UNIVERSITY OF ÇUKUROVA
INSTITUTE OF NATURAL AND APPLIED SCIENCE

MSc THESIS

Cemal ZERAY

RENEWABLE ENERGY SOURCES

DEPARTMENT OF ELECTRICAL ELECTRONICS ENGINEERING

ADANA, 2010

CUKUROVA UNIVERSITY

INSTITUTE OF NATURAL AND APPLIED SCIENCES

RENEWABLE ENERGY SOURCES

BY Cemal ZERAY

A THESIS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF ELECTRICAL&ELECTRONICS ENGINEERING

This thesis was accepted by the following jury on ..../...../2010 unanimously/by majority.

Signature	Signature	Signature.......................
Prof.Dr.Mehmet TÜMAY	Asst.Prof.Dr K.Çağatay BAYINDIR	Asst.Prof.Dr.Ramazan ÇOBAN
Supervısor	Member	Member

This thesis was written at the department of Electrical&Electronics Engineering of the institude.

Registration Number :

Prof. Dr. İlhami YEĞİNGİL
Director

ÖZ

YÜKSEK LİSANS TEZİ

YENİLENEBİLİR ENERJİ KAYNAKLARI

Cemal ZERAY

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
ELEKTRİK ELEKTRONİK MÜHENDİSLİĞİ ANABİLİM DALI

Danışman : Prof. Dr. Mehmet TÜMAY
Yıl : Ocak 2010, Sayfa : 112
Jüri : Prof. Dr. Mehmet TÜMAY
Yrd. Doç. Dr. K.Çağatay BAYINDIR
Yrd. Doç. Dr. Ramazan ÇOBAN

20. yüzyılın sonu ve 21.yüzyılın başında enerji talebi artmıştır ve bilim adamları bu enerji talebine karşılık çözümler üretmeye yeltendiler. Diğer taraftan, enerji talebinin ve tüketiminin artışı ile bilim adamları, dünyamızın enerji kaynaklarının çok sınırlı olduğu ve enerji tüketiminin sınırlı kaynakları tükettiği ve dünyayı kirlettiği sorunuyla yüzleşmek zorunda kaldılar. Bu, bilim adamlarını, dünyamızın enerji ihtiyacını, dünyayı kirletmeden ve sınırlı enerji kaynaklarını tüketirken dünyanın yenilenebilir enerji kaynaklarını kullanmaya yönelik, bütünüyle yenilenebilir yeni çözümler bulmaya yöneltti.

Bu tezde, yenilenebilir enerji kaynakları teknolojileri ile ilgili bilgi verilmektedir. Rüzgar ve güneş enerjisi teknolojileri daha çok önemsenmekle birlikte, jeotermal, hidrolik, dalga, gelgit, biyokütle ve hidrojen gibi diğer yenilenebilir enerji teknolojileri de anlatılmıştır. Türkiye'deki yenilenebilir enerji uygulamaları, politikaları, mevcut yasalar, kurumlar ve Ar-Ge çalışmaları ile ilgili güncel bilgiler ve öneriler sunulmuştur.

Anahtar Kelimeler : Yenilenebilir Enerji Kaynakları, Rüzgar, Fotovoltaik,

ABSTRACT

MSc THESIS

RENEWABLE ENERGY SOURCES

Cemal ZERAY

UNIVERSITY OF ÇUKUROVA
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL ELECTRONIC ENGINEERING

Supervisor : Prof. Dr. Mehmet TÜMAY
Year : January 2010, Pages : 112
Jury : Prof. Dr. Mehmet TÜMAY
Asst. Prof. Dr. K.Çağatay BAYINDIR
Asst. Prof. Dr. Ramazan ÇOBAN

At the end of 20th and the beginning of 21th century, energy demand has increased and scientists attempted to find solutions for compensating this energy demand. On the other hand, with the increase of energy demand and consumption, scientist had to face another issue that our World's energy resources are very limited and increasing demand is consuming our limited resources and polluting our World. This challenged the scientists to find new solutions like renewable energy sources that compensate our world's energy demand without polluting and consuming limited energy sources.

In this dissertation, information on technologies of renewable energy resources is given. Wind and solar energy are emphasized but geothermal, hydropower, wave, tidal, biomass and hydrogen energies are also discussed. Current information and proposals on renewable energy applications, policies, laws, institutions and R&D studies in Turkey are given.

Key Words: Renewable Energy Sources, Wind, Photovoltaic

ACKNOWLEDGEMENTS

I would like to thank my contributors, whose efforts help me to make this thesis. First of all we thank to my supervisor Prof. Dr. Mehmet Tumay who gave me an opportunity to search for this thesis subject. Then, I would like to thank Asist. Prof. Dr. K. Cagatay Bayindir for his suggestions and comments in my thesis.

I also thank to Asst. Prof. Dr. Ramazan Çoban for serving as a member of my committee.

Finally, I would like to thank my family for their endless support and encouragements during my studies.

CONTENTS **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N	Generator Speed
f	Frequency
n	Pole Number
E	Energy
m	Air Mass
v	Speed
ρ	Air Density
V	Volume
A	Area
L	Length
t	Time
P	Power
R	Turbine Rotor Radius
C_p	Turbine Power Coefficient
λ	Tip Speed Ratio
v_r	Rotational Speed
D	Duty Cycle
I_{ph}	Photovoltaic current
I_{sat}	is the reverse saturation or leakage current of the diode
q	Electron charge
k	Boltzmann constant
T	Temperature
A	Diode ideality constant

P	Power
V	Voltage
I	Current
R_s	Series Resistance
R_P	Paralel Resistance
V_{mp}	Voltage for Maximum Power Point
I_{mp}	Current for Maximum Power Point
N_p	Parallel connected Photovoltaic Cells
N_s	Series connected Photovoltaic Cells
L	Inductor
C	Capacitor
R	Resistor
S	Switch
I_d	Current flows through diode
T_t	Turbine torque
Ω	Rotating speed
P_m	Mechanical power
P_{hyd}	Hydraulic power
ρ	water density
g	gravity acceleration
H	water head
T_{ms}	PMSM torque for hydropower energy
T_{dfig}	DFIG torque for hydropower energy
p_{ms}	number of pole pairs for PMSM
M	Mutual inductance

LIST OF ABBREVIATIONS

SCIG	Squirrel Cage Induction Generator
DFIG	Doubly Fed Induction Generator
HVDC	High Voltage Direct Current
VSC	Voltage Source Converter
WRIG	Wound Rotor Induction Generator
TSR	Tip Speed Ratio
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
PV	Photovoltaic
AC	Alternating Current
MPPT	Maximum Power Point Tracking
PSF	Power Signal Feedback
HCS	Hill Climbing Searching
IG	Induction Generator
PWM	Pulse Width Modulation
Si	Silicon
CCM	Continuous Conduction Mode
DC	Direct Current
SEPIC	Single Ended Primary Inductor Converter
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor

PCB	Printed Circuit Board
LFT	Line-frequency transformer
HFT	High-frequency transformer
NPC	Neutral-Point-Clamped
DSP	Digital Signal Processor
PMSM	Permanentmagnet Synchronous Machine
PID	Proportional-Integral-Derivative (Controller)
AI	Artificial Intelligence
OWC	Oscillating Water Column
R&D	Research and Development
HVAC	High Voltage Alternative Current
MCED	Marine Current Energy Device
AD	Anaerobic digestion
CSP	Concentrating Solar Power
HEPP	Hydro Electric Power Plant
TEP	Tons Equivalent of Petroleum
MTEP	Million Tons Equivalent of Petroleum
EE	Energy Efficieny
RES	Renewable Energy Sources
EMRA	Energy Management Researching Agency
JREC	Johannesburg Renewable Energy Coalition
EU	European Union
E4	Energy Efficiency and Endogenous Energies
MTA	General Directorate of Mineral Research and Exploration

TEIAS	Turkish Electricity Transmission Company
EIE	General Directorate of Electrical Power Resources Survey and Development Administration
ETKB	Rebuplic of Turkey Ministry of Energy and Natural Resources
IEA	International Energy Agency
TUREB	Turkish Wind Energy Association
REGA	Republic of Turkey Official Newspaper
R&G	Researching and Development
DSI	Directorate-General of State Hydraulic Works
EUAS	Electricity Generation Company,
TEDAS	Turkish Electricity Distribution Company
TETAS	Turkish Electricity Trading and Contractor Company
TPAO	Turkish Petroleum Company
BOTAS	Turkish Pipeline Corporation
TKI	Turkish Coal Enterprises
TTK	Turkish Hard Coal Enterprises
MENR	Ministry of Energy and Natural Resources
DPT	State Planning Organization
TEYDEB	The Technology and Innovation Support Program
TTGV	Technology Development Foundation of Turkey

1. INTRODUCTION

Technology is developing day by day very rapidly. These developments affect all creatures dead or alive. In addition, human population and the requirement of energy is also increasing. The energy which human being need every day comes from resources. Resources are divided into two parts which are named as renewable and nonrenewable resources. Nonrenewable resources can be used once. The most used nonrenewable resources are coal and petroleum. Because of the cost of these resources and the lack of their reserve in the world, human being is forced to look for different sources. Nonrenewable resources are also polluting the world and causing global warming problems. Achieving solution to environmental problems that we face today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions. Renewable resources can be used repeatedly. They are unlimited, clean, practical, economical and environmentally friendly.

The majority of renewable energy technologies are powered by the sun. The Earth Atmosphere system is in equilibrium such that heat radiation into space is equal to incoming solar radiation, the resulting level of energy within the Earth-Atmosphere system can roughly be described as the Earth's "climate." The hydrosphere (water) absorbs a major fraction of the incoming radiation. Most radiation is absorbed at low latitudes around the equator, but this energy is dissipated around the globe in the form of winds and ocean currents. Wave motion may play a role in the process of transferring mechanical energy between the atmosphere and the ocean through wind stress. Solar energy is also responsible for the distribution of precipitation which is tapped by hydroelectric projects, and for the growth of plants used to create biofuels.

Renewable energy flows involve natural phenomena such as sunlight, wind, tides and geothermal heat, as the International Energy Agency explains:

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.

Each of these sources has unique characteristics which influence how and where they are used.

The aim of this study is to give information on technologies of renewable energy resources. An extensive literature study is done to collect technological knowledge. Wind and photovoltaic (PV) energy are emphasized and explained in detail in Chapter 2 and 3. System mechanical and electrical components, modeling, formulation and grid interaction issues are presented. In Chapter 4, other renewable energy systems geothermal, hydropower, wave, tidal, biomass and hydrogen energy are discussed. System configurations, mechanical and electrical parts are explained.

In Chapter 5, renewable energy applications and policies in Turkey are discussed. Applications and current status of each renewable energy resource, government policies, institutions, laws, barriers and R&D studies are presented in detail. Proposals are mentioned for improvement in related subjects.

Finally, conclusions of this study and references are given. In short words, this study presents a detailed up to date review on renewable energy resources and applications in Turkey.

2. WIND ENERGY

2.1. Main Components of A Wind Turbine

The electrical power produced by wind turbine generators has been increasing steadily, which directly pushes the wind technology into a more competitive area. Basically a wind turbine consists of a turbine tower, which carries the nacelle, and the turbine rotor, consisting of rotor blades and hub. Most modern wind turbines have three rotor blades usually placed upwind of the tower and the nacelle. On the outside the nacelle is usually equipped with anemometers and a wind wane to measure the wind speed and direction, as well as with aviation lights. The nacelle contains the key components of the wind turbine, e.g.the gearbox, mechanical brakes, electrical generator, control systems, etc. The wind turbines are not only installed dispersedly on land, but also combined as farms with capacities of hundreds MWs. The main components of a modern wind turbine system are illustrated in Fig. 2.1, including the turbine rotor, gearbox, generator, transformer and possible power electronics.

