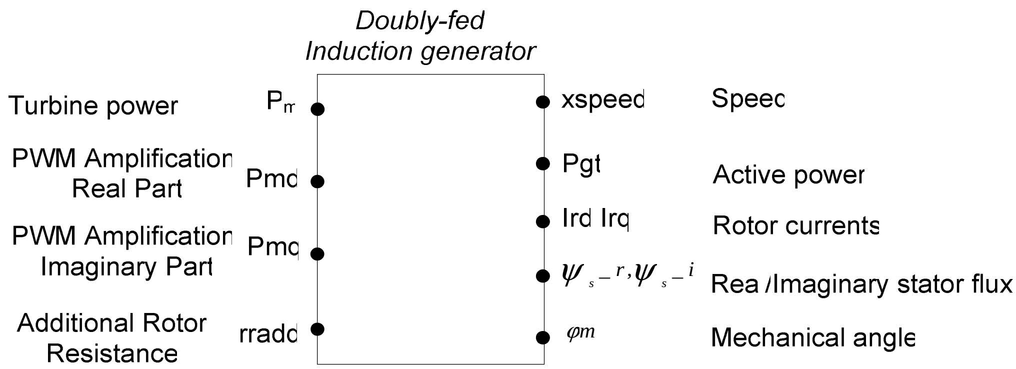

Figure 4-10: Doubly-fed induction generator (DFIG) blocks

Doubly-fed induction generator model has as inputs the mechanical power of the wind turbine, the pulse width modulation factors P_{md}, P_{mq} and the additional rotor resistance. As outputs, besides the speed and the active power, the rotor currents, the stator flux and the mechanical angle of the rotor can be delivered. In the load flow calculation, the active power for the stator, the reactive power and the slip have to be specified. Internally, the corresponding modulation factors of the converter are calculated and together with power balance between the AC and DC side of the converter, the DFIG equivalent circuit illustrated in this figure 4-11.

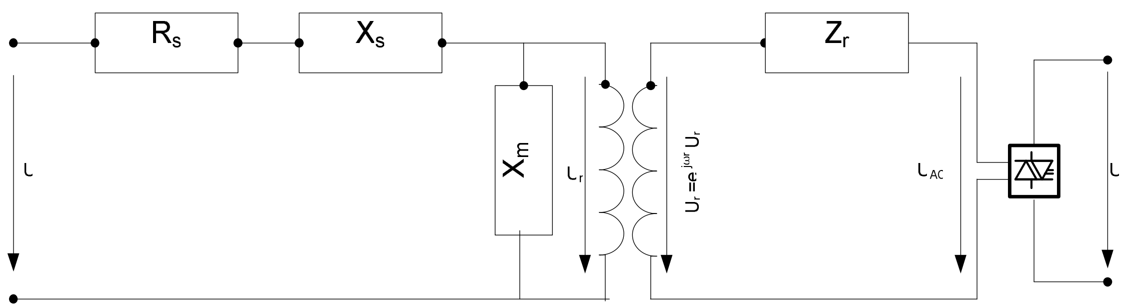

Figure 4-11: Doubly-fed induction machine with rotor side converter.

The PWM converter inserted in the rotor circuit allows for a flexible and fast control of the machine by modifying the magnitude and phase angle of the generator's AC voltage output U_{AC} on the rotor side.

This is done by modifying the modulation factor PWM. Based on the power balance and relationship between the AC and DC side of the PWM converter is:

$$U_{AC_r} = \frac{\sqrt{3}}{2\sqrt{2}}.PWM_r.U_{DC}\ [V] \quad (4\text{-}8)$$

$$U_{AC_i} = \frac{\sqrt{3}}{2\sqrt{2}}.PWM_i.U_{DC}\ [V] \quad (4\text{-}9)$$

(Note: The AC voltage is expressed as line-to-line voltage)

Where:

PWMr and PWMi - The real and imaginary components of the modulation factor respectively

$$P_{AC} = \mathrm{Re}(U_{AC} I^{*}_{AC}) = U_{DC} I_{DC} = P_{DC}\ [W]. \quad (4\text{-}10)$$

Note: The relationship between AC and DC currents can be found by assuming that the PWM converter is loss free.

The model equations of the doubly-fed machine can be derived from the normal induction machine equations by modifying the rotor-voltage equations:

$$u_s = R_s i_s + j\frac{\omega_{syn}}{\omega_n}\psi_s + \frac{1}{\omega_n}\frac{d\psi_s}{dt}\ [-]. \quad (4\text{-}11)$$

$$u_r e^{-j(\omega_{syn}-\omega_r)t} = R_r i_r + j\frac{(\omega_{syn}-\omega_r)}{\omega_n}\psi_r + \frac{1}{\omega_n}\frac{d\psi_r}{dt}\ [-]. \quad (4\text{-}12)$$

Per unit rotor voltage that appears in the above equation is related to the DC-voltage as:

$$u_{rd} = \frac{\sqrt{3}}{2\sqrt{2}}.PWM_d.\frac{U_{DC}}{U_{rnom}}\ [p.u.]. \quad (4\text{-}13)$$

$$u_{rq} = \frac{\sqrt{3}}{2\sqrt{2}}.PWM_q.\frac{U_{DC}}{U_{rnom}}\ [p.u.]. \quad (4\text{-}14)$$

Where:

U_{rnom} - The nominal rotor voltage.[V]

4.4 Power Converter

The rectifier/inverter model is used to create DC power links, or for building power electronic devices such as variable speed drives

The power convertors used in wind turbines are usually realized by self commutated pulse width modulated circuits as illustrated in the figure 4-13

These circuits are built by six valves with turn-off capability and six anti-parallel diodes. The valves are typically realized by IGBTs (insulated gate bipolar transistors) because they allow for higher switching frequencies.

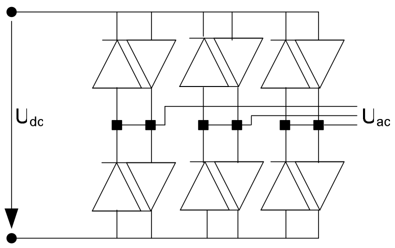

Figure 4-12: Generic PWM converter model

The general model of the PWM converter, that usually operated as a voltage source converter is shown in the figure 4-14.

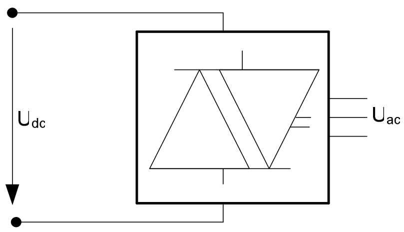

Figure 4-13: PWM converter-general model

The model equations are expressed as follows:

$$U_{AC_r} = K_0.PWM_r.U_{DC}\ [V]. \quad (4\text{-}15)$$

$$U_{ACi} = K_0 . PWM_i . U_{DC} \; [V] . \qquad (4\text{-}16)$$

The U_{ACr} and U_{ACi} are the real and imaginary of the AC voltage, corresponding to the positive and negative sequence component, PWMr , PWMi , defined as follows:

For a sinusoidal PWM is:

$$K_0 = \frac{\sqrt{3}}{2\sqrt{2}} \qquad (4\text{-}17)$$

For a rectangular PWM or for no modulation is:

$$K_0 = \frac{\sqrt{2}\sqrt{3}}{\pi} \quad . \qquad (4\text{-}18)$$

Note: Assuming the PWM to be loss-less

5 Simulation of a wind turbine with double-fed induction generator by Matlab

This chapter deal with simulation of wind speeds and wind turbine with double fed induction generator connected to the local network as in example the wind simulation has been chosen according to the data which I have received from GECOL and it was measured during 2003 to 2004 and it is about a project has been supported strongly by GECOL, the reason behind this project is, to concentrate in the field of renewable power sources instead of the conventional energy sources.

In the begging of 2000 the renewable power sources department was created in Tripoli for the reason of researching and improving the energy sector in Libya, and to find alternative source of energy instead of the conventional fuel, so they had proposal of wind power meteorology, which has evolved as an applied science, firmly founded on boundary-layer meteorology, but with strong links to climatology and geography. It concerns itself with three main areas: sitting of wind turbines, regional wind resource assessment, and short-term prediction of the wind resource. The history, status and perspectives of wind power meteorology are presented, with emphasis on physical considerations and on its practical application. Following a global view of the wind resource, the elements of boundary-layer meteorology which are most important for wind energy are reviewed: wind pro les, shear turbulence, gust, and extreme winds The data used in wind power meteorology stem mainly from three sources: onsite wind measurements, the synoptic networks, and the reanalysis projects. Wind climate analysis, wind resource estimation and sitting further require a detailed description of the topography of the terrain with respect to the roughness of the surface, near-by obstacles, and aerographical features. Finally, the meteorological models used for estimation and prediction of the wind are described; their classifications, inputs, limitations and requirements. A comprehensive modeling concept micro-scale modeling is introduced and a procedure for short-term prediction of the wind resource is described.

- The following study evaluates classified wind speed data from selected cities in Libya to determine the usable wind energy
- In 2002 - 2003, a measurement campaign at prospective wind park sites was launched in Libya, charged by the national utility company (GECOL).In the coastal wind speeds in Libya identified three sections of the coast with different levels of annual average wind speeds in 50 m above ground:
- At the west coast between 4.7 to 9.1 m/s.
- At the central coast between 5.4 and 8.9 m/s, and.
- At the east coast between 5.6 and 10.4 m/s.

Naturally, the indication of wind speed ranges does not allow a useful assessment of energy output. However, the comparison of these predictions with a map derived from the World Wind Atlas (WWA) agrees well with the quantitative statement, that the Eastern Libyan cost experiences higher wind speeds than the Western part see the figure below.

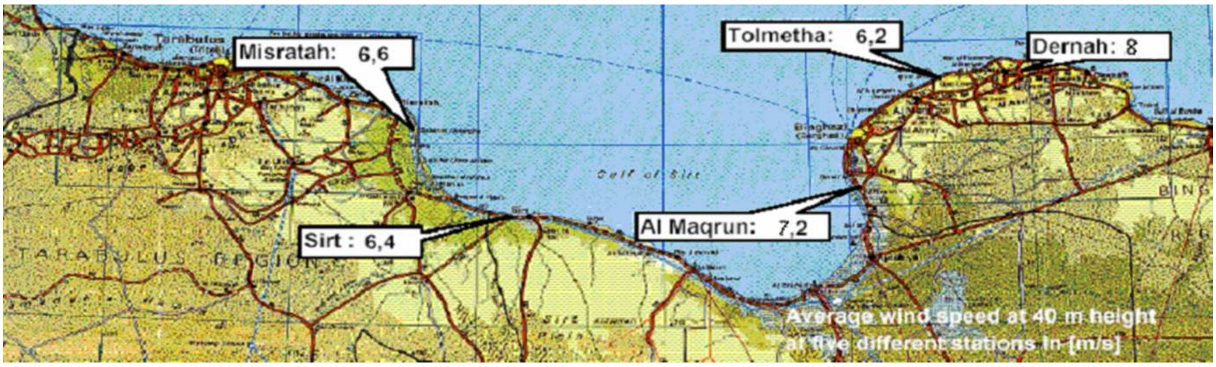

Figure 5-1: Chosen wind site locations on the Libyan coast

The GECOL project has measured five coastal sites with 40 m measuring towers and anemometers in 10, 20 and 40 m above ground the location of which is given in the previous figure.5-1

The cities have been chosen according to their locations and the measuring of the metro speed per seconds are; Misratah , Sirt, Al Maqrun, Tolmetha and Dernah from the west to the east respectively

These locations with their average wind speeds are Misratah (6.6 m/s), Sirt (6.4 m/s), Al-Maqrun (7.2 m/s), Tolmetha (6.2 m/s) and Dernah (8 m/s). In remaining areas of Libya, GECOL evaluated other locations for possible wind farms (e.g. Al-Bayda, Aziziyah, Asaaba, Murzuq, Ghat, Ubari and Sabha). Various wind farm sizes (5 MW, 15 MW and 25 MW) and wind turbine types (< 1 MW, < 1.5 MW and > 1.5 MW) have been considered. Based on excellent measured conditions in Dernah location, also due to logistical and operational reasons (especially transport of material to the seaport of Dernah), pilot project of 60 MW was declared with estimated construction start in 2008. However, this concept has been thoroughly reviewed resulting in a more elaborated plan for the following decade concerning the wind power plants in Libya.