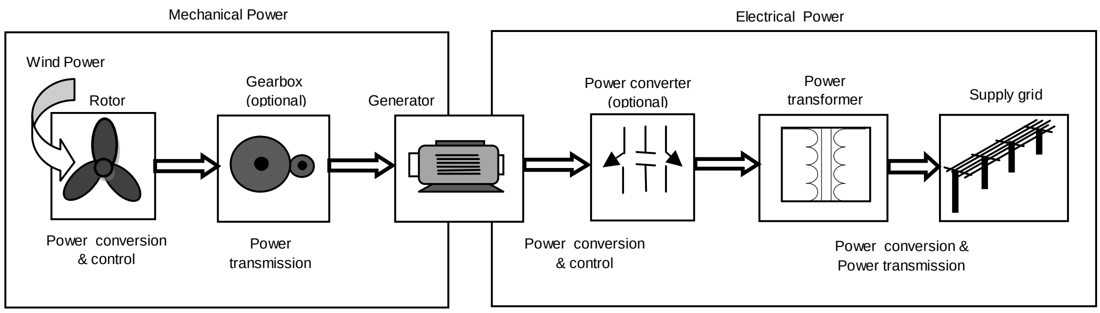

Figure 2.1. Main components of a wind turbine (Chen and Blaabjerg,2009)

Wind turbines capture the power from wind by means of the turbine blades and convert it to mechanical power. The conversion of wind power to mechanical power is done aerodynamically. The available power depends on the wind speed but it is important to be able to control and limit the power at higher wind speed to avoid damage. The power limitation may be done by stall control (the blade position is fixed but stall of the wind appears along the blade at higher wind speed), or active stall (the blade angle is adjusted in order to create stall along the blades) or pitch control (the blades are turned out of the wind at higher wind speed), which result in power curves as shown in Figure 2.2 (Chen and Blaabjerg,2009;Chen,Guerrero and Blaabjerg,2009)

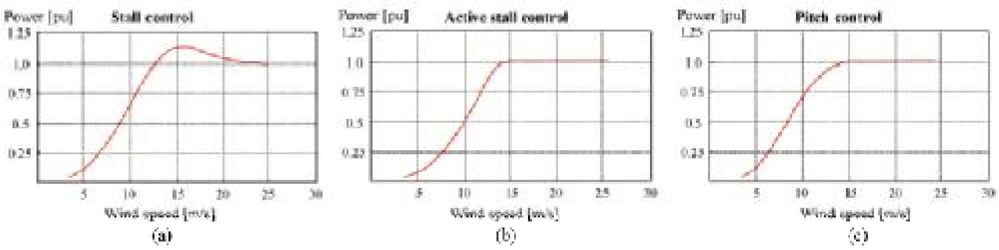

Figure 2.2.Power characteristics of fixed speed wind turbines (Chen and Blaabjerg, 2009;Chen,Guerrero and Blaabjerg,2009)

The common way to convert the low-speed, high torque mechanical power to electrical power is using a gearbox and a generator. The gearbox adapts the low speed of the turbine rotor to the high speed of generator mechanically. The generator converts the mechanical power into electrical power. The most common types of electrical machines used in wind turbines are induction generators and synchronous generators.

Mainly three types of typical wind generator systems exist . The first type is a constant-speed wind turbine system with a standard squirrel-cage induction generator (SCIG) directly connected to the grid. The second type is a variable speed wind turbine system with a doubly fed induction generator (DFIG) or wound rotor induction generator. The power electronic converter feeding the rotor winding has a power rating of approximately 30% of the rated power; the stator winding of the DFIG is directly connected to the grid. Wound rotor induction generator has a rotor with copper windings, which can be connected to an external resistor or to ac systems via power electronic systems. The third type is a variable speed wind turbine with full-rated power electronic conversion system and a synchronous generator or a SCIG. A multi-stage gearbox is usually used with the first two types of generators. Synchronous generators, including permanent magnet generator, may be direct driven, though a low ratio gear box system, one or two stage gearbox, becomes an interesting option.

While most of the turbines are nowadays connected to the medium-voltage system, large offshore wind farms may be connected to the high-voltage and extra high-voltage systems. The transformer is normally located close to the wind turbines to avoid high current flowing in long low-voltage cables. The electrical protection system of a wind turbine system protects the wind turbine as well as secures the safe operation of the network.

For long distance transmission, the transmission capacity of the cables may be mainly occupied by the produced reactive power. In this situation high voltage direct current (HVDC) transmission techniques may be used. The new technology, voltage source converter based HVDC system, provides new possibilities for performing voltage regulation and improving dynamic stability of the wind farm as it is possible to control the reactive power of the wind farm and perhaps keep the voltage during a fault in the connected transmission systems.(Chen and Blaabjerg,2009;Chen,Guerrero and Blaabjerg,2009)

2.2. Wind Turbine Systems

Generally wind turbine systems can be grouped into two main categories,

1. Fixed speed wind turbines
2. Variable-speed wind turbines

Various configurations have been evolved for fixed and variablespeed wind turbines as the technology of wind power has progressed but use of the induction generator dominates them.

2.2.1. Fixed Speed Wind Turbines with SCIG and Soft-Starter

For the fixed-speed wind turbine system the induction generator is directly connected to the electrical grid as shown in Fig. 2.3. The rotor speed of the fixed-speed wind turbine is determined by the gearbox ratio and the generator pole-pair number. (Arabian-Hoseynabadi,Oraee and Tavner ,2010).

$$N = \frac{120\,f}{n} \tag{2.1}$$

where , N is the generator speed

f is frequency

n is pole number

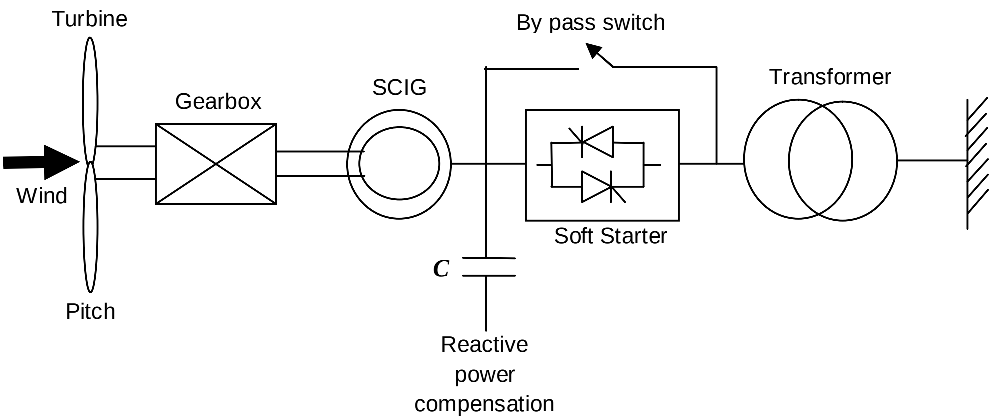

Figure 2.3.SCIG-based fixed-speed wind turbine with soft-starter (Chen,Guerrero and Blaabjerg,2009)

The speed of on induction generator with 4 pole is 1500 rpm, with 6 pole is 1000 rpm and with 8 pole is 750 rpm (revolution per minute).

A Squirrel-cage induction generator (SCIG) , is connected via a transformer to the grid and operaties at an almost fixed speed. The power can be limited aerodynamically either by stall control,active stall or pitch control. The advantages of wind turbines with induction generators are the simple and cheap construction, in addition that no synchronization device is required. These solutions are attractive due to cost and reliability.

This system has some disadvantages:

1. The wind turbine has to operate at constant speed,
2. It requires a stiff power grid to enable stable operation,
3. It may require a more expensive mechanical construction.

SCIG can be used in fixed speed wind turbines due to the damping effect.The reactive power necessary to energize the magnetic circuits must be supplied from the network or parallel capacitor banks. Connecting the induction generators to power system produces transients that are short duration with very high inrush currents, thus causing disturbances to both the grid and high torque spikes in the drive train of wind turbines with a directly connected induction generator. Such a transient disturbs the grid and limits the acceptable number of wind turbines. The high starting currents of induction generators are usually limited by a thyristor soft-starter. To reduce the impact on the grid, the soft-starter also effectively dampens the torque peaks associated with the peak currents and hence reduces the loads on the gearbox. (Chen,Guerrero and Blaabjerg,2009; Li and Chen,2008)

2.2.2. Variable Speed Wind Turbines

Variable-speed operation of a wind turbine system has many advantages. For instance, the wind turbine can increase or decrease its speed if the wind speed and torque vary. This means less wear and tear on the tower, gearbox, and other components in the drive train. Also, variable-speed systems can increase the production of the energy and reduce the fluctuation of the power injected into the grid. In variable-speed systems, the generator is normally connected to the grid through a power electronic system.

Variable speed wind turbines can be grouped into two categories, partial variable speed control and full-rated variable speed control. Wind turbines with partial variable speed control can also be investigated two parts. One of them is Wounded rotor induction generator and the other is Doubly fed induction generator. Full-rated variable speed control systems use Synchronous generator or SCIG.

2.2.2.1. Wounded Rotor Induction Generator with Rotor Resistance Control

The rotor windings are connected with variable resistors. The equivalent resistance in the circuit can be adjusted by an electronic control system, as shown in Figure 2.4 . The higher the resistance of the rotor windings, the higher the slip is. In this way, the generator speed can be varied in a limited range. Conventionally, the connection is usually done with brushes and slip rings , which is a drawback in comparison with the simple technical design of a cage rotor induction machine. It also introduces parts, which raise the maintenance requirements. (Chen, Guerrero and Blaabjerg,2009)

This circuit still needs a soft-starter like SCIG. Both cage induction generators and rotor resistance controlled wounded induction generators need to operate at a supersynchronous speed to generate electricity. Both of them draw reactive power that might be supplied from the grid or from installed compensation equipment, such as capacitor banks or additional power electronic equipment. In order to keep the cost as low as possible, capacitor banks are normally used. A typical limited variable speed range is less than 10% above the synchronous speed.

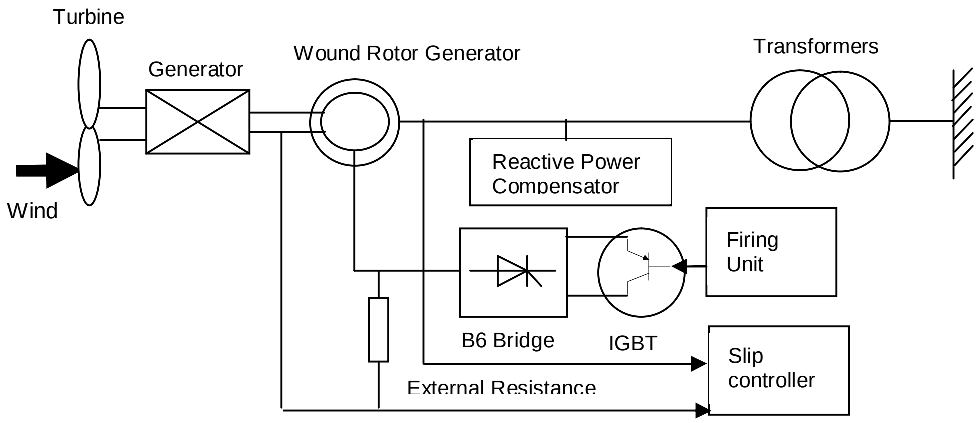

Figure 2.4.Wounded rotor induction generator with a rotor resistance converter (Chen, Guerrero and Blaabjerg,2009)

2.2.2.2. Doubly Fed Induction Generator

The stator of a doubly fed induction generator (DFIG) is connected to the grid directly, while the rotor of the generator is connected to the grid by electronic converters through slip rings, as shown in Figure 2.5. (Chen, Guerrero and Blaabjerg,2009; Arabian-Hoseyn,Oraee and Tavner,2010)

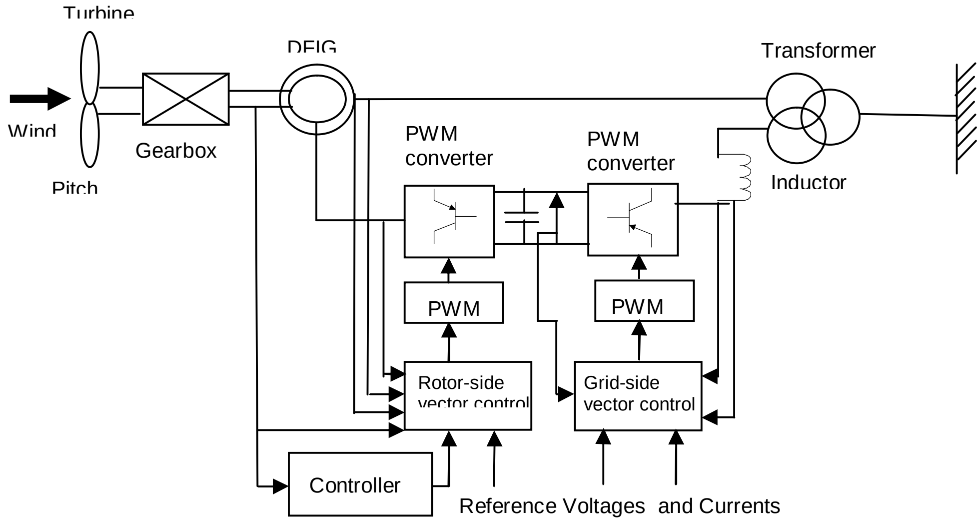

Figure 2.5.Wind turbine topologies with double fed induction generator (Chen, Guerrero and Blaabjerg,2009)

The generator can deliver energy to the grid at both supersynchronous and subsynchronous speeds. The slip is varied with the power flowing through the power electronic circuit. The advantage is that only a part of the power production is fed through the power electronic converter. Hence, the nominal power of the power electronic converter system can be less than the nominal power of the wind turbine. In general, the nominal power of the converter may be about 30% of the wind turbine power, enabling a rotor speed variation in the range of about ±30% of the nominal speed. By controlling the active power of the converter, it is possible to vary the rotational speed of the generator, and thus the speed of the rotor of the wind turbine. In DFIG, a multi-stage gearbox is still necessary in the drive train. (Chen, Guerrero and Blaabjerg,2009; Li and Chen,2008)

2.2.2.3. Wind Turbine Systems With Full Rated Variable Speed Control

SCIG and synchronous generators may be integrated into power systems with full rated power electronic converters. The wind turbines with a full scale power converter between the generator and grid give the added technical performance. Usually, a back-to-back voltage source converter (VSC) is used in order to achieve full control of the active and reactive power, though with synchronous generators, diode rectifiers may be used but in this case, it would be more difficult to fully control whole system.