For the verification data professional programming tool Matlab has been employed this software package enables broad variety of data analysis and simulations Matlab is a tool for doing numerical computations with matrices and vectors. It can also display information graphically the program was my chosen software program for this purpose.

5.1 Obtain the Data

To collocate an accurate and real data about the power network in Libya or any information about new researches for any new project in a case of a government think about these information are one of the state secrete which no one can go throw these information or they didn’t even have these data in their monthly or annually reports in the GECOL’s reports which more than logic for any company to have them in their websites, as same as any electric company in the world has the same responsibility for generation, transmission and distribution electric power or even as a documentations in their offices for a public to go throw specially for students researches, that is why it take from me a long time to collect these data which I have used for these research from some personal contacts.

The data which I have it was in the documents format (txt) when I received and it was huge amounts of random data and it was about five cities, in each city four units and in each unit three values (maximum, minimum and average values) every ten minutes for the whole year , these data was saved in memory cards fixed in each measurement unit and they change them once per month and they collate these data in a computer in their department that is all what they did ,and the figure 5-2 it is just a short example about how it look like the data when I receive it .

```
File_ LY_Maqrun_03.01_EKO.txt

*EKO-20* serial number : 220213
Identification text :Al Maqrun B
Start date : 01.01.2003
Start time : 00:00:00
Record interval : 00:10:00
Sample interval : 00:00:03
No, channels : 11
Readings :

Channel specifications :
No;; 0; 0; 0; 0; 1; 1; 1; 1; 2; 2; 2; 2; 3; 3; 3; 3; 4; 5; 6; 7; 8; 9; 10
Minimum;;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;-;0;762,5;-;0
Maximum;;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;51,15;360;360; 360; 100; 1137,5; 360; 15
Units;;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;m.s;deg;deg;C;%;hPa;;V
Quantity;;windspeed 1;windspeed 1;windspeed 1;windspeed 1;windspeed 2;windspeed 2;windspeed 2;windspeed 2;windspeed 3;windspeed 3;windspeed 3;windspeed
date;time;max 0;min 0;avg 0;dev 0;max 1;min 1;avg 1;dev 1;max 2;min 2;avg 2;dev 2;max 3;min 3;avg 3;dev 3;pol 4;pol 5;log 6;log 7;log 8;log 9;log 10
01.01.03;00:00:00;6,65;4,75;5,66;0,37;8,15;6,25;7,06;0,37;10,10;7,40;8,99;0,47;9,40;7,10;8,46;0,46;262,7;289,1;17,0;57,48;1014,3;16,8;12,90;
01.01.03;00:10:00;7,05;4,45;5,61;0,41;8,25;6,05;6,98;0,42;9,90;7,95;8,90;0,36;9,20;7,45;8,36;0,35;262,0;288,3;17,2;58,36;1014,3;16,6;12,90;
```

Figure 5-2: Data in document format

So I had to check and filter the data and estimate some values if there is some missing numbers or irrational numbers as well so I had to transform the data to an excel format to be easier even for the simulink program as the next step. I used Matlab for this propose and the figure 5-3 shows the data in the excel format after the transformation.

(Note: All the data are included with this project in the software format).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	1	2003	0	0	0	6,65	4,75	5,66	8,15	6,25	7,06	10,10	7,40	8,99	9,40	7,10	8,46
1	1	2003	0	10	0	7,05	4,45	5,61	8,25	6,05	6,98	9,90	7,95	8,90	9,20	7,45	8,36
1	1	2003	0	20	0	7,30	4,80	5,68	8,40	6,00	7,08	9,95	7,80	9,07	9,45	7,50	8,58
1	1	2003	0	30	0	7,45	4,90	5,92	8,60	6,30	7,29	9,90	7,95	8,98	9,40	7,45	8,57
1	1	2003	0	40	0	7,60	4,90	6,05	8,70	6,15	7,42	10,25	7,90	9,14	9,70	7,30	8,67
1	1	2003	0	50	0	7,55	4,90	5,98	8,50	6,20	7,38	10,00	7,50	8,88	9,55	7,20	8,38
1	1	2003	1	0	0	5,90	4,40	5,08	7,70	5,30	6,35	9,10	7,15	8,13	8,45	6,70	7,63
1	1	2003	1	10	0	6,60	4,35	5,32	7,95	5,70	6,66	9,10	7,30	8,26	8,60	6,75	7,79
1	1	2003	1	20	0	5,50	3,90	4,76	6,90	5,25	5,97	8,20	6,60	7,48	7,65	6,05	6,99
1	1	2003	1	30	0	5,10	3,55	4,26	6,15	4,75	5,51	8,15	6,70	7,37	7,50	6,20	6,86
1	1	2003	1	40	0	4,95	3,60	4,20	6,00	4,65	5,39	7,40	6,20	6,81	6,95	5,75	6,31

Figure 5-3: Data in excel format

5.2 Checking the Data

I created a software program to calculate and draw the data to be visible and comparable, by Matlab software program and simulate it. According to the output; I could choose which city is suitable for the first project as wind farm power plant. I used one software program for the all units and cities; the change was only for the input data for each city individually and together.

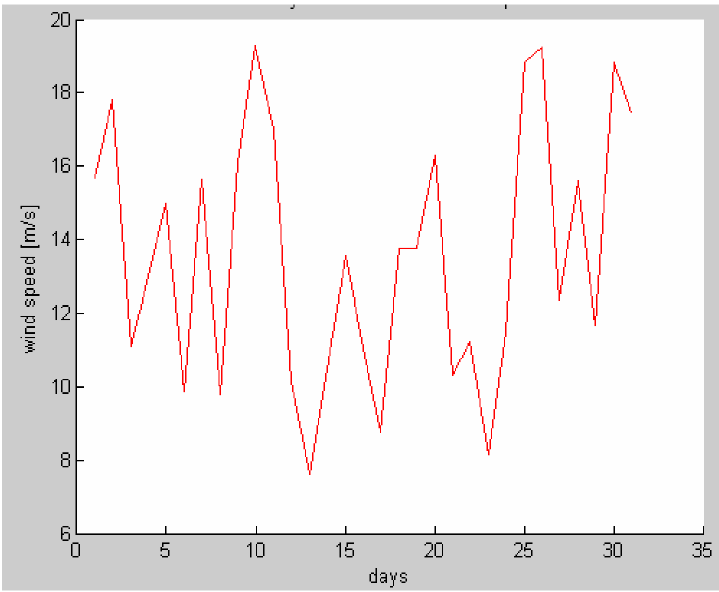

Figure 5-4a: The maximum wind speed values

The first proposal was to run this software for each unit per year and see the maximum, minimum and average values respectively. The result was 48 figures for each unit and the figures 5-4 is just a sample of the results from the test units in Dernah city.

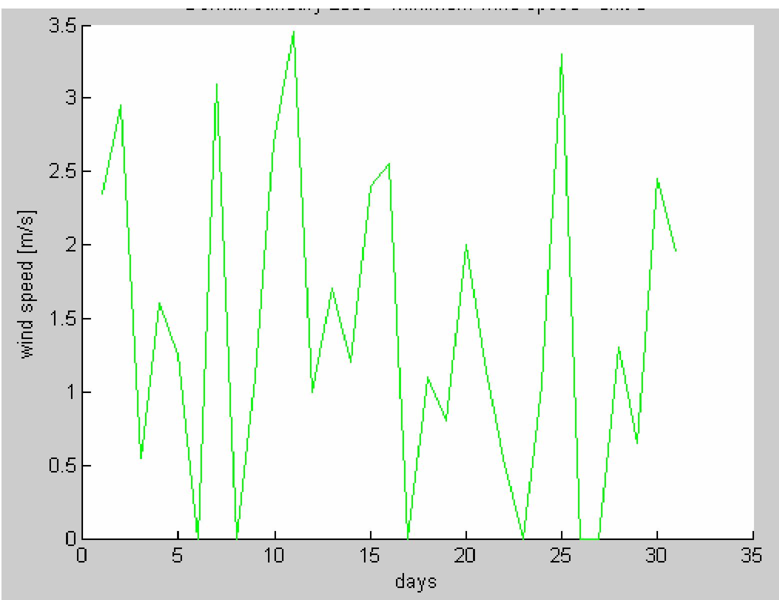

Figure 5-4b: The minimum wind speed values

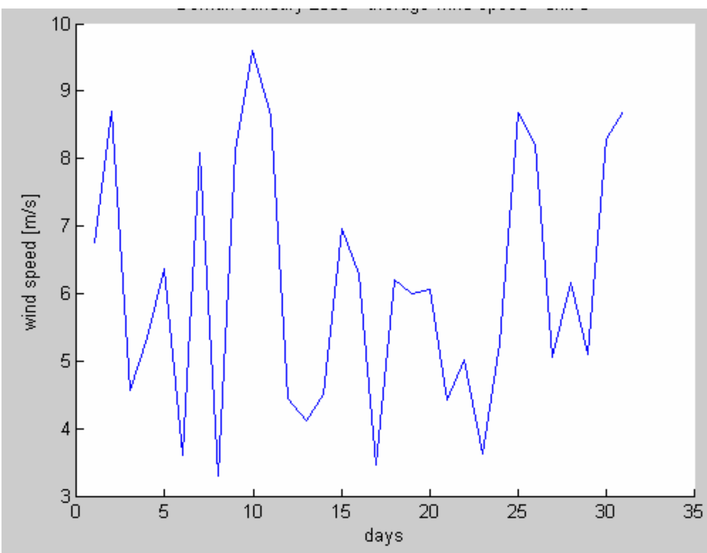

Figure 5-4c: The average wind speed values

From the previous figures I can't see more options to compare, but it was visible how the different between the values in the same units and it was necessary as well to know the minimum values and how long it takes when it was zero and the minimum and maximum values in the day time or night times, for the over and under-speed protections.

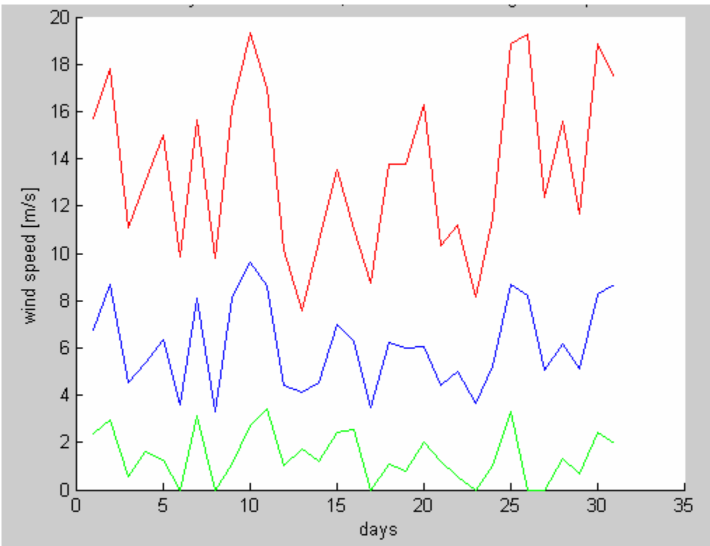

Figure5-4d: The comparison of wind speeds three values

Then I have chosen the four units in the same city and see the result so maybe it will be possible to compare the locations by comparing the average, maximum and the minimum values together the figure 5-5 present the values of the four units together and the results were almost the same and I just present the simulation output in December as sample and in the same city Dernah .

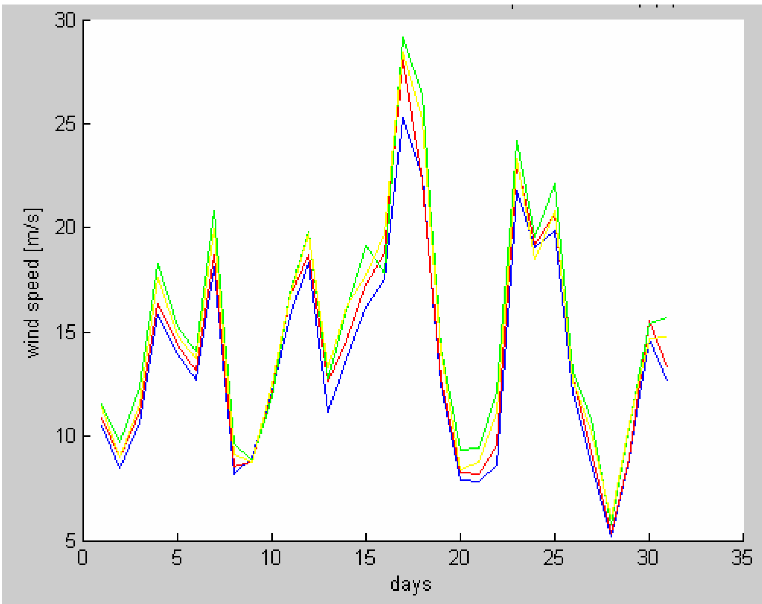

Figure 5-5a: The maximum values for Dernah four units

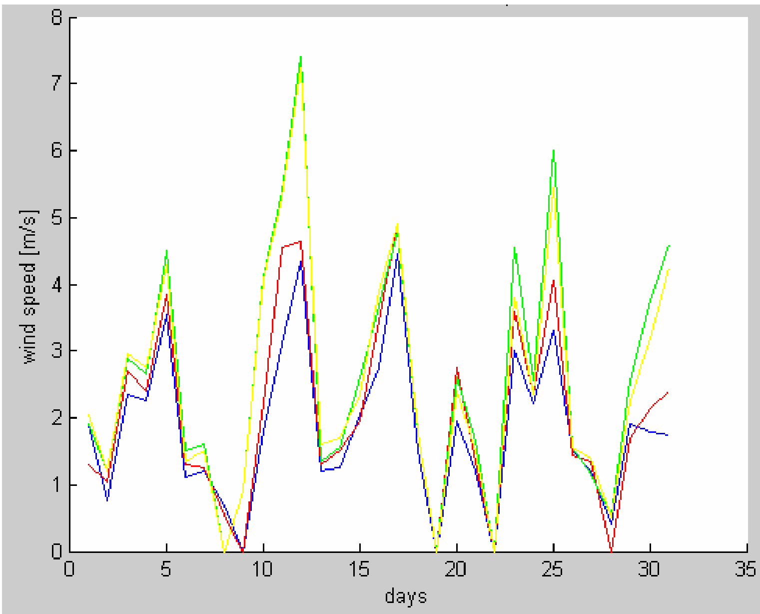

Figure 5-5b: The minimum values for Dernah four units

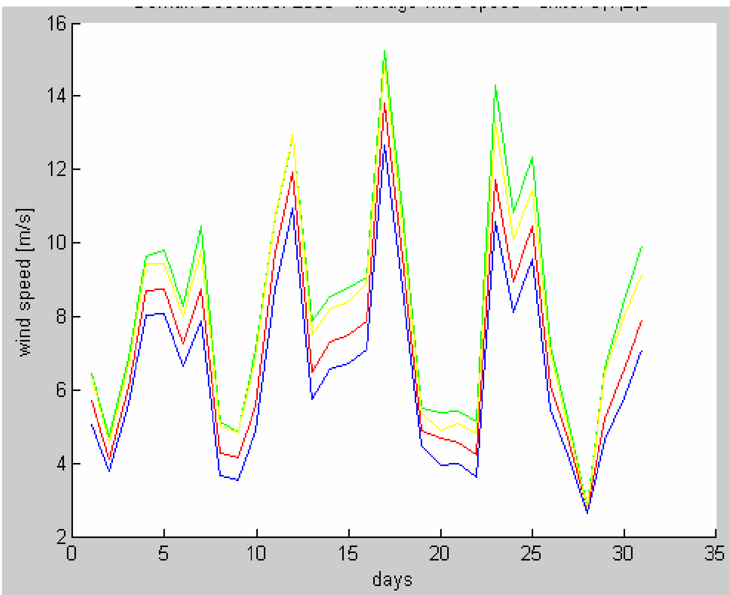

Figure 5-4c: The average values for the four units

These values were for one month and I even compare them together for the whole year in each city, the same results were with the others and the give almost the same outputs. ‘

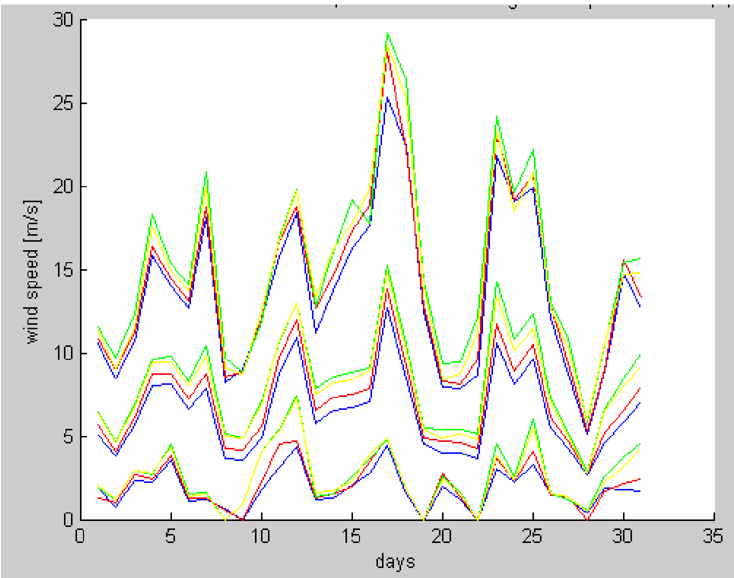

Figure 5-5d: The comparison speed values for Dernah four units

The next step was in the same city and same data as an example but I just have chosen only the maximum values from the maximums data in the day and the minimum value from the minimum data in the day and the average from the averages data in the day. It was for checking the data for protection reasons, the figure 5-6 below present the output of that process.

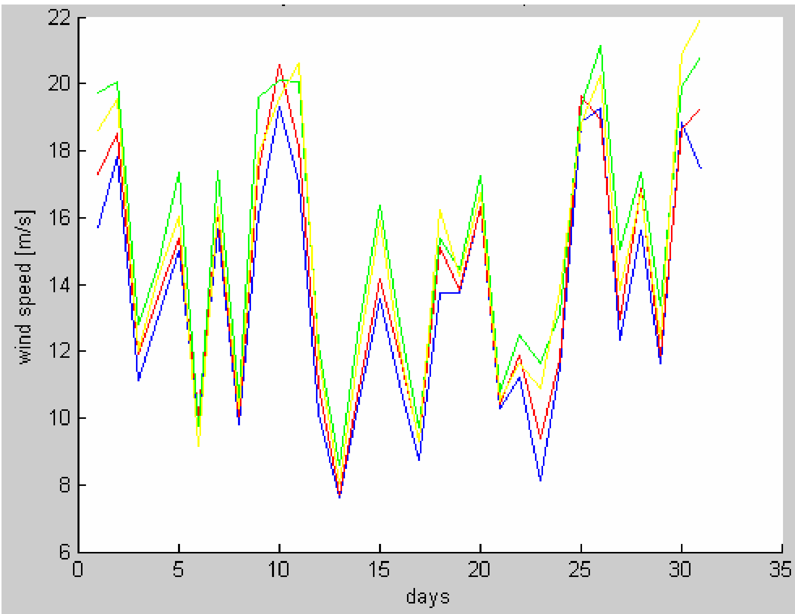

Figure 5-6a: The max values per day

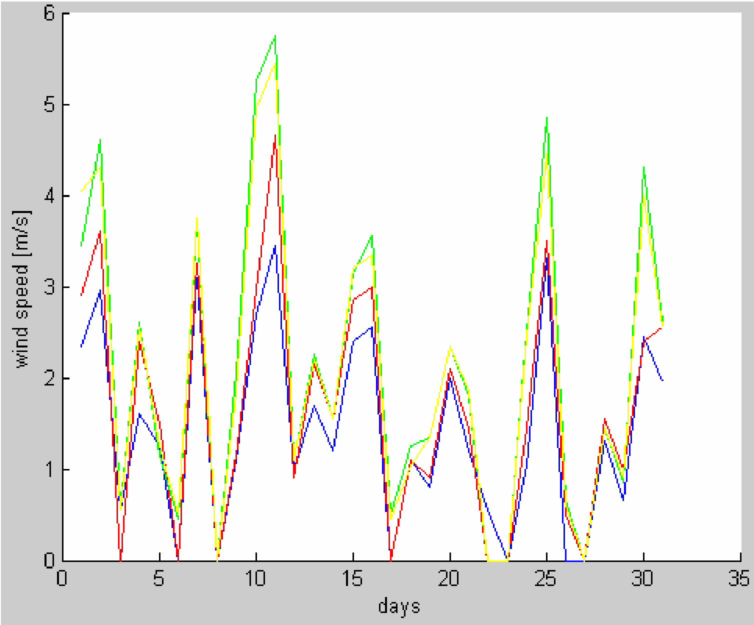

Figure 5-6b: The min values per day

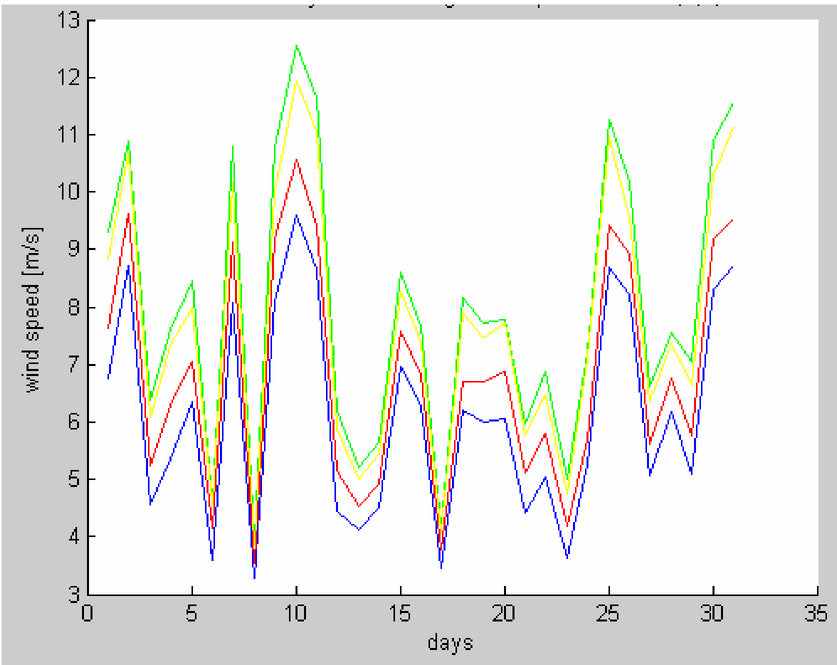

Figure 5-6c: The average values per day.