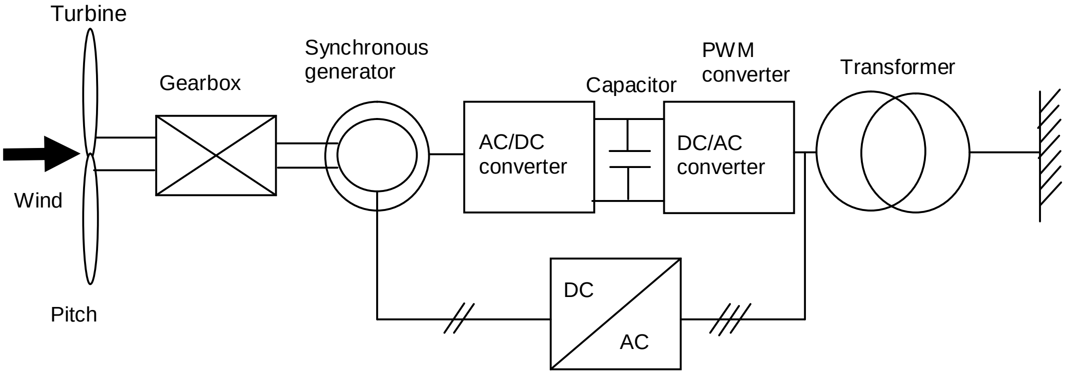

Figure 2.6.Wind turbines with synchronous generator for full rated variable speed (Chen, Guerrero and Blaabjerg,2009; Li and Chen,2008)

Since the generator is decoupled from the grid in this system, the generator can operate at a wide variable frequency range for optimal operation while the generated active power will be sent to the grid through the grid-side converter that can be used for controlling the active and reactive power independently and dynamic response may be improved. A multi-stage gearbox is usually used with SCIG, WRIG and DFIG. Synchronous generators, including permanent magnet generator, may be direct driven, though a low ratio gear box system, one or two stage gearbox, becomes an interesting option. (Chen and Blaabjerg,2009;Chen,Guerrero and Blaabjerg,2009; Li and Chen,2008)

2.3 Power and Energy at Wind Turbines

In the wind energy, E is equivalent to flux of the moving air mass, m; kinetic energy with a speed, $\boldsymbol{v}$ as

$$E = \frac{1}{2} m v^2 \tag{2.2}$$

Since, the measurement of *m* is almost impossible in aero-dynamics one can express it in terms of volume, V. It is preferable to convert the volume to specific mass ρ= *m/V (ρ is air density)* Hence, the substitution of *m* into Equation (2.2) gives,

$$E = \frac{1}{2}\rho V v^2 \tag{2.3}$$

The volume can be expressed as *V=AL* (Volume = Area * Length) in which A is vertical control cross-section and L is the horizontal distance. Physically, *L= vt* (Distance = Velocity * time) and its substitution into Equation (2.3) lead to (Sahin,2004)

$$E = \frac{1}{2}\rho A t v^3 \tag{2.4}$$

The Power (P) is the energy in per time.

$$P = \frac{1}{2}\rho A v^3 \tag{2.5}$$

We can write πR^2 *(R is turbine rotor radius)* instead of area *(A)* and we can add this formula C_p *(turbine power coefficient)* and its substitution into Equation (2.5) gives,

$$P = \frac{1}{2}\rho \pi R^2 v^3 C_p \tag{2.6}$$

Formula (2.6) shows that, the power is proportional to cube of wind speed.

C_p is the turbine power coefficient that represents the power conversion efficiency of a wind turbine. C_p is a function of the tip speed ratio (TSR), λ , λ is equal,

$$\lambda = \frac{R v_r}{v} \tag{2.7}$$

v_r is the rotational speed, *R* is radius of rotor and *v* is the wind speed.

The rotor efficiency curve C_p (λ) is a nonlinear function of the TSR, λ , which is determined by the blade design and the pitch angle. Relationship between the TSR and the power coefficient (with a fixed pitch angle) is shown in Figure 2.7. At ideal condution, Maximum C_p value can be 16/27=0,593. This value is named Betz limit. (Chen,Guerrero and Blaabjerg,2009;Sahin,2004)

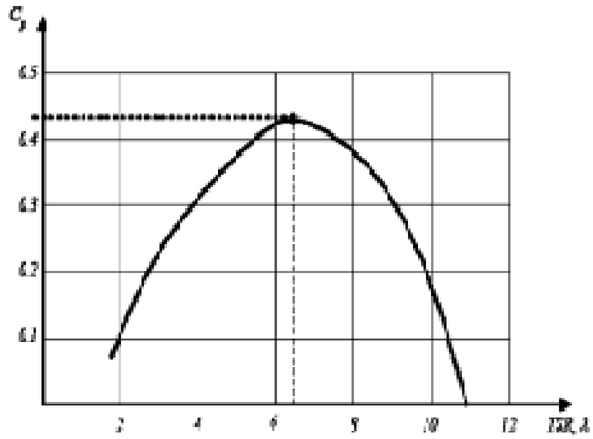

Figure 2.7.Relationship between the TSR and the power coefficient (Chen,Guerrero and Blaabjerg,2009)

2.4. Maximum Power Control at Wind Turbines

The relationship between the wind speed and the power generated by the wind turbine is shown in Figure 2.8. The blades start to move around 4 m/s, and optimal aerodynamic efficiency is achieved up to the rated wind speed, about 15 m/s. Between the rated wind speed and 25 m/s, the power delivered is limited in order to avoid overloading on the wind turbine system. Over the cutout wind speed, the turbine has to be stopped in order to avoid damages.

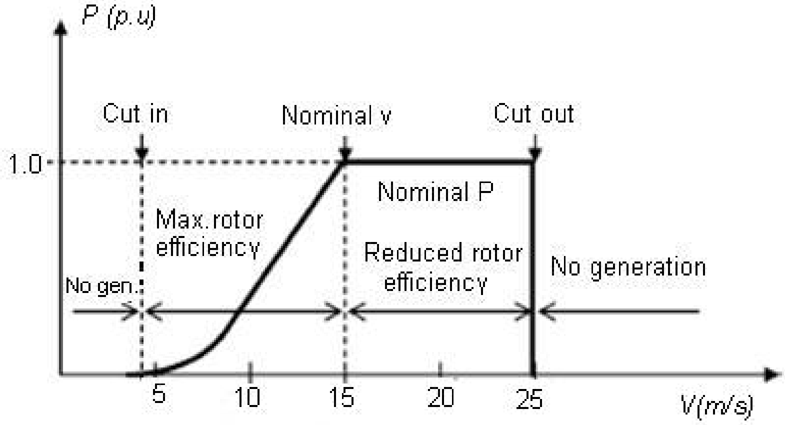

Figure 2.8.Output power of a wind turbine as a function of the wind speed (Chen,Guerrero and Blaabjerg,2009)

The power electronic converter may control the turbine rotation speed to get the maximum possible power by means of maximum power point tracking (MPPT) algorithm. In this way, it is possible to avoid exceeding the nominal power if the wind speed increases. At the same time, the dc-link capacitor voltage is kept as constant as possible, achieving a decoupling between the turbine-side converter and the grid-side converter. During the optimal efficiency wind speed range, the wind generator may be adjusted to follow MPPT. There are some methods to perform maximum power control for wind turbines. (Chen,Guerrero and Blaabjerg,2009)

2.4.1. Tip Speed Ratio (TSR) Control

Figure 2.9 shows this kind of maximum power controller, which needs the wind speed measured by an anemometer. The controller regulates the wind turbine speed to maintain an optimal TSR. However, the accurate wind speed may be different to obtain. In Addition, the use of an external anemometer increases the complexity and cost of the system.

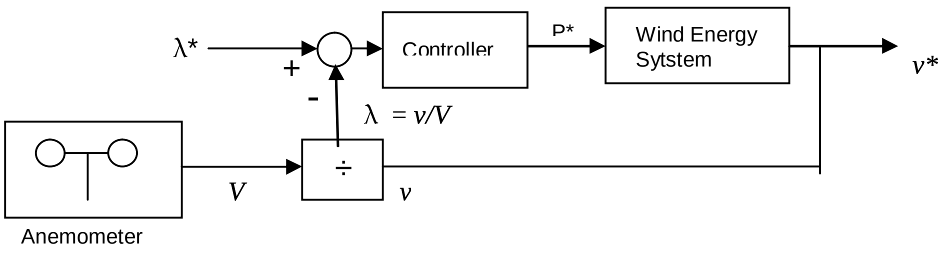

Figure 2.9.Block diagram of the TSR control (Chen,Guerrero and Blaabjerg,2009)

2.4.2. Power Signal Feedback (PSF) Control

This control, depicted in Figure 2.10, requires the knowledge of the maximum power curve of the turbine. The speed of the wind turbine is used to select the stored power curve, which gives the target power to be tracked by the system.In many cases, this power curve may be substituted by a predictor or observer of the wind speed as a function of the power and the wind turbine speed.

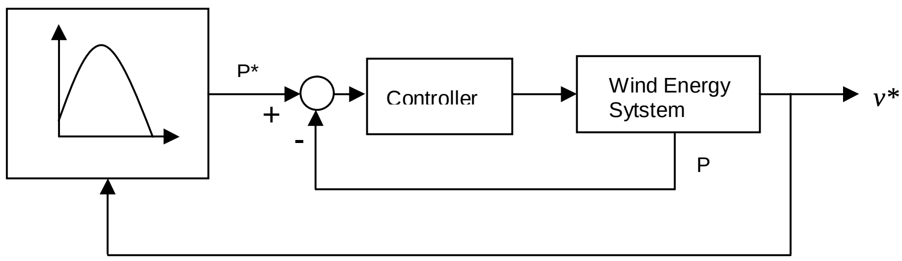

Figure 2.10.Block diagram of the PSF control (Chen,Guerrero and Blaabjerg,2009)

2.4.3. Hill Climbing Searching (HCS) Control

When the wind-turbine speed increases, the output power should normally increase as well, otherwise the speed should be decreased after the maximum power point shown in Figure 2.11. However, this method could be ineffective for large wind turbines, since the large turbines are difficult to adjust the speed fast. In practice, Maximum power controllers may use combinations ot the aforementioned three techniques.

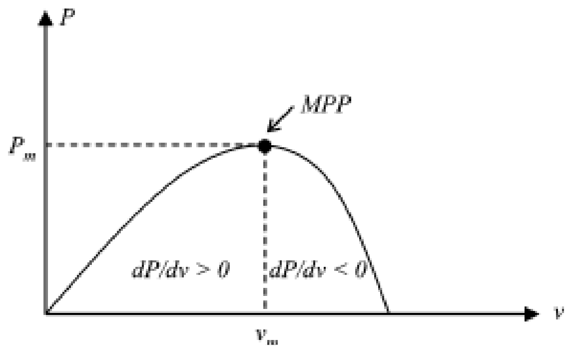

Figure 2.11.Block diagram of the HCS control (Chen,Guerrero and Blaabjerg,2009)

2.5. Wind Farm Configurations and Offshore Wind Farms

Merger of a large number of wind turbines form wind farms. Wind farms can also be called wind stations or wind parks.Wind farms can be built in offhore. This type of wind farm is called Offshore wind farm. A typical scheme of wind farm is as shown in Figure 2.12.

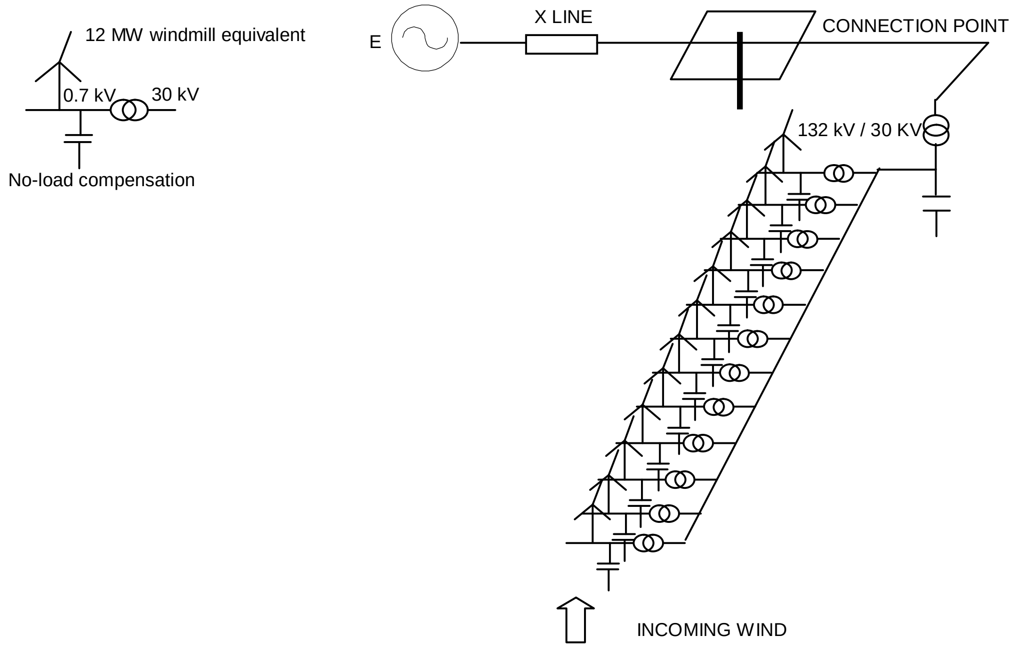

Figure 2.12.The scheme of the Wind Farms (Akhmatov and Knudsen,2002)

Wind projects need a large area to achieve significant levels of energy production, however, it may not be easy to find suitable sites for land-based wind farms, while offshore wind farms have no such problems. Other advantage of moving turbines to offshore is that wind speed is more consistent and less turbulent, therefore more energy production and less wear and tear on turbines.