As it seen in the figures 5-6, the values are quit the same as on the figures before. It means that the wind speeds are almost stable in each unit and in each city, therefore I made the same procedure with the all cities for the whole data.

After that it was the time to compare the all cities together to choose the first city for the first wind farm. Figure 5-7 presents the simulation output of average values for the all cities together.

The conclusion of the sensitivity analysis, which was made, is that the Dernah site in Libya's east which was mentioned (the blue color line), is the most suitable place for the first wind farm. And it is most feasible from both an economical and technical point of view and can present to most important which should be respected in the wind power station interconnection to the grid network:

- Excellent wind conditions.
- Good accessibility.
- Easy terrain.
- Good grid connection possibilities.
- Manageable logistical problems.
- Crane availability for installation and repair must be secured.
- High extension potential (100 – 150 MW).
- Low additional foundation requirements in a homogenous soil environment.
- Dernah it is an industrial, agriculture city
- The people mentality cause to have new project like this it is necessary to be accepted from the local people.

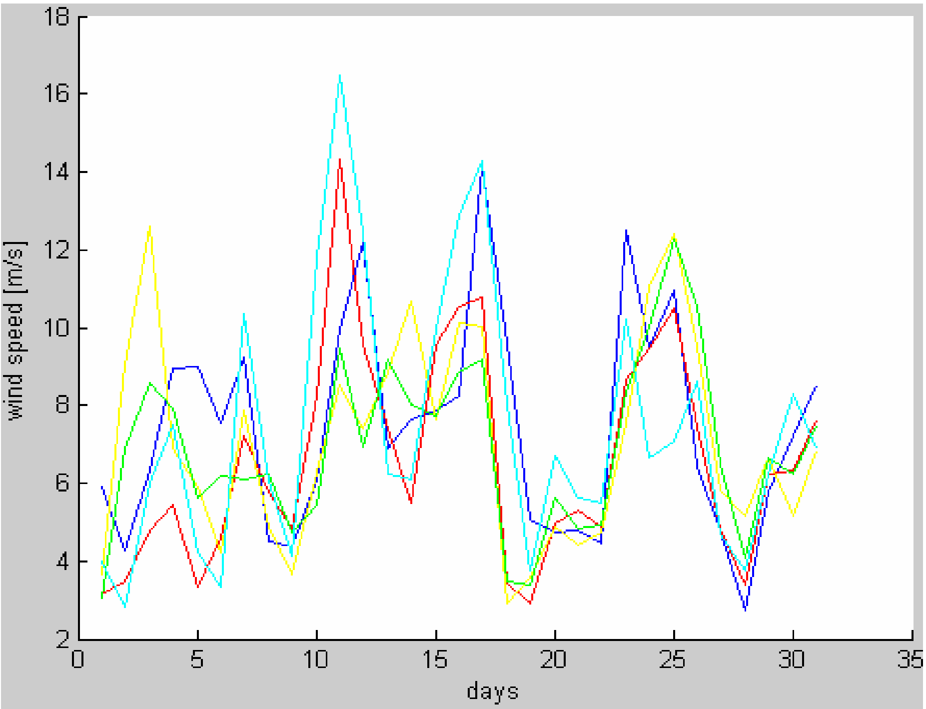

Figure 5-7: Average of the average wind speed values for whole cities

5.3 Case Study (Dernah)

According to the new concept, a wind farm of 60 MW (1st stage) has been put into construction process in Fattaih area, Dernah in May 2010. Another 60 MW (2nd stage) are scheduled to be finished until the end of 2012. In total, this power plant should consist of 37 turbines of 1.65 MW each with total installation costs of 103 million Euros. Second wind farm project in Benghazi region (also to be realized in 2 stages) is in Al-Maqrun location with planned total of 240 MW, first half (80 Siemens turbines, 1.5 MW/each) being constructed since 2011. Other projects are the installations of 50 MW wind farms (25 turbines, 2 MW/each) in Misratah and Tarhona. Moreover, feasibility studies for building 120 MW wind farms are currently under way in the west (Asaaba), in the south (Jallo, Almasarra, Tazerbo) and in the south-west (Aljofra, Sabha, Ghat and Ashwairef) regions. These projects will be started during the next three-year term.

All these projects are strongly supported by Libya's government, GECOL and by government organization Renewable Energy Authority of Libya (REAOL) which is carrying out all planning and building operations relating to renewable power sources. By these huge projects, REAOL tries to reach the strategy target of 10 percent of electric power generation from renewable power sources until 2020 with estimated capacity of 800 MW (CSPs), 150 MW (PVs), 300 MW (solar water heaters) and 1500 MW (wind).

5.3.1 Simulation results

Since when I have chosen a location for the first wind farm in Dernah city, in this paragraph the simulation via Matlab software program will be presented with the basic operation of DFIG and its controls using AC/DC/AC converter connected to the grid.

First I simulated a wind turbine driven isolated (not connected to grid) induction generator. But for best efficiency the DFIG system is used which is connected to grid side and has better control. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. So finally I simulated grid side and wind turbine side parameters and the corresponding results have been displayed

The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. Considering the results it can be said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems.

As an example for the modeling and simulation I suppose the Dernah farm has 9MW capacity and it is consist of (6 of 1.5 MW each) wind turbines connected to 30KV distribution system exports power to a 220 KV grid through a 30 Km, 30 KV feeder as a maximum length.

A 2300 V, 2 MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200 kW resistive load is connected on the same feeder at bus B25. Both the wind turbine and the motor load have a protection system monitoring voltage, current and machine speed. The DC link voltage of the DFIG is also monitored.

The DFIG is controlled in order to follow the red curve and the turbine speed optimization is obtained between point B and point C on the same curve in the figure 5-8 below.

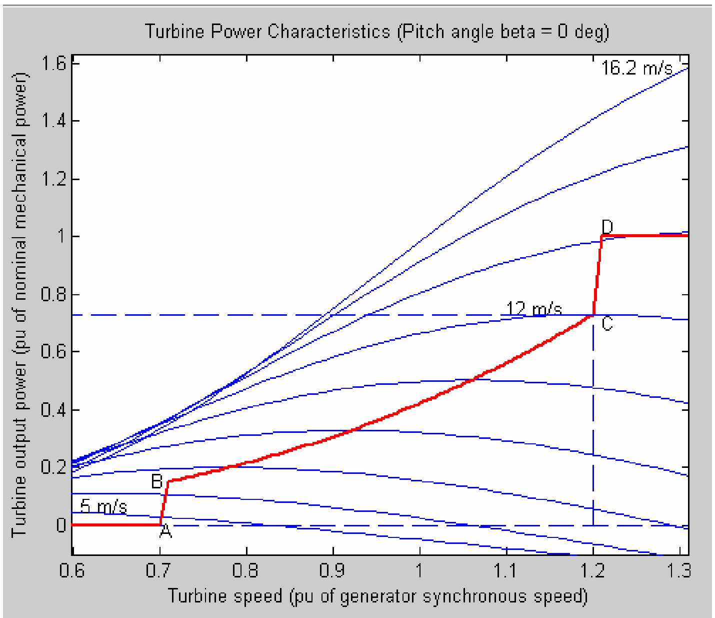

Figure 5-8: The realtion between turbine speed and power output

Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generators.

The Simulink diagram for a doubly fed induction generator wind farm connected to grid side with protection schemes involved for protection from single phase faults and ground faults.The grid volateg level is 220 KV, the figure 5-9 presents the wind farm connected to the grid .

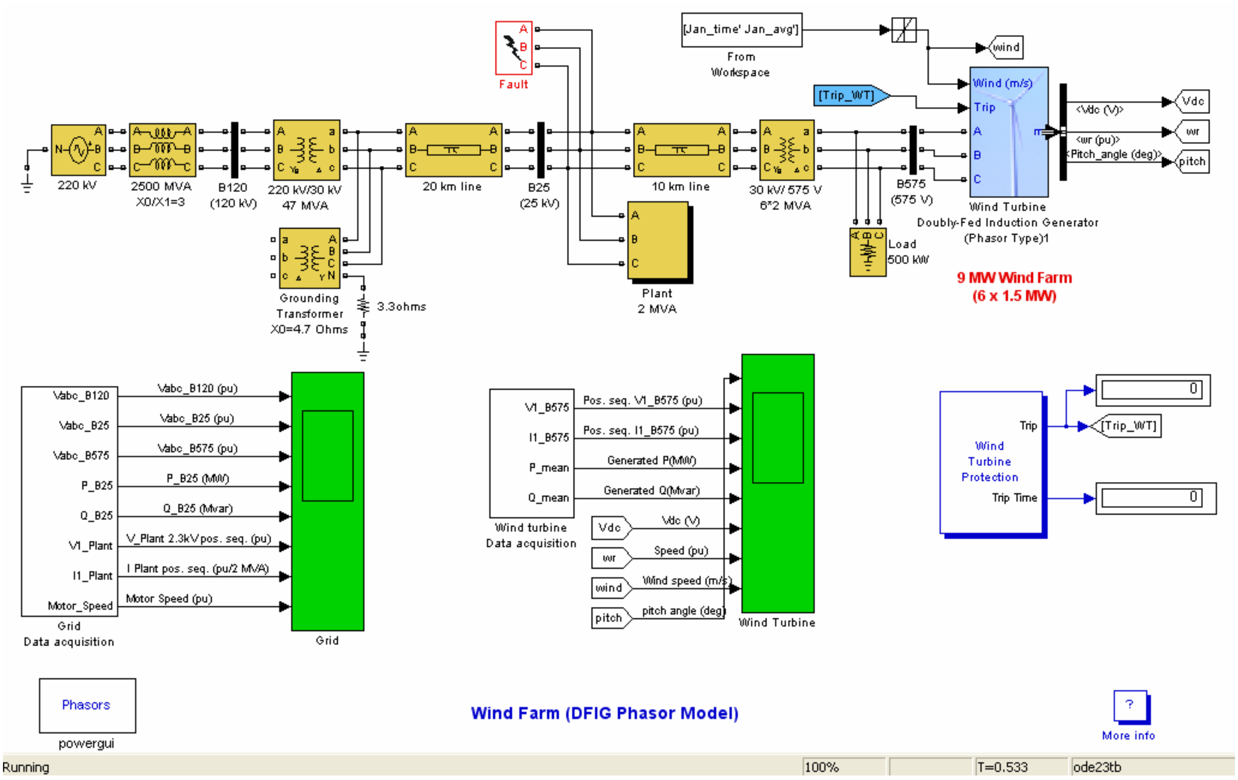

Figure 5-9: Wind farm connected to the grid model

5.3.2 Wind Turbine Protection

This is the block for wind turbine protection in which the positive sequence voltage and current and DC voltage are given as input and for their corresponding values trip data is used to see whether it should be tripped or not.

The different reasons for tripping may be AC over voltage, under voltage, over current, undercurrent, DC overvoltage, over speed and under speed.

Depending on the reasons stated above the trip signal is given to trip the circuit within the trip time. The figure 5-10 present the wind turbine protection.

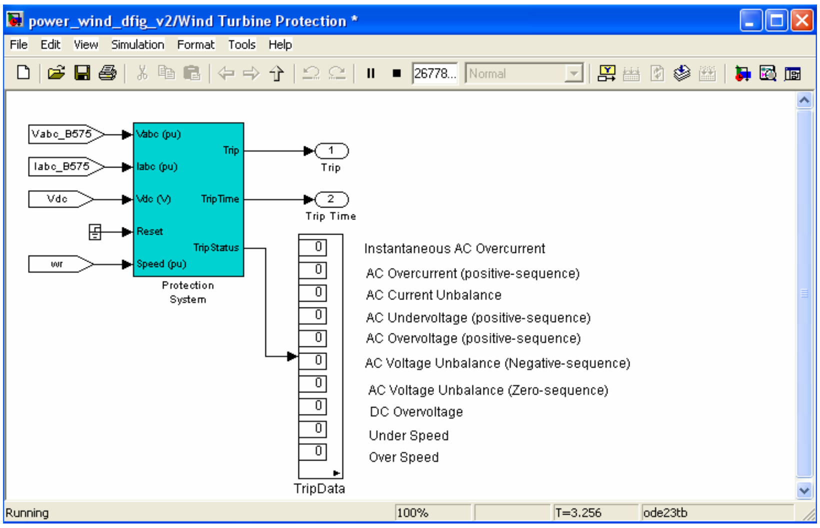

Figure 5-10: Wind turbine protection

5.3.3 Wind turbine data acquisition

This is the Block diagram for generator data acquisition. In this the input signal are voltage and current which are passed through gains and finally the outputs provided are positive sequence current, voltage and active and reactive power mean values. The figure 5-11

$$K= \quad j\pi \quad j\pi$$

presents the data acquisition and the gain is (

)

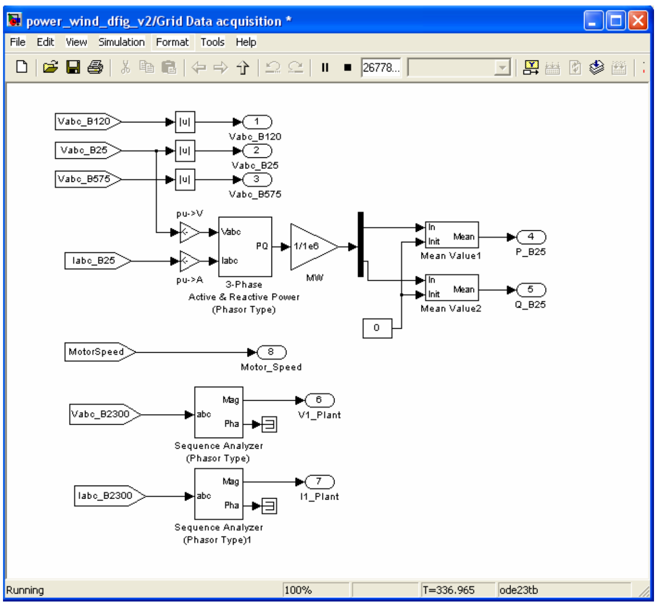

Figure 5-11: Grid data acquisition

5.3.4 Grid data acquisition

This is the block diagram for Grid data acquisition. The voltage, current, and speed are input to various blocks giving p.u. active and reactive power outputs along with motor speed, the figure 5-12 presents the Grid data acquisition

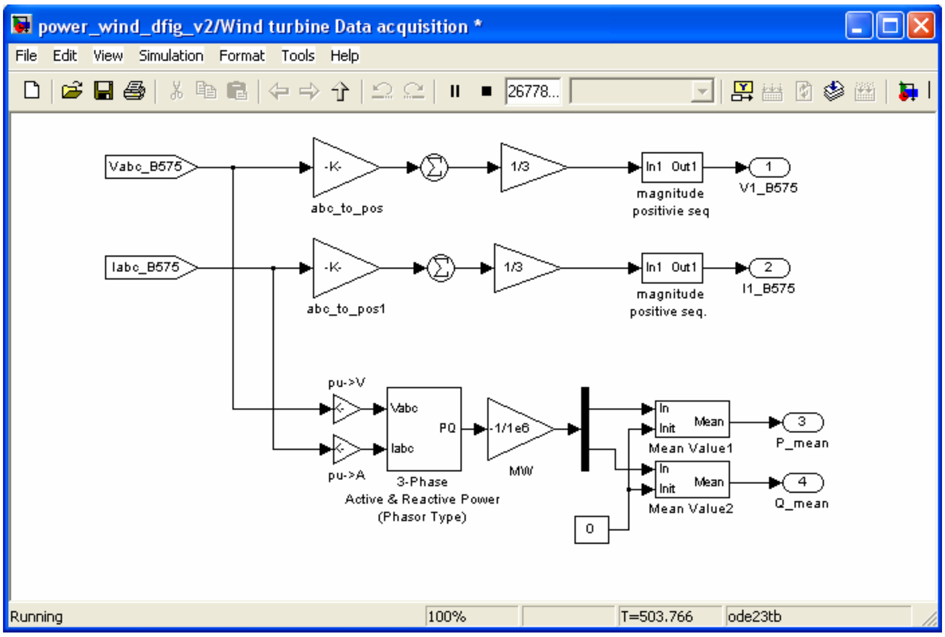

Figure 5-12: Wind turbine data acquisition

5.3.5 Turbine Response to a Change in Wind Speed

To measure the response of the wind turbine and the grid which connected to the wind farm I have to run the program in the figure 5-9 after changing all the parameters according to the standard parameters (i.e. line to line voltage, rated power and the frequency), I will find the results are presented in the figures 5-13 and figure 5-14.

In the "Wind Speed" step block the wind speed is specifying. Initially, the wind speed is set at the initial value 8 m/s, then at t = 5 s, wind speed increases suddenly at 14 m/s. Start simulation and observe the signals on the "Wind Turbine" scope monitoring the wind turbine voltage, current, generated Active and Reactive powers, DC bus voltage and turbine speed.

At t = 5 s, the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 20 s. Over that time frame the turbine speed will have increased from 0.8 p.u. to 1.21 p.u.. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the red curve of the turbine power characteristics up to point D shown in the previous figure 5-8. Then the pitch angle is increased from 0 deg to 0.76 deg in order to limit the mechanical power. We also observed the voltage and the generated reactive power.

The reactive power is controlled to maintain the level of 1 p.u. voltage. At nominal power, the wind turbine absorbs 0.68 MVar to control voltage at 1p u.

If we change the mode of operation and the parameters we will get many different types of the out puts and each output presents the way of controlling the system according to the our demand output for the wind farm till it will be suitable to connected to the power network.