Wind farms may present a significant power contribution to the grids, and therefore, play an important role on the power quality and the control of power systems. Consequently, high technical demands are expected to be met by these generation units, such as to perform frequency and voltage control, regulation of active and reactive power, quick responses under power system transient and dynamic situations, for example, it may be required to reduce the power from the nominal power to 20% power within 2 s. The power electronic technology is again an important part in both the system configurations and the control of the wind farms in order to fulfill these demands. Some possible electrical configurations of wind farms are shown in below figures. (Chen,Guerrero and Blaabjerg,2009;Akhmatov and Knudsen,2002)

A wind farm equipped with Double fed induction generator and power electronic converters as shown in Figure 2.13, can perform both active and reactive power control also operate the wind turbines in variable speed to maximize the captured energy as well as reduce mechanical stress and noise. This system can be called System A.

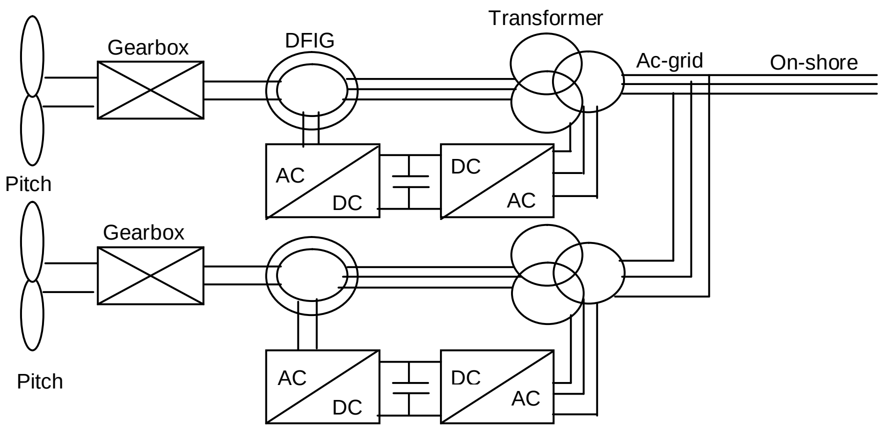

Figure 2.13.DFIG system with ac grid (System A) (Chen and Blaabjerg,2009; Chen,Guerrero and Blaabjerg,2009)

Figure 2.14 shows a wind farm with induction generators. A STATCOM or SVC can be used to provide the reactive power to meet the system reactive power and voltage control requirements. It can help to control the voltage as well as to provide the reactive power demanded by the induction generators in the wind farm. This system can be called System B.

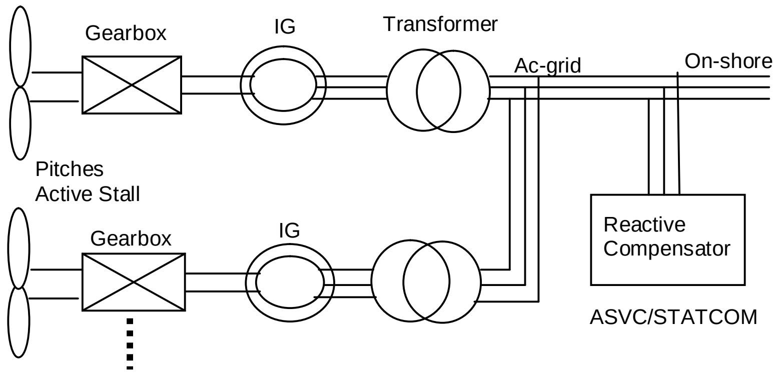

Figure 2.14.Induction generator with ac grid (System B) (Chen and Blaabjerg,2009; Chen,Guerrero and Blaabjerg,2009)

For long distance transmission of power from an offshore wind farm, HVDC may be an interesting option. In a HVDC transmission, the low or medium AC voltage at the wind turbines/farms is converted into a DC voltage, the DC power is transferred to the onshore system, then it is converted back into AC power as shown in Figure 2.15 and Figure 2.16. First system can be called System C and second system can be called System D.

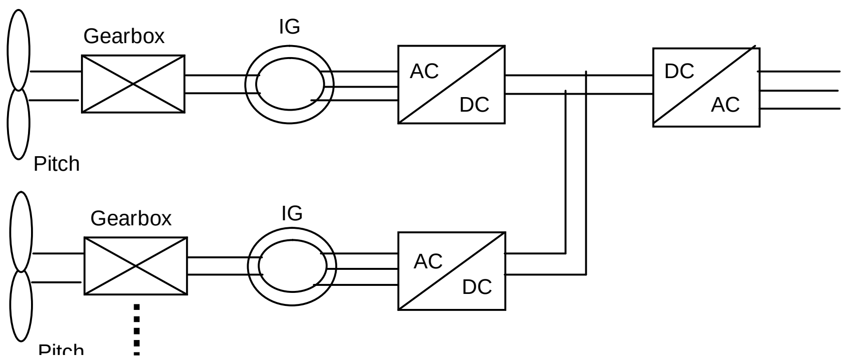

Figure 2.15.Speed-Controlled IG with common dc bus (System C) (Chen and Blaabjerg,2009; Chen,Guerrero and Blaabjerg,2009)

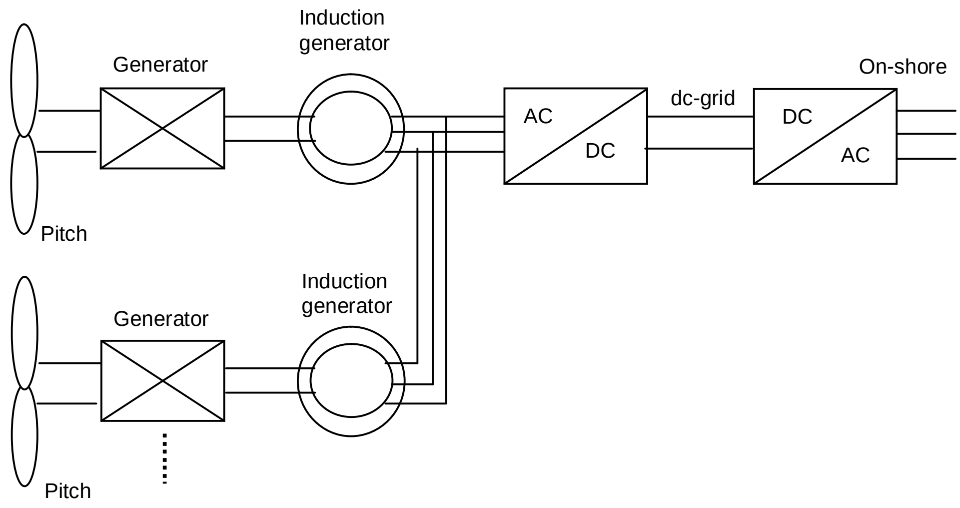

Figure 2.16.SpeedControlled IG with common ac grid and dc transmission(SystemD) (Chen and Blaabjerg,2009; Chen,Guerrero and laabjerg,2009)

The HVDC transmission system may be either the conventional thyristor based technology or the voltage source converter based technology. At System C, each wind turbine has its own power electronic converter, so it possible for each wind turbine to operate at an indivual optimal speed. At System D, wind turbines are connected as an AC network in the wind farm, therefore each wind turbine does not need a seperated power electronic converter system.

There are also possibilities, such a field excited synchronous machines or permanent magnet synchronous generators, that can be sued in the systems, as System C and D. In the case of a multiple-pole generator,the multi-stage gearbox may be removed or replaced by a lower ratio gearbox.

We can compare all systems with each others. A comparison of topologies is given in Table 1. As it can be seen, the wind farms have interesting features in order to act as a power source to the grid. Some have beter abilities then others. The overall considerations will include production, investment, maintenance and reliability. (Chen and Blaabjerg,2009; Chen,Guerrero and Blaabjerg,2009)

Table 2.1.Comparison of four wind farm topologies (Chen and Blaabjerg,2009; Chen,Guerrero and Blaabjerg,2009)

Farm Configuration	**A**	**B**	**C**	**D**
Individual speed control	Yes	No	Yes	No
Control active power electronically	Yes	No	Yes	Yes
Control reactive power	Yes	Centralized	Yes	Yes
Short circuit (active)	Partly	Partly	Yes	Yes
Short circuit power	Contribute	Contribute	No	No
Standby-function	Yes	No	Yes	Yes
Softstarter needs	No	Yes	No	No
Rolling capacity on grid	Yes	Partly	Yes	Yes
Investment	+	++	+	+
Maintenance	+	++	+	+

Note : ++ is better than +.

2.6. Power Quality and Grid Interaction

Power quality means electricity generation performance of the wind turbine and its impact on the grid.While wind power plant is being established, weak grid and the regions of transmission lines should be avoided. The impact of wind turbines to grid usually shows itself as voltage sag and swell (decrease or increase in voltage). This can occur due to below causes.

- Harmonic (>50 Hz)
- Flicker (0.01-35 Hz)
- Over voltage (<0.01 Hz)
- Transients

In addition to voltage changes, the reactive power requirement of wind turbine from grid is also on unwanted situation. Events like power generation, turbulence intensity and wind shift depends on terrain and meteorological conditions. During active and reactive power production and consumption, sags and swells can occur. Events that cause at voltage changes are shown in Table 2. These voltage changes can be calculated by using power and grid impedance. Flicker means that voltage oscillations of voltage up to 35 Hz. (Ozakturk,2007)

Table 2.2.Voltage changes and causing events (Ozakturk,2007)

Parameter	Events
Voltage Sags / Swells	Power production
Voltage Oscillations	Wind shift, Turbulence intensity, Wind speed
Harmonics	Frequency converter, Thyristor Control
Reactive Power Consumption	Generator Operator
Voltage Transients and Voltage Extreme	Switching

When wind power plants are connected to national grid in Turkey, the most important main point is that the capacity of power plants in the region should not exceed 5% of the grid short-circuit capacity. This is limiting factor for wind power investments. In Turkey attractive places for wind power are usually located along the coasts where local energy consumption is low. These areas are grid's weak end points where line capacities are limited. This is a limiting factor for wind power investments in Turkey. Transmission company (TEIAS) and regulating committee (EPDK) are studying for improving wind power investments capacity.

3. PHOTOVOLTAIC (PV) ENERGY

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. A set of connected cells form a panel. Panels are generally composed of series cells in order to obtain large output voltages. Panels with large output currents are achieved by increasing the surface area of the cells or by connecting cells in parallel. A PV array may be either a panel or a set of panels connected in series or parallel to form large PV systems. (Villalva, Gazoli and Filho, 2009).

PV energy applications can be divided into two categories: one is stand-alone system and the other is grid-connected system. Stand-alone system requires the battery bank to store the PV energy and it is suitable for low-power system. (Maris, Kourtesi, Ekonomouc and Fotis, 2007). Stand-alone PV systems, shown in Figure 3.1, are used in remote areas with no access to a utility grid. (Nayar, Islam, Dehbonei and Tan, 2006).

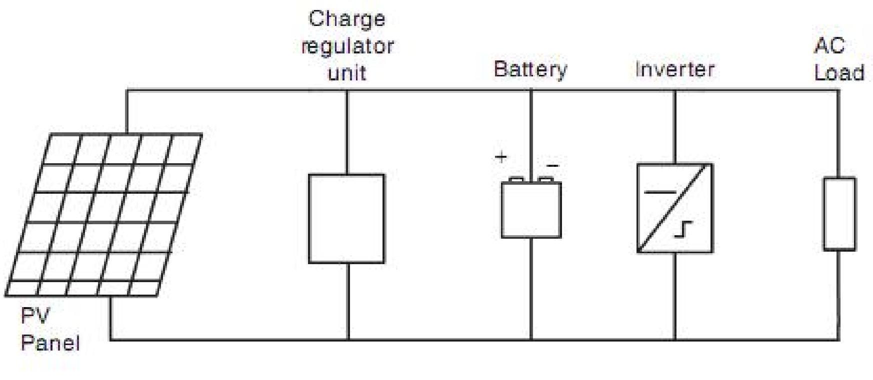

Figure 3.1. Stand-Alone Photovoltaic Systems Block Diagram (Nayar, Islam, Dehbonei and Tan, 2006)

Grid-connected system does not require the battery bank and has become the primary PV application for high-power applications. The main purpose of the grid-connected system is to transfer maximum solar array energy into grid with a unity power factor. Because of the high cost of PV modules, PV generation systems are attractive only for remote isolated areas and for small-scale applications such as PV refrigerators and water-pumping systems. (Maris, Kourtesi, Ekonomouc and Fotis, 2007). Grid-connected PV power offers consumers both economic and environmental advantages. Where utility power is available, consumers can use a grid-connected PV system to supply a portion of the power they need while using utility-generated power at night and on very cloudy days.

3.1. System Components of PV Energy

A PV system for the grid-connected applications is typically composed of five main components: 1) a PV array that converts solar energy to electric energy, 2) a dc-dc converter that converts low dc voltages produced by the PV arrays to a high dc voltage, 3) an inverter that converts the high dc voltage to a single- or three-phase ac voltage, 4) a digital controller that controls the converter operation with MPPT capability, and 5) a AC filter that absorbs voltage/current harmonics generated by the inverter. (Liu,Wu and Cheng, 2004).

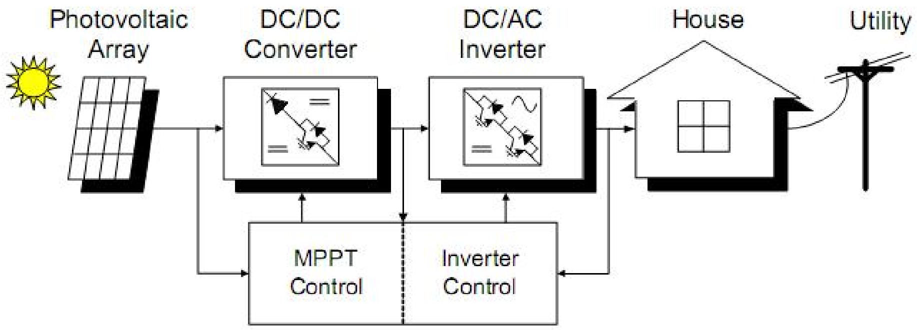

Figure 3.2. Block diagram of grid-connected Photovoltaic system (Liu,Wu and Cheng, 2004)

3.1.1. Photovoltaic Cell

A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The monocrystalline and polycrystalline silicon cells are the only found at commercial scale at the present time. Silicon PV cells are composed of a thin layer of bulk Si or a thin Si film connected to electric terminals. One of the sides of the Si layer is doped to form the p–n junction. A thin metallic grid is placed on the Sun-facing surface of the semiconductor. Figure 3.3 roughly illustrates the physical structure of a PV cell. (Villalva, Gazoli and Filho, 2009).

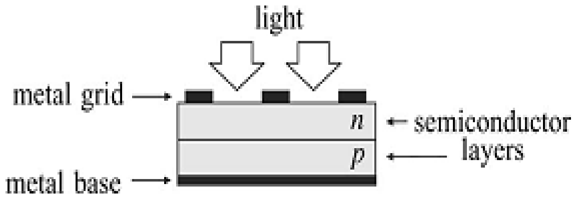

Figure 3.3.Physical structure of a PV cell (Villalva, Gazoli and Filho, 2009)

The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short-circuited. Charges are generated when the energy of the incident photon is sufficient to detach the covalent electrons of the semiconductor ; this phenomenon depends on the semiconductor material and on the wavelength of the incident light. Basically, the PV phenomenon may be described as the absorption of solar radiation, the generation and transport of free carriers at the p–n junction, and the collection of these electric charges at the terminals of the PV device. (Villalva, Gazoli and Filho, 2009).

The rate of generation of electric carriers depends on the flux of incident light and the capacity of absorption of the semiconductor. The capacity of absorption depends mainly on the semiconductor bandgap, on the reflectance of the cell surface (that depends on the shape and treatment of the surface), on the intrinsic concentration of carriers of the semiconductor, on the electronic mobility, on the recombination rate, on the temperature, and on several other factors. (Villalva, Gazoli and Filho, 2009).

The solar radiation is composed of photons of different energies. Photons with energies lower than the bandgap of the PV cell are useless and generate no voltage or electric current. Photons with energy superior to the bandgap generate electricity, but only the energy corresponding to the bandgap is used - the remainder of energy is dissipated as heat in the body of the PV cell. (Villalva, Gazoli and Filho, 2009).

3.1.2. DC-DC Converters

It is widely known that dc–dc converters increase or decrease the magnitude of the dc voltage and/or invert its polarity. This is accomplished by the pulsewidth modulation (PWM) technique, usually to a constant frequency. The duty cycle (D) is the ratio of the time of conduction (T_{ON}) to the switching period (T_S). The three basic configurations of converters (buck, boost, and buck–boost derived) are similar to a dc transformer, both in CCM and discontinuous conduction mode (DCM). In a dc transformer, the relationship of transformation can be controlled electronically by changing the duty cycle of the converter in the range. (Aranda, Galan, Sidrach and Marquez, 2009).

Several topologies such as buck–boost (single inductor), Zeta,Cuk, and SEPIC provide the same conversion ratio and same input resistance. Nevertheless, in buck–boost and Zeta topologies, the input current is always discontinuous because the switch is located in series with the panel causing great harmonic components in the current, and therefore producing high-input ripple and significant noise problems. (Aranda, Galan, Sidrach and Marquez, 2009).

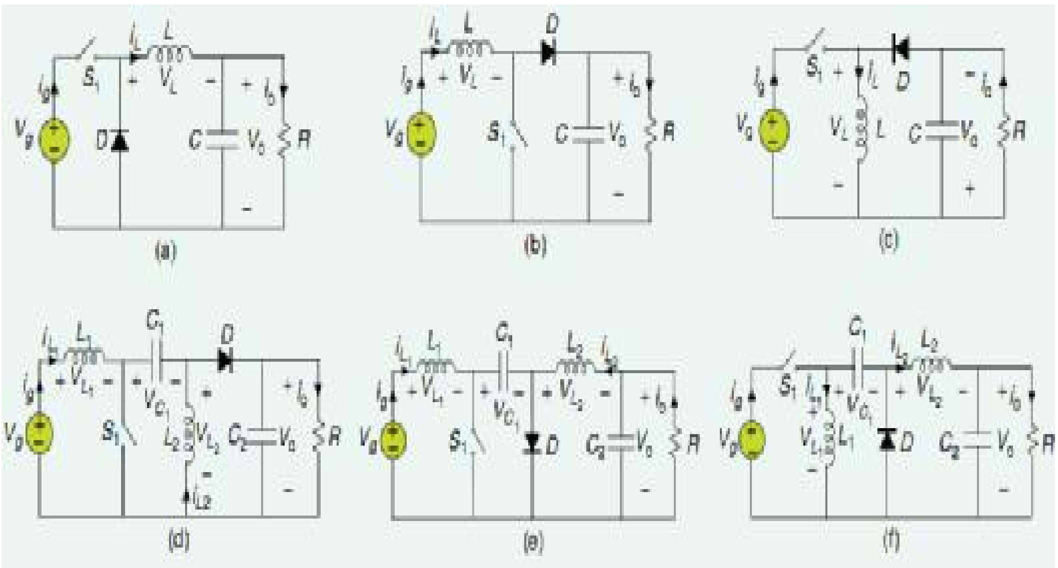

Figure 3.4. Different converters analyzed : (a) buck converter, (b) boost converter, (c) buck–boost single - inductor converter, (d) SEPIC converter, (e) Cuk converter, and (f) Zeta converter. (Aranda, Galan, Sidrach and Marquez, 2009)

The Cuk and SEPIC converters exhibit nonpulsating input current; therefore, the sweep of the I–V curve is carried out in a more reliable and less noisy way, so these topologies are more suitable. (Aranda, Galan, Sidrach and Marquez, 2009).

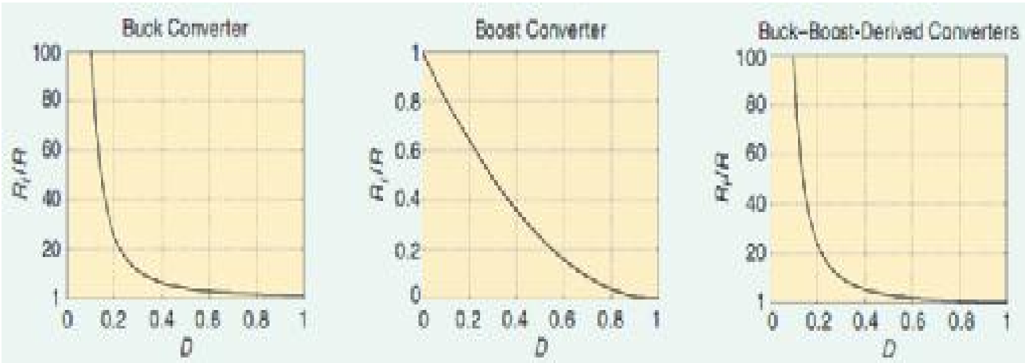

Figure 3.5. Representation of input resistance versus duty cycle for CCM (Aranda,Galan, Sidrach and Marquez, 2009)

3.1.3. Inverters

Inverters convert power from DC to AC while rectifiers convert it from AC to DC. Many inverters are bi-directional, i.e. they are able to operate in both inverting and rectifying modes. (Nayar, Islam, Dehbonei and Tan, 2006).

The past technology, illustrated in Figure 3.6 a, was based on centralized inverters that interfaced a large number of PV modules to the grid. The PV modules were divided into series connections (called a string), each generating sufficiently high voltage to avoid further amplification. These series connections were then connected in parallel, through string diodes, in order to reach high power levels. (Kjaer, Pedersen and Blaabjerg, 2005).

The present technology consists of the string inverters and the ac module. The string inverter, shown in Figure 3.6 b, is a reduced version of the centralized inverter, where a single string of PVmodules is connected to the inverter. The present solutions use self-commutated dc–ac inverters, by means of IGBTs or MOSFETs, involving high power quality in compliance with the standards. (Kjaer, Pedersen and Blaabjerg, 2005).

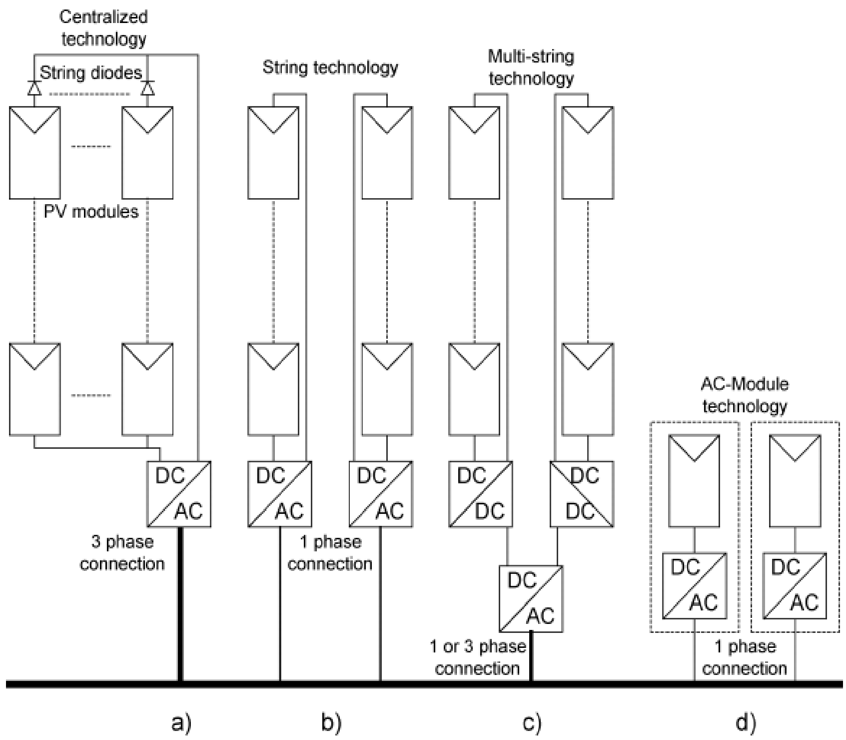

Figure 3.6. Historical overview of PV inverters. (a) Past centralized technology. (b) Present string technology. (c) Present and future multi-string technology. (d) Present and future ac-module and ac cell technologies. (Kjaer, Pedersen and Blaabjerg, 2005)

The multi-string inverter depicted in Figure 3.6 c is the further development of the string inverter, where several strings are interfaced with their own dc–dc converter to a common dc–ac inverter. This is beneficial, comparedwith the centralized system, since every string can be controlled individually. Thus the operator may start his/her own PV power plant with a few modules. (Kjaer, Pedersen and Blaabjerg, 2005).