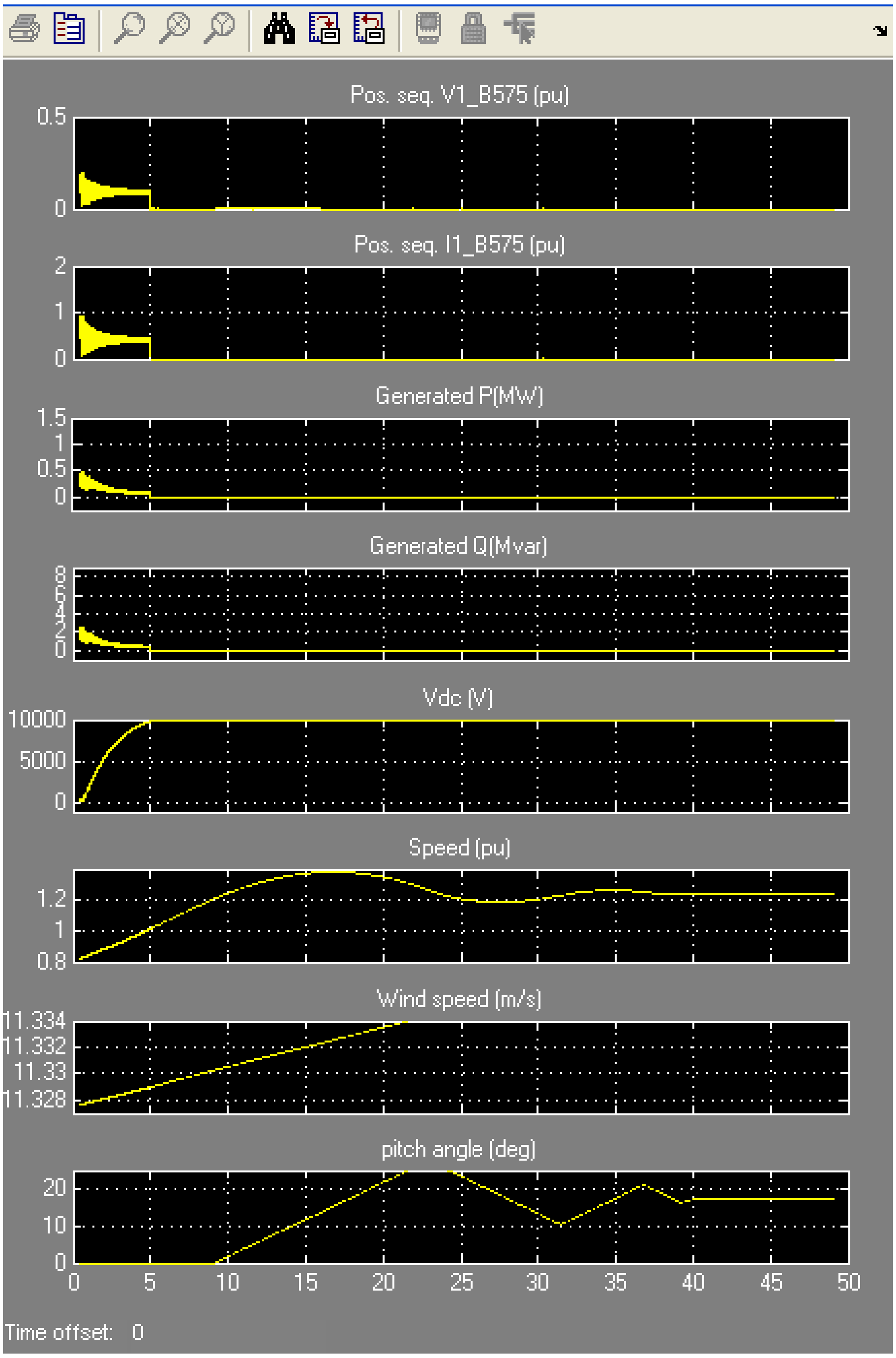

Figure 5-13: Wind farm output

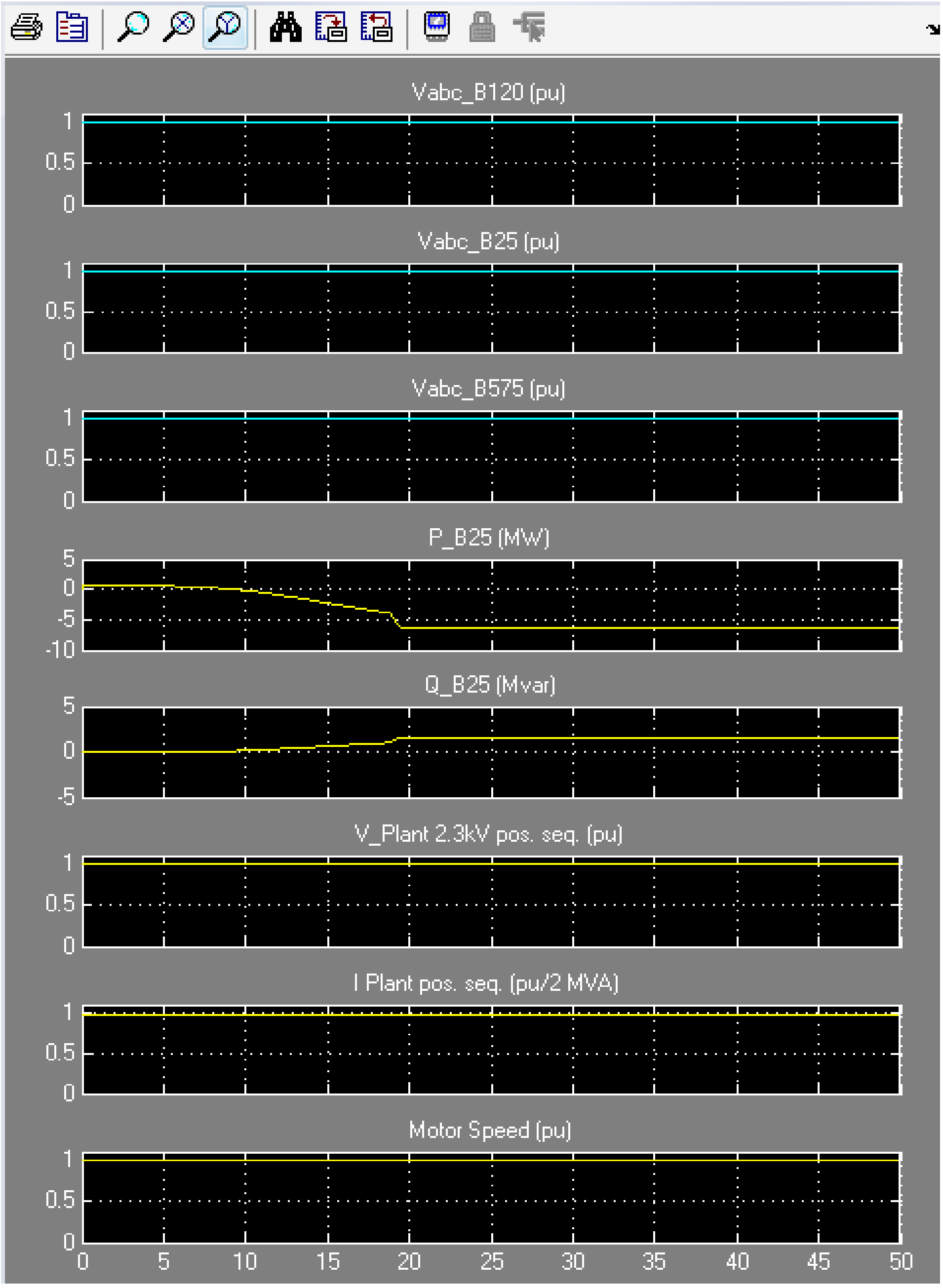

Figure 5-14: The gird output

6 The national transmission of Libyan power system and its analysis

This chapter deals with the transmission power system of Libya and its capacity to incorporate renewable power sources, especially large wind power farms.

First, the initial load flow case of the eastern part of the Libyan transmission network has been performed.

Second, another load flow study has been analyzed to demonstrate the steady-state behavior (especially voltage and power conditions) of the network when incorporating planned wind power farms for year 2010.

Final load flow problem has been strictly defined as an optimization problem to examine maximum possible power generations from prospective wind power farms in selected locations of the eastern network part in 2015 (with estimated loading situations) for maintaining all bus voltages and branch power flows within their permitted limits. Based on these simulations, further research activities in this area will continue.

6.1 National power system of Libya

Unlike the rest of the African countries, where less than 10 percent of population has an access to the electricity, Libya is a fully electrified country with current electricity consumption of 4360 kWh the transmission system network shows in the figure 6-1.

In Tripoli in 1984, the General Electric Company of Libya (GECOL) has been established for providing distribution services of electrical energy to the entire population of Libya and securing declared inter-tie flows on the transmission level to all electric power utilities in neighbouring countries with particular focus on reliability, sustainability and economy of the power system operation and control. Moreover, it is state-owned

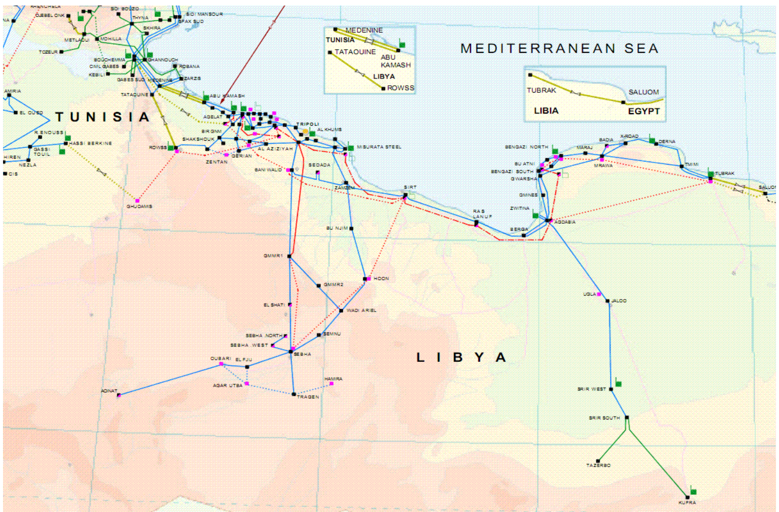

Figure 6-1: Libyan grid contacting with East and West neighbors utilities

GECOL is responsible for the entire power sector in the country, from the generation, transmission and distribution of electrical energy, through the oil and gas industry up to the branch of water desalination.

For covering the load-growth rate of 8 percent per year on average, the transmission network with all main electric power plants remains the most important part of the Libyan power sector. The transmission power system of Libya consists of six geographically dispersed, sparsely interconnected island areas (West, Tripoli, Central, Benghazi, Eastern and Southern regions). In a simplified form, the entire transmission power system Fig. 6-2. Shows the single line diagram of the national power network of Libya which consists of approximately. 75 substations on 400KV (442Km) and 220 kV (13,677 km) and 132 kV (1,208 km) voltage levels with connections to sub-transmission networks of 66 kV (13,973 km) and distribution systems of 30 kV (8,583 km) and 11 kV. Connections in the transmission network of Libya are realised as overhead lines (14,747 km) and cables (138 km).

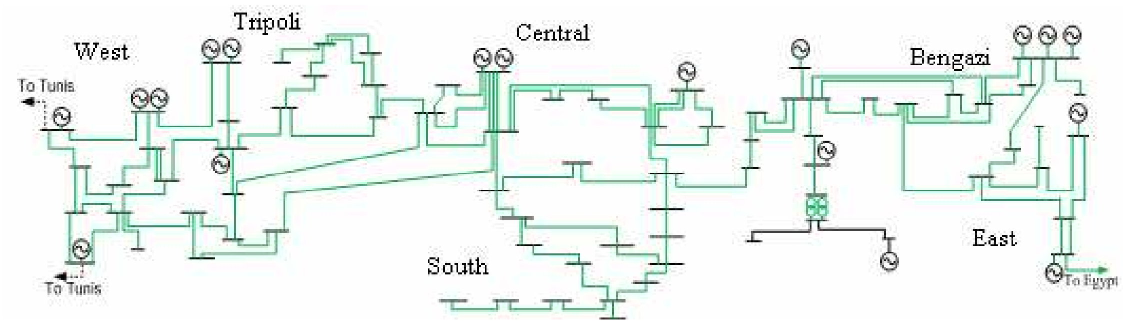

Figure 6-2: Transmission power system of Libya

Since being constructed in a broad time interval, huge variety of technological solutions performed by distinct power utilities and companies can be seen in the transmission network. This can be taken mostly as an advantage for the operation of the entire system, because this technological diversity prevent the occurrence of massive faults caused by possible hidden defect in the appliances provided by only one manufacturer.

For covering the power consumption, over 62 generating units are connected to the transmission network of Libya. These are mainly steam/gas-turbine and combined cycle power plants along with several smaller diesel generators located in rural areas of the Sahara Desert.

Natural gas, residual fuel oil (heavy/light oil) and distillate are used as prime fuels. When comparing the volumes of individual prime fuels spent during each year, both heavy and light oils are used only complementarily (mostly due greater amounts of emissions released during the burning process). During each year, almost 40 percent of electric energy is produced by combined-cycle power plants, while 35 and 25 percents supplied by gas and steam power plants, respectively.

Libya is fully self-reliant in terms of electricity production. In 2008, total power generation was 28,666 GWh, while transferred electrical energy from neighboring countries was only 66 GWh.

The statistic and collate the information it was one of the difficulty during this research the GECOL and even the department of energy they don't have enough information in the public where it is possible for anyone to find these information and data in their webpage so I have to collocate these information personally. These tables below are some information about the Libyan's grid in the last years according to the last data which I get from the GECOl

Unit to compare	2007	2008	%
Electric power generation	25415 (GW/h)	28666 (GW/h)	13
Power from neighbors country	77 (GW/h)	66(GW/h)	-10
Maximum load	4420 (MW)	4756 (MW)	8
Minimum load	1807(MW)	1973(MW)	9
Electricity consumption per capita	4158(KW/h)	4360(KW/h)	5
Heavy oil (m^3)	1563178	1802846	15
Light oil (m^3)	2966136	3363604	13
Natural gas (m^3)	3479442721	3323188774	-4
SPS(400kv)	2400 (MVA)	2400 (MVA)	0
SPS(220kv)	13058(MVA)	13308(MVA)	2
SPS(66kv)	3559(MVA)	3679(MVA)	3
SPS(30kv)	9980(MVA)	10404(MVA)	4

Table 6-1 Libya's Grid in the last years

Power plant	Fuel used	Units	Unit capacity (MW)	Capacity (MW)	Operation date
Homs p/s	Heavy oil/Gas	4	120	480	1982
Tripoli west P/S	Heavy oil Heavy oil	4 2	65 120	260 240	1976 1980
Derna	Heavy oil	2	65	130	1985
Tobruk	Heavy oil	2	65	130	1985

Table 6-2: Steam power plants

Power plants	Fuel used	Units	Unit capacity (MW)	Capacity (MW)	Operation date
Abu Kamash	Light oil	3	15	45	1982
Homs	Gas/light oil	4	150	600	1995
Tripoli South	Light oil	5	100	500	1994
Zwitina P/S	Gas/light oil	4	50	200	1994
Kufra-132	Light oil	2	25	5o	1982
Nahr p/s	Light oil/Gas	5	15	75	1990
Misurata Steel	Heavy oil/Gas	6	84.5	507	1990
west mountain	Gas/light oil	2	156	312	2005
		2	156	312	2006

Table 6-3: Gas power plants

Power plant	Fuel used	Units & fuel	Unit capacity (MW)	Capacity (MW)	Operation date
Zawia power	Gas Steam	4	165	660	2000
		2	165	660	2005
		3	150	450	2007
Bengazi North	Gas Steam	3	150	450	1996
		1	165	165	2002
		2	150	300	2007

Table 6-4: Combined cycle power plants:

Fuel	Power production (MW/h`)	Fuel consumed (m3)	Production %
Gas	10541915	3323188774	36
Light oil	8851515	3363604	31
Heavy oil	5670738	1802846	20
Co.cycle	3601973		13
Total	28666141		100

Table 6-5: The power productions and the fuel consumptions in 2008

The load in the last years was growing rapidly cause of changing the futures plane in the country and focus to the industries sectors and the agricultures as well. The graphs below explain the increasing the loads in the last years per years and per month as well.