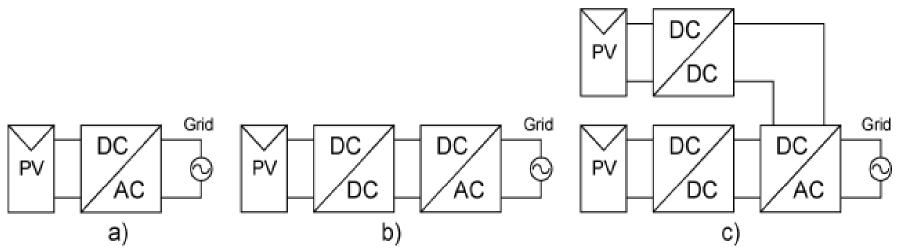

Figure 3.7. Three types of PV inverters. (Kjaer, Pedersen and Blaabjerg, 2005)

Figure 3.7 shows three cases of single and multiple-stage inverters. The inverter of Figure 3.7 a is a single-stage inverter, which must handle all tasks itself, i.e., MPPT, grid current control and, perhaps, voltage amplification. Figure 3.7 b depicts a dual-stage inverter. The dc–dc converter is now performing the MPPT (and perhaps voltage amplification). Dependent on the control of the dc–ac inverter, the output from the dc–dc converters is either a pure dc voltage (and the dc–dc converter is only designed to handle the nominal power), or the output current of the dc–dc converter is modulated to follow a rectified sine wave (the dc-dc converter should now handle a peak power of twice the nominal power). Finally, Figure 3.7 c is the solution for the multi-string inverter. The only task for each dc–dc converter is MPPT and perhaps voltage amplification. The dc–dc converters are connected to the dc link of a common dc–ac inverter, which takes care of the grid current control. (Kjaer, Pedersen and Blaabjerg, 2005).

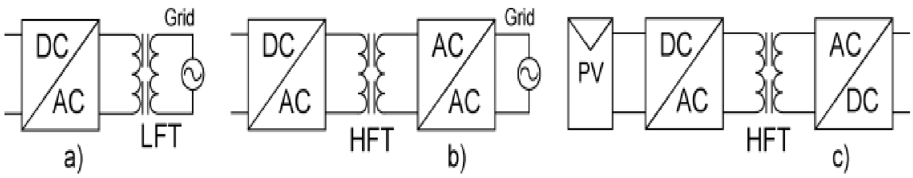

Figure 3.8. Examples of transformer-included inverter solutions. (a) Line-frequency transformer (LFT) is placed between the grid and the inverter. (b) High-frequency transformer (HFT) is embedded in an HF-link grid-connected ac/ac inverter. (c) HFT is embedded in a dc-link PV-module-connected dc–dc converter. (Kjaer, Pedersen and Blaabjerg, 2005)

Some inverters use a transformer embedded in a high-frequency dc–dc converter or dc–ac inverter, others use a line-frequency transformer toward the grid and, finally, some inverters do not include a transformer at all (see Figure 3.8). The line-frequency transformer is regarded as a poor component due to increased size, weight, and price. Modern inverters tend to use a high-frequency transformer. This results in entirely new designs, such as the printed circuit board (PCB) integrated magnetic components (Kjaer, Pedersen and Blaabjerg, 2005).

Multilevel converters have been mainly used in medium- or high-power system applications, such as static reactive power compensation and adjustable-speed drives. In these applications, due to the limitations of the currently available power semiconductor technology, a multilevel concept is usually a unique alternative because it is based on low-frequency switching and provides voltage and/or current sharing between the power semiconductors. (Daher, Schmid and Antunes, 2008).

On the other hand, for low-power systems (< 10 kW), multilevel converters have been competing with high-frequency pulsewidth-modulation converters in applications where high efficiency is of major importance. (Daher, Schmid and Antunes, 2008).

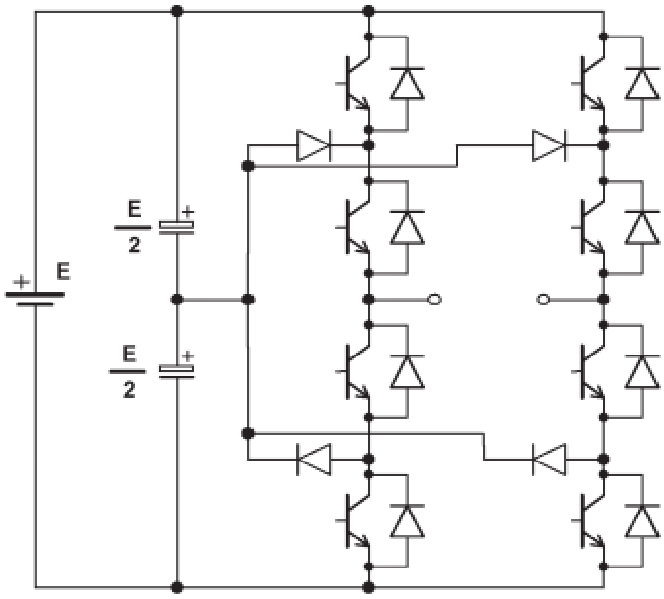

Figure 3.9. Diode clamped Topology (NPC) (Daher, Schmid and Antunes, 2008)

Figure 3.9 shows a three-level neutral-point-clamped (NPC). It was the first widely popular multilevel topology, and it continues to be extensively used in industrial applications. Later, the NPC inverter was generalized for a greater number of levels, using the same concept of diode-clamped voltage levels, which resulted in the current designation of a diode-clamped converter. (Daher, Schmid and Antunes, 2008).

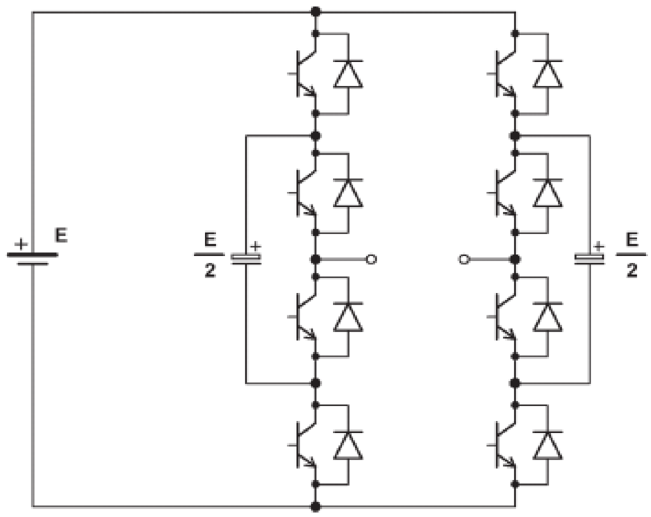

Figure 3.10. Flying Capacitor Topology (Daher, Schmid and Antunes, 2008)

The three-level flying capacitor topology, as shown in Figure 3.10, can be considered as a good alternative to overcome some of the NPC topology drawbacks. In this topology, additional levels and voltage clamping are achieved by means of capacitors that “float” with respect to the dc source reference. It does not require additional clamping diodes and provides redundant switch states that can be used to control the capacitor charge even under loads with the dc level. Nevertheless, larger structures require a relatively high number of capacitors, and additional circuits are also required to initialize the capacitor charge. (Daher, Schmid and Antunes, 2008).

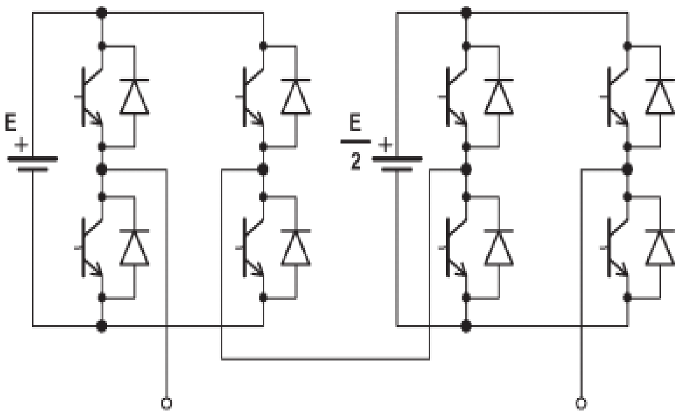

Figure 3.11. Cascaded H-Bridge Topology (Daher, Schmid and Antunes, 2008)

The cascade topology (see figure 3.11) allows the use of dc sources with different voltage values, and high-resolution multilevel waveforms can be achieved with a relatively low number of components. In addition, dc sources can be added or subtracted, which can increase the number of output levels. (Daher, Schmid and Antunes, 2008).

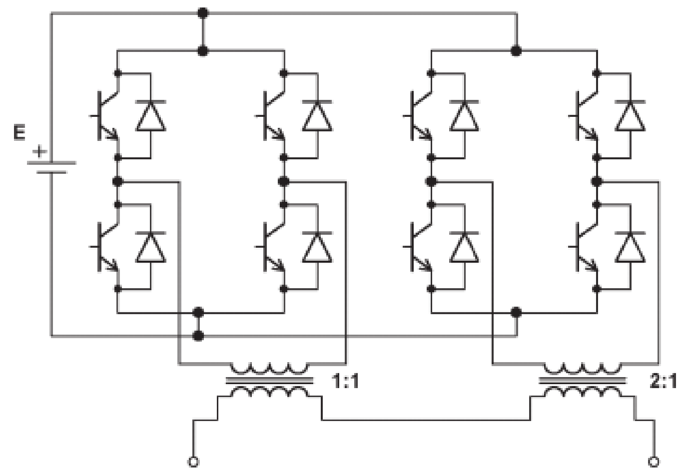

Figure 3.12. Multiple Transformer Topology (Daher, Schmid and Antunes, 2008)

Figure 3.12 shows a multiple-transformer topology composed of two cells. It is similar to the cascaded H-bridge topology, but the outputs of the isolation transformers are cascaded instead of directly cascading the H-bridge outputs. As a result, only one dc source is required. (Daher, Schmid and Antunes, 2008).

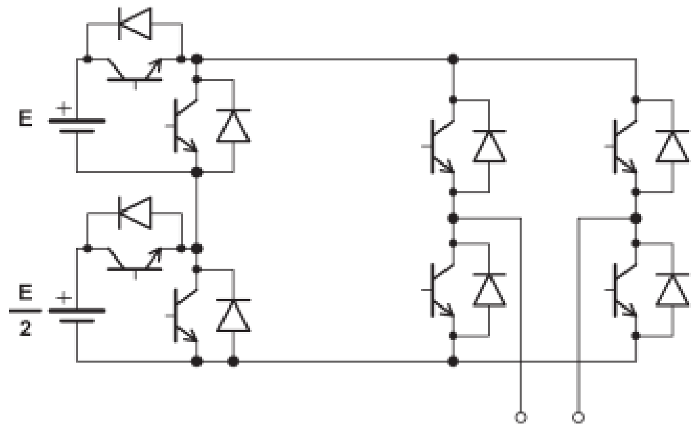

Figure 3.13. Multiple source topology (Daher, Schmid and Antunes, 2008)

The multiple-source topology, as shown in Figure 3.13, uses several isolated dc sources to produce a rectified multilevel waveform, which is then converted into an ac voltage. In practice, the multiple-source topology is one of the most efficient multilevel topologies currently available. (Daher, Schmid and Antunes, 2008).

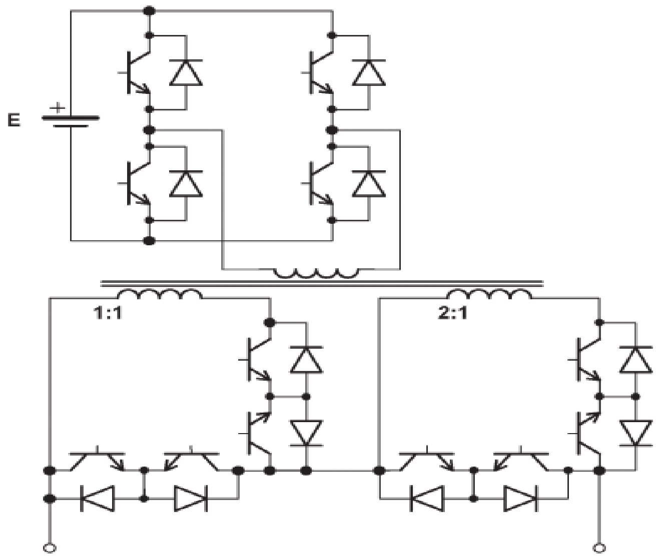

Figure 3.14. Multiwinding transformer topology (Daher, Schmid and Antunes, 2008)

The multiwinding-transformer topology can be considered as a variation of the multiple-source topology. A three-cell multiwinding inverter is shown in Figure 3.14. Unlike the multiple-source topology, the multiwinding topology requires only a single dc input, which is achieved using a multiwinding line-frequency transformer. It provides input-output isolation, and because it employs only one transformer, high efficiency can be achieved. The major disadvantage is the relatively high number of switches presented in the output stage. (Daher, Schmid and Antunes, 2008).