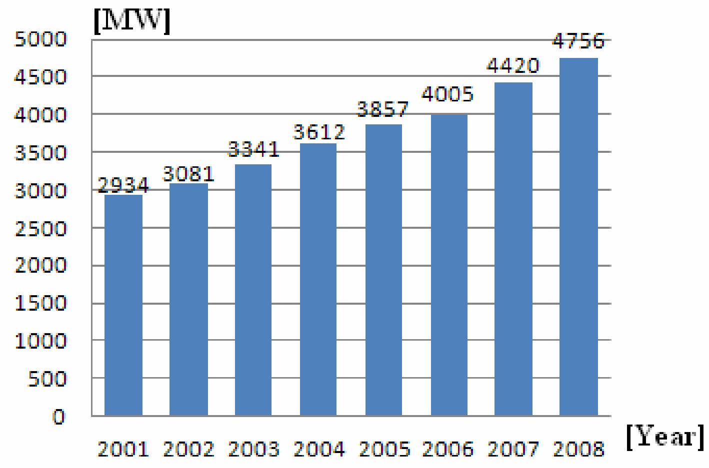

Figure 6-3: The load per years

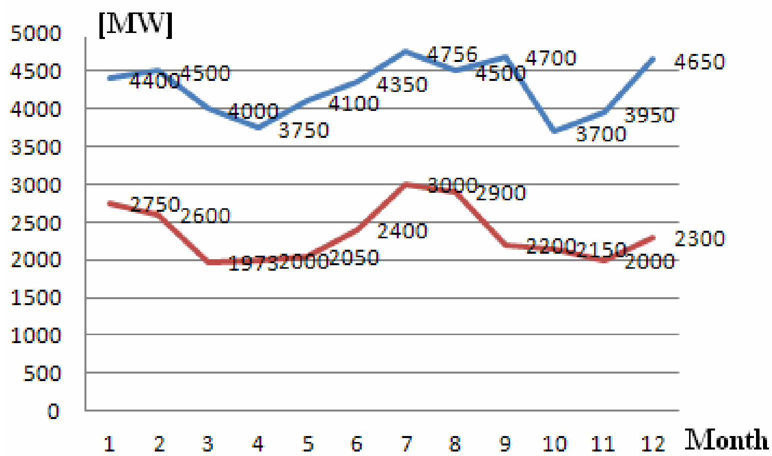

Figure 6-4: The maximum and minimum load per months in 2008

6.2 Load Flow Analysis of the Transmission Power System of Libya

In this paragraph I decided to examine the power network and the possibilities to connect new wind power farms into the Eastern part of the Libyan transmission power system.

Load flow analysis of the Libyan transmission network is relatively challenging due to several reasons:

First, the transmission network is only sparsely linked interconnecting individual consumption points at long distances (quite often over 200 kilometres).

Second, the entire system is rather over-dimensioned, i.e. markedly lower loadings than transfer capacities of transmission lines/transformers can be found in the network leading to the Ferranti's phenomenon in some parts of the system. Therefore, large number of reactive power compensators (shunt inductors) is used almost at every substation to compensate capacitive currents in long lightly loaded circuits. Because of an insufficient capability for transmitting reactive power for long distances, however, bus voltage conditions can be strongly affected by these 'artificial loads'. Then, it is almost impossible to model the network without exact loading values in each bus of the system.

Third, approx. 61 percent of total electric power is generated on the 220 kV level when compared to 30 percent of power produced on the 400 kV level. Along with working interconnection to Egypt via a 220 kV circuit, it is more difficult to choose appropriate slack bus in the entire network for intended load flow calculations.

Fourth, in total, this network contains two 400 kV, twenty-two 220 kV and three 132 kV buses. From the 400 kV network, only Sirt and Benghazi North substations with fully operational gas power plant in the latter one have been included.

According to the result situation I could made a discussion about connecting of wind farms to the system and inputting data for calculations of the operation states:

The 220 kV Benghazi North Power substation has been chosen as the slack bus for all simulations. Each PV bus in the network has been modelled with limited reactive power generations. Moreover, power injection from the 400 kV network to Sirt substation along with the inter-tie flows from Sirt to Zamzam in the west part from the local power network and from Tobruk to Salum it is in the east part from a neighbour network from Egypt power network both injections have been included. Unfortunately, power flows in these circuits for a certain time interval were unknown.

Therefore, their active and reactive power values must be reasonably optimized for preserving full active power generation in the slack bus and voltage profiles within their permissible limits (±5% in 400 kV, ±10% otherwise). To preserve the maximum supply system independency on surrounding networks, the objective function minimizing the total area interchange has been used.

Fifth, With power factor of 0.9, the maximum active power(MW) for year 2010 have been used in the GECOL annual report for the loads along with estimated power self-consumption (10 and 6 percent) in each of considered three steam and six gas power plants, respectively. Network topology with branches and shunt compensation data have been also provided by the annual report as well.

For the optimization process, one particular non-commercial software package for optimization purposes – the NEOS Server [7] – has been used. The NEOS (Network Enabled Optimization System) Server contains a broad variety of solvers, divided into several groups according to the type of optimization task and capable to deal with a large number of problems including binary variables and nonlinearities. For each examined problem, the user needs to choose appropriate solver and formulate the problem in the input data file using a specific text format (e.g. GAMS, AMPL, MPS or others). Then, this input data file must be submitted to the NEOS Server, mostly through the e-mail or web interface. Next, the problem is sent from NEOS Server to a remote solver station, where the entire optimization process will be performed by the solver. Finally, when optimizing the objective function value, the solution is sent back to the NEOS Server and either it can be seen on the NEOS webpage or it is delivered to the user's e-mail address, if required. For more information about the definition of the load flow problem as an optimization task - see [9].

For the verification of results obtained from the NEOS Server, professional programming tool PowerWorld 13 GSO version [8] has been employed. This software package enables broad variety of electric network simulations, such as the load flow analysis, optimal power flow (OPF), sensitivity calculations, AGC modelling, and others. Particularly, this software is useful for its easy operation and its ability for providing transparent visualisation of all outputs for each investigated problem.

In the first study, the load flow analysis of the intended part of the Libyan transmission power system has been performed without any wind power plant considered. The PowerWorld results can be seen in the Figure 6.5 below.

All bus voltages are inside their permitted limits along with majority of branch loadings below 30 percent. The maximum branch loading of 67.4 percent was located on the overhead line between substations Bu Atni and Benghazi South.

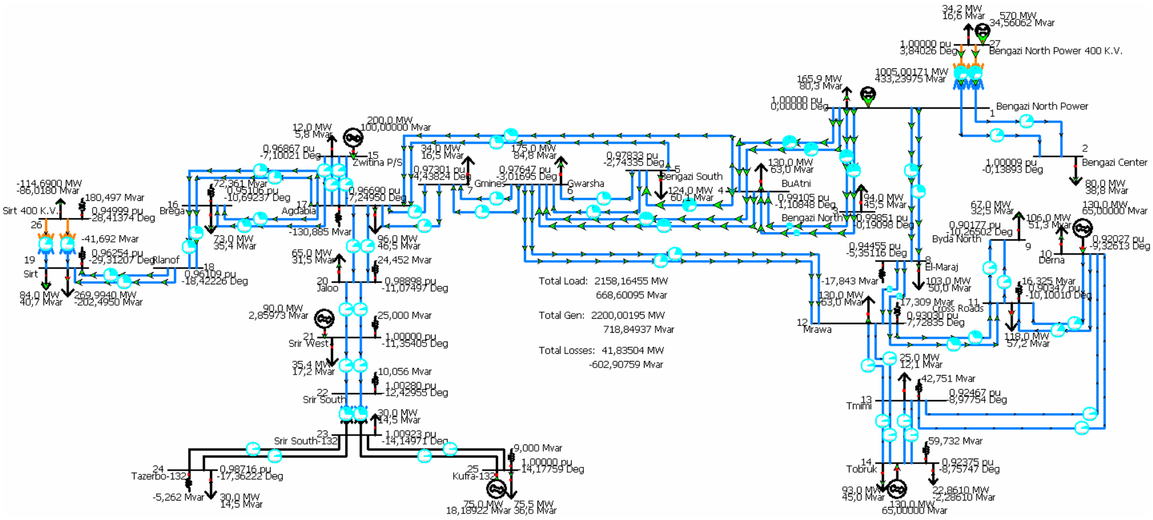

Figure 6-5: Load flow solution of the first study (PowerWorld)

In the second study, planned wind power plant of 60 MW (application factor of 40 percent) has been connected to Dernah, i.e. the active power in bus 10 has been increased from 1.3 pu to 1.54 pu. Cable lines connecting the wind farm to the transmission network have been neglected.

The PowerWorld solution verifying the results from the NEOS Server is shown in Figure 6-6 below.

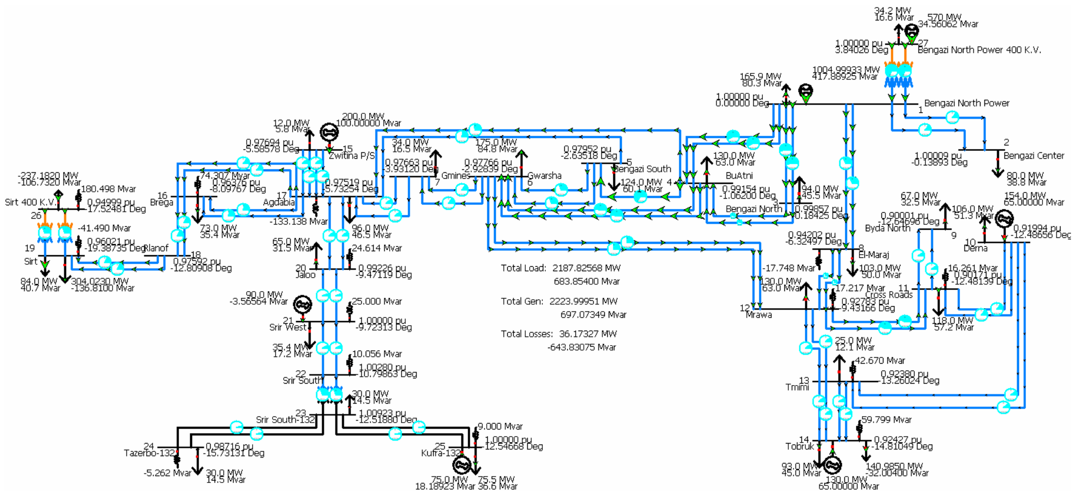

Figure 6-6: Load flow solution of the second study (PowerWorld)

In the third study, the estimation of the loading conditions in Eastern part of the Libyan transmission network for year 2015 (with constant annual load increase of 8 percent) for maximizing the power generation from prospective wind power farms in Dernah, Sirt, Gmines (Al-Maqrun) and Tazerbo. Possible new conventional power plants, buses and bus connections through new transmission lines and transformers constructed have been neglected. As the objective function, the sum of active power generations from all these four wind power farms had to be maximized. Active power dependent var limits in new PV buses (Sirt, Gmines and Tazerbo) have been used. The PowerWorld solution with maximum generation from all four wind power farms is shown in Figure 6-7.