Figure 3.15 shows an eight-module modular topology that has been recently proposed for high-power applications. (Daher, Schmid and Antunes, 2008).

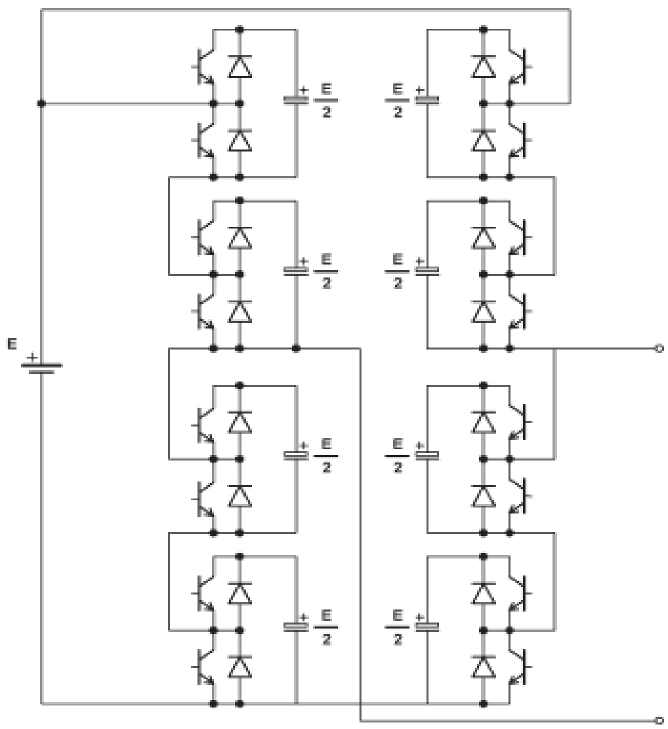

Figure 3.15. Modular topology (Daher, Schmid and Antunes, 2008)

Figure 3.16 shows the single-phase multi-string five-level inverter topology. It consists of three dc-dc boost converters connected to a common dc bus, an auxiliary circuit and a full-bridge inverter configuration. Input sources, PV string 1, PV string 2 and PV string 3 are connected to the inverter via the dc-dc boost converters. Since the proposed inverter is used in a grid-connected PV system, the utility grid is used instead of a load. Multi-string approach is adopted since each dc-dc-converter can independently perform maximum power point tracking (MPPT) for its PV strings. Multi-string approach is adopted since each dc-dc-converter can independently perform maximum power point tracking (MPPT) for its PV strings. (Abd and Selvaraj, 2009).

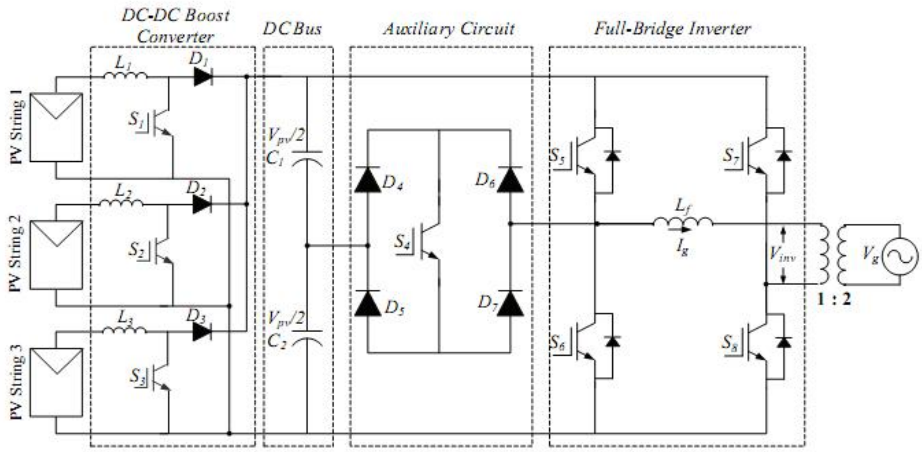

Figure 3.16. Single-phase multi-string five-level inverter topology (Abd and Selvaraj, 2009)

3.1.4. Batteries

Stand-alone PV energy system requires storage to meet the energy demand during periods of low solar irradiation and night time. Several types of batteries are available such as the lead acid, nickel–cadmium, lithium, zinc bromide, zinc chloride, sodium sulfur, nickel–hydrogen, redox, and vanadium batteries. The provision of cost-effective electrical energy storage remains one of the major challenges for the development of improved PV power systems. Typically, lead-acid batteries are used to guarantee several hours to a few days of energy storage. Their reasonable cost and general availability has resulted in the widespread application of lead-acid batteries for remote area power supplies despite their limited lifetime compared to other system components. The following factors are considered in the selection of batteries for PV applications (Nayar, Islam, Dehbonei and Tan, 2006) :

- Deep discharge (70–80% depth of discharge).
- Low charging/discharging current.
- Long duration charge (slow) and discharge (long duty cycle).
- Long life time.
- Less maintenance requirement.
- High energy storage efficiency.
- Low cost

3.2. Modelling PV Cells and Arrays

The equivalent circuit of the solar cell is composed of the internal serial resistance (R_s) and the shunt resistance (R_{sh}) of the diode. (Park, Cha, Jung and Won 2009).

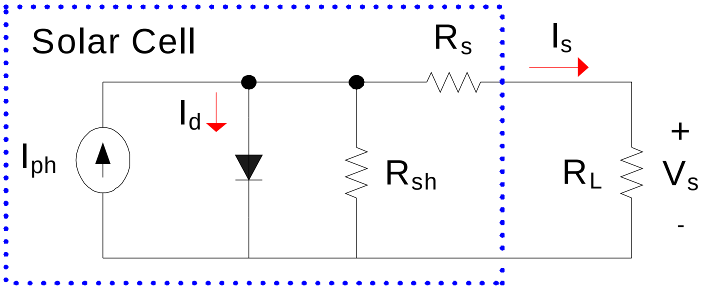

Figure 3.17. The equivalent circuit of a solar cell. (Park, Cha, Jung and Won 2009)

Figure 3.17 shows a commonly used equivalent circuit model of single PV cell. V_s and I_s are the output voltage and current of the PV cell. Actual PV cell is deemed to be a current source whose value equals to I_{ph}, paralleling with a forward diode. Forward current that flows through the diode is viewed as dark current I_d in the PV cell. R_s and R_{sh} are the series and parallel resistance of the PV cell. R_s is made up of surface resistance of the roof of the proliferation, body resistance of the cell, resistance between the top and bottom electrode and PV cell as well as resistance of the metal conductor. R_{sh} is mainly caused by the following factors: the surface leakage current along the edge of the cell, which is caused by the surface spots; the leakage current along the small bridge that caused by the disfigurement of the micro-cracks, grains and crystal after the electrode metal processing, or caused by the dislocation and the irregular spread of the grains. (Xue,Yin,Wu and Peng, 2009).

The solar cell output characteristics are expressed as (Park, Cha, Jung and Won 2009) :

$$I_{sat} = I_{ph} - I_{sat}\left[exp\left(\frac{q(V_s + I_s R_s)}{AKT}\right) - 1\right] - \frac{V_s + I_s R_s}{R_{sh}} \tag{3.1}$$

In equation (3.1), it is assumed that Rs equals zero and the Rsh equals infinity, thus, the equation can be simplified as equation (3.2) :

$$I_s = I_{ph} - I_{sat}\left[exp\left(\frac{qV_s}{AKT}\right) - 1\right] \qquad (3.2)$$

where $\mathbf{I_{ph}}$ is the current generated by the incident light (it is directly proportional to the sun irradiation), $\mathbf{I_{sat}}$ is the reverse saturation or leakage current of the diode, **q** is the electron charge (1.60217646 × 10^{-19} C), **k** is the Boltzmann constant (1.3806503 × 10^{-23} J/K), **T** (in Kelvin) is the temperature of the p–n junction and **A** is the diode ideality constant.(Park, Cha, Jung and Won 2009) Figure 3.18 shows the I–V curve and P-V curve of a photovoltaic originated from (3.2)

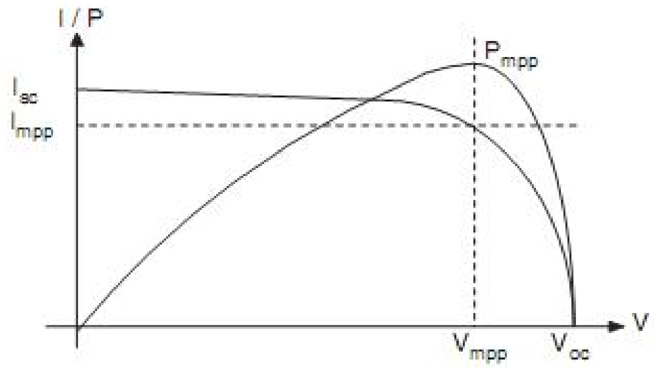

Figure 3.18. Current vs Voltage (I–V) and Power vs Voltage (P–V) characteristics for a photovoltaic cell (Xue,Yin,Wu and Peng, 2009)

A plot of power (P) against voltage (V) for this device (Figure 3.18) shows that there is a unique point on the I–V curve at which the solar cell will generate maximum power. This is known as the maximum power point (V_{mp}, I_{mp}). (Nayar, Islam, Dehbonei and Tan, 2006).

The variation of the output I–V characteristic of a commercial PV module as a function of temperature and irradiation is shown in Figures 3.19 - 3.22. It can be observed that the temperature changes mainly affect the PV output voltage, while the irradiation changes mainly affect the PV output current. (Salas, Olias, Barado and Lazaro, 2006).

Figure 3.19 shows the I-V curves of the PV-Module. If increasing irradiance, fluctuation of the open circuit voltage is very little. But the short circuit current has sharp fluctuations with respect to the irradiance. However for a rising operating temperature, the variation of the short circuit current is decreased and the open circuit voltage is decreased in a non-linear fashion. (Park, Cha, Jung and Won 2009).

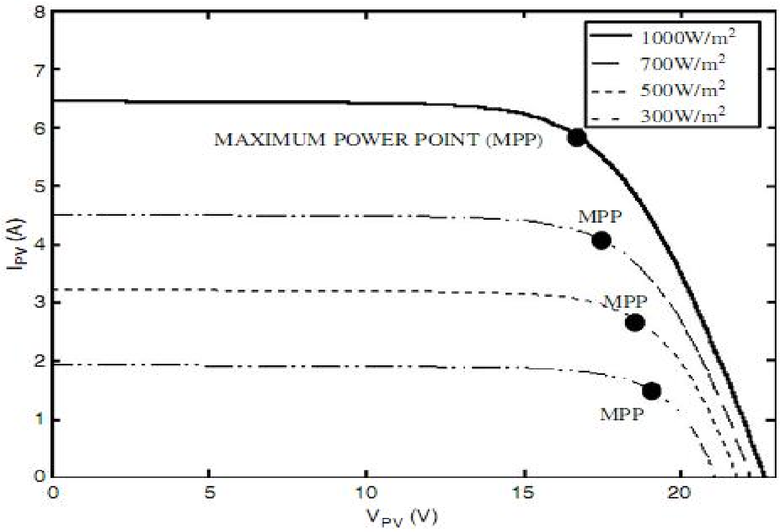

Figure 3.19. I–V photovoltaic characteristic for four different irradiation levels (Park, Cha, Jung and Won 2009)

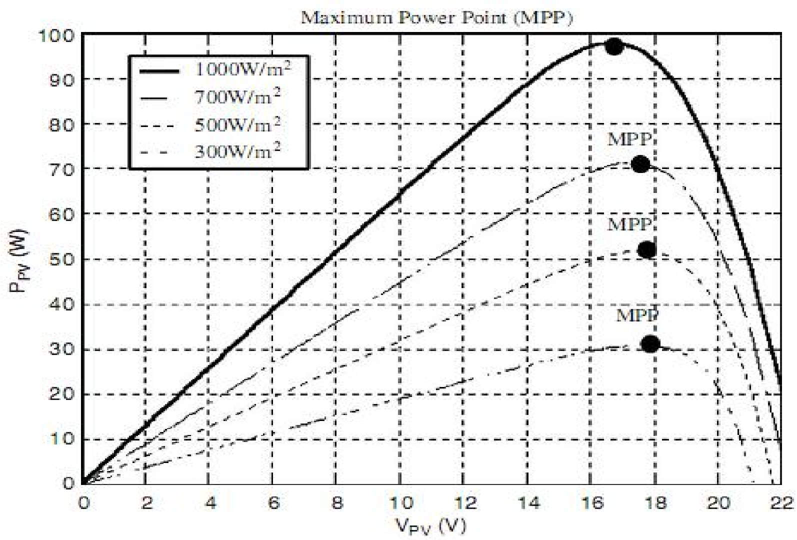

Figure 3.20. P–V photovoltaic characteristic for four different irradiation levels. (Park, Cha, Jung and Won 2009)