In remaining two simulations, the maximum branch loading of 67.0 percent was located on each of both parallelly connected transformers between Benghazi North Power and Benghazi North Power 400K.V.

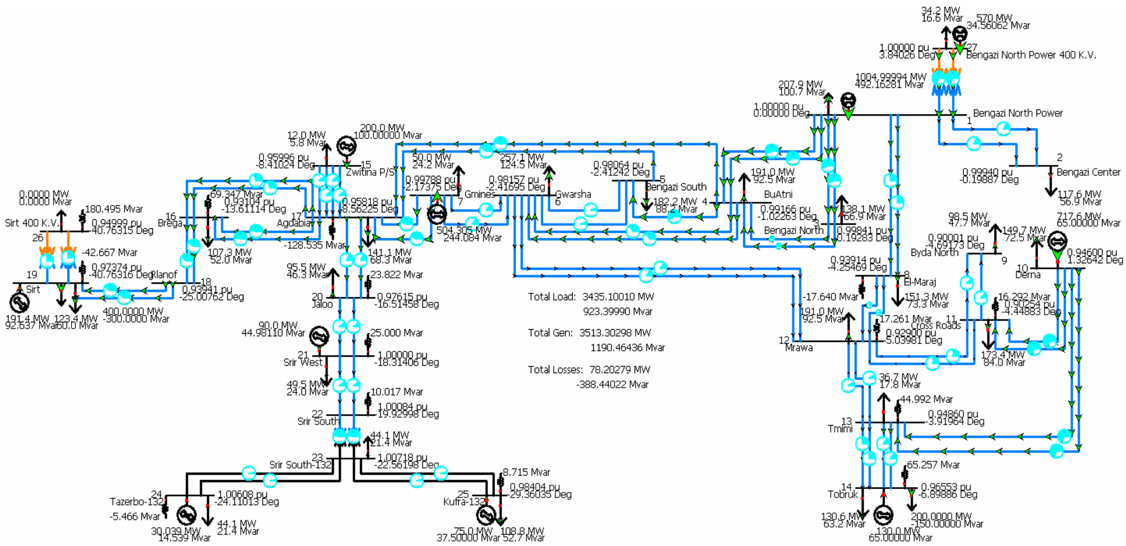

Figure 6-7: Load flow solution of the third study (PowerWorld)

In the Table 6-6, final comparison of planned wind farm generation capacities in individual four locations to relevant theoretical capacity limits computed using the NEOS Server is clearly stated.

For all wind power plants except Dernah, application factor of 30 percent has been employed.

Wind power farm	Planned [MW]	Theoretical [MW]
Dernah	120	1794
Al-Maqrun	240	1681
Sirt	N/A	638
Tazerbo	120	100

Table 6-6: Planned and theoretical wind farms

As it was seen in Table 6-6, theoretical capacities for each proposed wind farm location are more than enormous. However, the theoretical limit for Tazerbo location is less than the planned generation. Understandably, more practical limits should be evaluated using the transient power system analysis since it will more simulate the dynamics of the wind power generation and related network responds to these impacts. Nevertheless, the steady-state analysis clearly specifies the ceiling of the electricity generation because the limits obtained from the transient analysis will be always lower.

Similarly as in another countries lying in subtropical or tropical regions, electric power consumption in Libya is significantly higher in summer months than during the winter. This is caused especially by massive use of air-conditioners and ventilators in large consumption centres in the country. In 2008, the maximum/minimum load in Libya was 4,756 and 1,973 MW measured in July and March, respectively. In comparison, the maximum load in 2008 is more than 62 percent higher than in 2001.

Unfortunately, many problems are typical for the operation of the Libyan transmission system in respect to rather adverse operating conditions of the system. First, the majority of electric power installations (especially the overhead power lines) are located close to the sea. Therefore, all insulation parts on the lines and in substations suffer from salt sediments which may eventually cause numerous faults or even local blackouts. Second, similar problems can be found in areas in the Sahara Desert, where the wind containing large volume of very soft sand may result in scratches on the outdoor insulators or even chokes of important power appliances inside the substations leading again to the fault. Third, relatively large number of illegal power consumptions occurs in the Libyan distribution network. Therefore, proper investigations must be carried out not only for reducing power losses created by these ‘black consumptions’ but also for increasing the reliability of the power system operation. Moreover, load flow studies examining current and future operational/failure state conditions of the system would correspond better to the real network behaviour.

Currently, electric power system of Libya undergoes the period of significant upgrades and developments corresponding to new global trends in the area of power engineering. Reasons for these changes are especially increasing tendency of electric power consumption not only in present large consumption centres in the north but also in developed localities outside the seacoast. To these challenges especially belongs the construction of the superior 400 kV power system, planned interconnections to foreign national grids, infrastructure reinforcements and capacities for incorporation of renewable power sources (especially photovoltaic systems and large wind power farms).

Summary and Conclusion

In Libya, the energy sector plays a very important role in achieving social and economic development through satisfying the energy needs of the different economic sectors, in addition to the sector's effective contribution, particularly the oil and gas sector, to the GDP.

In spite of such vital role, the sector has several features that can affect its contribution to the achievement of sustainable development this is mainly due to unsustainable energy production and consumption patterns, particularly in the end use sectors, the sector has its adverse environmental impacts on air, water and soil resources.

Libya is experiencing strong economic during last years which made Libya one of highest per capita GDP in Africa.

Oil export revenues are extremely important to the economic development of the country as they represent 90% of the total revenue.

Libya has continues increasing in total primary energy supply with average annual growth of about 5 % and the oil has the largest share, while the total energy demand reached 9.1 Mtoe in 2003 with highest consumption in oil sector.

The electricity is covering more than 99% of population; PV systems are used to supply electricity to about 2,000 inhabitants in rural areas.

The electric energy demand is expected to grow very rapidly in the next few years; water desalination plants will be the major drive for energy demand as Libya planned to install desalination plants with amount of one million meter cub per day in the next five years.

The share of renewable energy technologies in Libya up to now holds only a small contribution in meeting the basic energy needs; it is used to electrify rural areas for sustainable development, supply microwave repeater station, and in cathodic protection. A setup plane was planned for implementing renewable energy sources is to contribute a 10 % off the electric demand by the year 2020. The short plane for renewable energy is to invest 500 million euro in the next five years.

During the past three decades, photovoltaic is the most technology which has been used in rural applications, particularly for small- and medium-sized remote applications with proven economic feasibility, several constraints and barriers, including costs exist. The experience raised from PV applications indicates that there is a high potential of building a large scale of PV plants in the required of the Mediterranean.

There is a great potential for utilizing, home grid connected photovoltaic systems, and large scale grid connected electricity generation using wind farms and solar thermal for electricity generation, with capacities of several thousands of MW. The high potential of solar energy in Libya may be considered as a future source of electricity for the northern countries of Mediterranean.

Solar energy resources in particular can be of great source of energy for Libya after oil and natural gas. Renewable energy resources offer good opportunities for technology transfer and international cooperation. The modularity and decentralized nature of renewable energy technologies make them particularly well suited for rural energy development. In this aspect, use can be made of the Clean Development Mechanism (CDM) adopted by Kyoto Protocol in renewable energy applications that would reduce greenhouse gases. Libya is located in a place which can be considered as a good place for renewable energy technology and applications development. It is also has great a resources for photovoltaic basic industry and a solar cell technology which can be built with the share of international investors. The usual practice in Libya showed low efficiencies in energy production and consumption, there is a real challenge to develop an efficient energy use in most sectors, with several barriers including: lack of access to technology, capacity building, and institutional issues.

Energy efficiency can be implemented in both energy consumption and production sides. Almost in all energy end-uses, sectors, the focus is on improving the efficiency of equipment that provides the services, such as heating and air conditioning equipment, appliances, lighting and motors. In contrast, supply-side energy management focuses on performance-based improvements resulting in more-efficient energy generation, improved industrial processes, co- generation and energy recovery systems. On the production side there is a great importance in increasing efficiency in large- scale energy production. Energy efficiency can help reducing cost, preserving natural resources and protecting the environment. Energy efficiency can also be enhanced through access to appropriate technology, capacity-building, and institutional issues. Libya is non annex country under the UN FCCC, and is signatory to the Kyoto protocol, thus Libya currently is eligible to the CDM. The main emitters of CO_2 in 2003 are fuel combustion in the power generation sector. Libya's energy related CO_2 emissions increased by more than 78 % in one decade mostly due to increased energy supply. The analysis of the present energy situation in Libya clearly indicates that there are no programs toward rational use of energy. This situation related to many factors summarized as follow:

- Low electricity tariff especially for residential sector.
- Cheap oil prices for transportation.

- Lack of national policy toward the conservation of energy.
- Lack of specialized national institution which deal with the rational use of energy.
- Lack of detailed and deep studies related to the rational use of energy (RUE).

Many studies have indicated that the country's energy demand generation could be significant reduced if improved energy utilization efficiency by the major energy sectors is achieved.

To develop and support, technically, financially, and institutionally, the national research and application institutions concerned with issues relevant to energy for sustainable development.

To develop national energy policies and regulatory frameworks that will help to create the necessary economic, social and institutional conditions in the energy sector to improve access to reliable, affordable, economically viable socially acceptable and environmentally sound energy services for sustainable development.

Developing and implementing policies and programs to change the current energy production and consumption patterns, through improving energy efficiencies in all sectors, particularly the highest energy consuming sectors, as well as promoting the use of cleaner fuels and renewable energy resources.

The objective of my thesis is to study the wind energy and the connection of wind farms to the local electric networks in order to find the best solution of renewable power sources utilization under the Libyan’s condition.

I have chosen Dernah city as the wind farm for this project base on; among other reasons; the result of the first Matlab simulation. The wind speed for this area makes it ideal to be the first farm and the other cities will follow on.

I used also Power World program to construct modules for the Libyan electric network at the actual and proposed situations. I calculated the load flow and the results show that the network could easily accept new power sources connections. These sources could be wind farms or any another renewable power source of even from neighbour’s power networks.

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Appendix

Due to the huge amount of data the appendix will be available only in the attached CD which includes:

- Raw data it is in text documents (txt) for the five cities (Almqrun monthly data – Dernah monthly data – Misrate monthly data – Sirt monthly data – Tolmeth monthly data)
- Folder for transformed data from raw data (txt) to Microsoft Office Excel format for the five cities
- Math work the constructed mathlab programs for the five cities.
- Math output folder in this folder is the samples of the out put
- Dernah Model case of study
- Transmission line data folder:
    - Single line diagram of the existing 220 kv Libyan network year 2007-2008Single line in Adobe Acrobat Document.
    - Libyan's electric network connects to the countries in the west side in Adobe Acrobat Document.
    - Libyan's electric networks connect to eight countries in the east side in Adobe Acrobat Document.
    - GECOL 220-400Kv network in Adobe Acrobat Document.
    - Year 2015 220KV substations for regions in Microsoft Office Excel format
    - Loads of 220kv substations divided by region western, middle and south Microsoft Office Excel format
    - Load of 220KV in Benghazi and Green Mountain area Microsoft Office Excel format
    - Transmission lines data Microsoft Office Word format