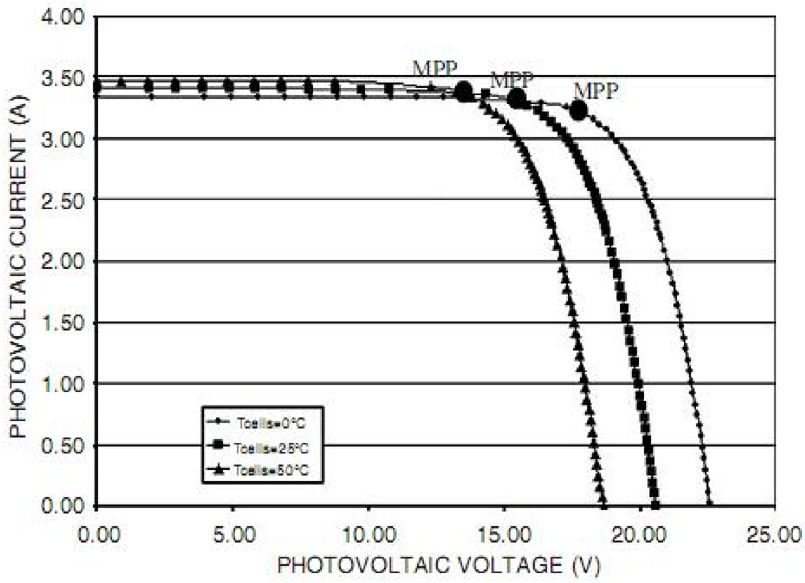

Figure 3.21. I–V characteristics for three temperatures level (Salas, Olias, Barado and Lazaro, 2006)

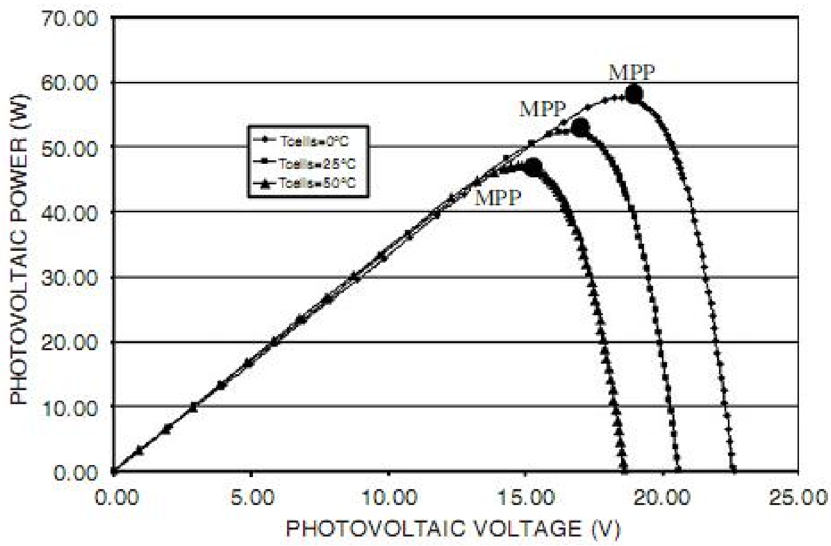

Figure 3.22. P–V characteristic for three temperatures level (Salas, Olias, Barado and Lazaro, 2006)

The well-known double diode model of a PV cell is described in (Sandrolini, Artioli and Reggiani, 2010). The double-diode model in Figure 3.23 represents the physics of amonocrystalline silicon PV module as it is more accurate than the single-diode model. Further, this model is commonly accepted as reflecting the behaviour of polycrystalline silicon PV modules. Both single and double diode models, developed and are widely used for PV cells. (Sandrolini, Artioli and Reggiani, 2010).

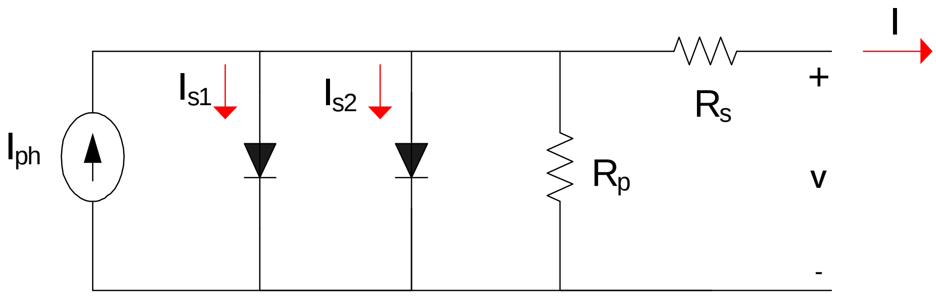

Figure 3.23. Double-diode circuit model for a photovoltaic module (Sandrolini, Artioli and Reggiani, 2010)

One of the two diodes represents the diffusion current in the p–n junction, whereas the other is added to take the space charge recombination effect into account. With reference to Figure 3.23, the current versus voltage characteristic I-V is given by the equation (Sandrolini, Artioli and Reggiani, 2010) :

$$I - I_{ph} + I_{s1}\left[exp\left(\frac{V + IR_s}{n_1 V_T}\right) - 1\right] + I_{s2}\left[exp\left(\frac{V + IR_s}{n_2 V_T}\right) - 1\right] + \frac{V + IR_s}{R_p} = 0 \qquad (3.3)$$

where

I_{ph} is the photocurrent

I_{s1}; I_{s2} are the diode saturation currents

n_1; n_2 are the diode ideality factors

R_S is the series resistance

R_P is the parallel or shunt resistance

$V_T = kT/q$ is the thermal voltage, where k is Boltzmann's constant

T is the PV module absolute temperature and q is the electron charge. (Sandrolini, Artioli and Reggiani, 2010)

The equivalent circuit for solar cells arranged in N_p-parallel and N_s-series is shown in Figure 3.24 and the mathematical equation relating the array current to the array voltage becomes (Kim, 2006) :

$$I_{sa} = N_p I_{ph} - N_p I_{sat}\left\{exp\left[\frac{q}{AkT}\left(\frac{V_{sa}}{N_s} - \frac{I_{sa}R_s}{N_p}\right)\right] - 1\right\} - \frac{N_p}{R_{sh}}\left(\frac{V_{sa}}{N_s} + \frac{I_{sa}R_s}{N_p}\right) \qquad (3.4)$$

where N_p represents the number of parallel modules. Note that each module is composed of N_s cells connected in series; N_pI_{ph} corresponds to the short-circuit current of the photovoltaic array. (Kim, 2006)

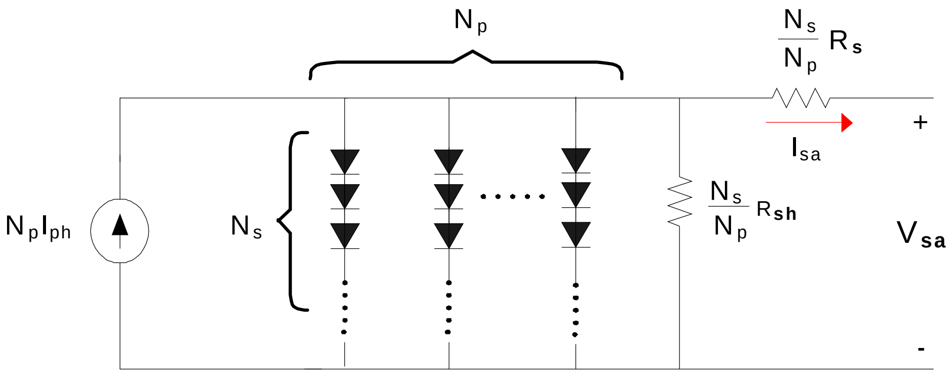

Figure 3.24. Photovoltaic array circuit (Kim, 2006)

MATLAB/SIMULINK simulation for the Photovoltaic array circuit in Figure 3.24 is given in (Tsai, Tu, Su, 2008). I-V and P-V caharacteristics for different temperature and irradiation levels are also simulated in (Tsai, Tu, Su, 2008).

Another photovoltaic array circuit is described in (Maffezzoni and D'amore, 2009). The photovoltaic module is considered as composed of a large number (N_s) of series-connected identical solar cells, V_M and I_M are indicated as the voltage and current of the module, respectively seen in Figure 3.25. (Maffezzoni and D'amore, 2009).

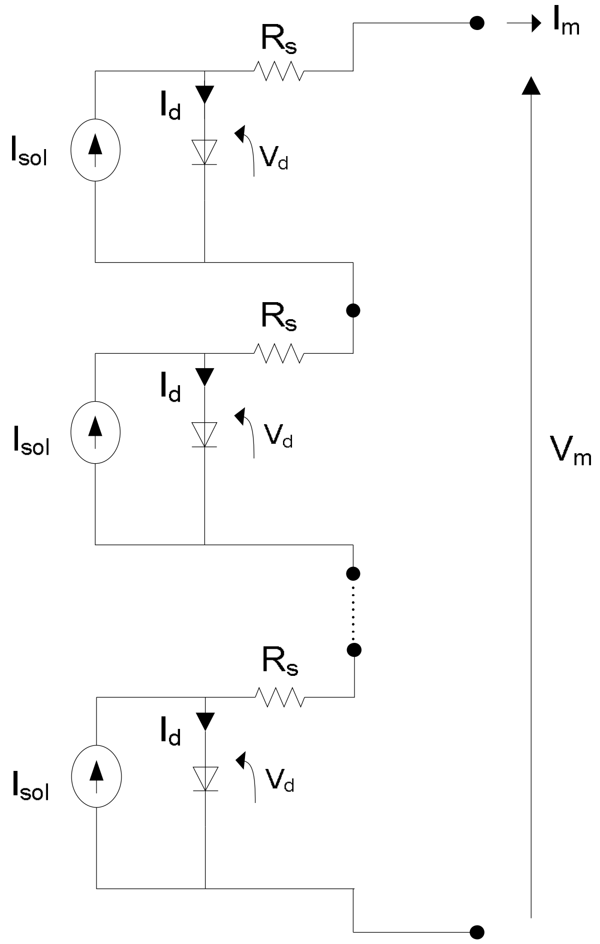

Figure 3.25. Photovoltaic array model (Maffezzoni and D'amore, 2009)

3.3. Control Techniques of PV Systems

3.3.1. Inverter Control

PWM (Pulse width modulation) is used for inverter controller. The block diagram of the DSP based control method is shown in Figure 3.26 which is dicussed in (Shireen, Srinivas and Nene, 2007).

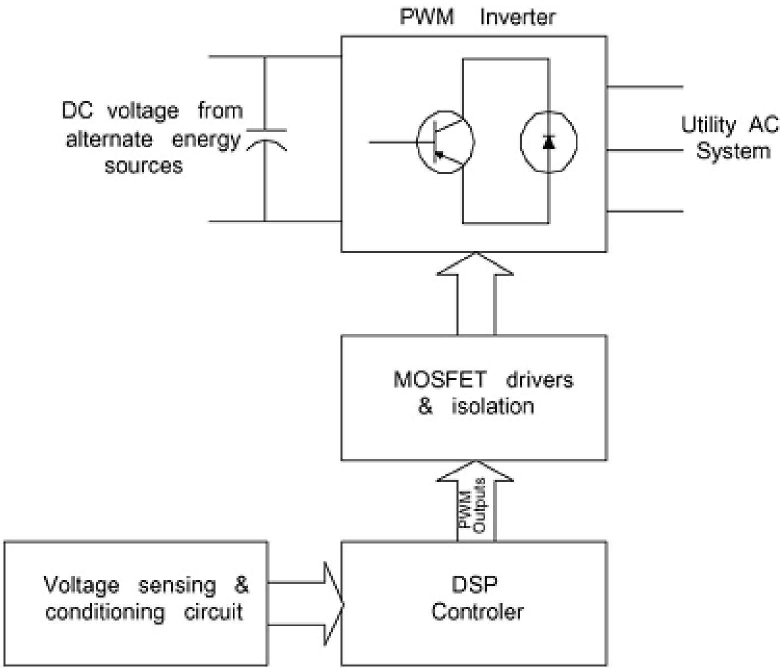

Figure 3.26. Block diagram of the DSP based PWM control (Shireen, Srinivas and Nene, 2007)

A three-phase pulse width modulated (PWM) inverter acts as the interface between the alternate energy system (which produces or stores electric energy in dc form) and the ac power system. The dc bus voltage information is fed into the DSP controller that generates the PWM control signals for the inverter switches and maintains the stiffness of the ac voltages regardless of variation in the input dc bus voltage. (Shireen, Srinivas and Nene, 2007).

Another control method for Inverter is explained in (Patcharaprakiti, Premrudeepreechacharn and Sriuthaisiriwong, 2005). The inverter circuit converts direct current to alternating current by using predictive current control. Predictive current control (see Figure 3.27) provides current with sinusoidal waveform. Therefore, the system is able to deliver energy with low harmonics and high power factor. The inverter circuit is composed of a DC source from a boost chopper circuit, four controllable switches (S1–S4), an inductance, and a transformer. (Patcharaprakiti, Premrudeepreechacharn and Sriuthaisiriwong, 2005).

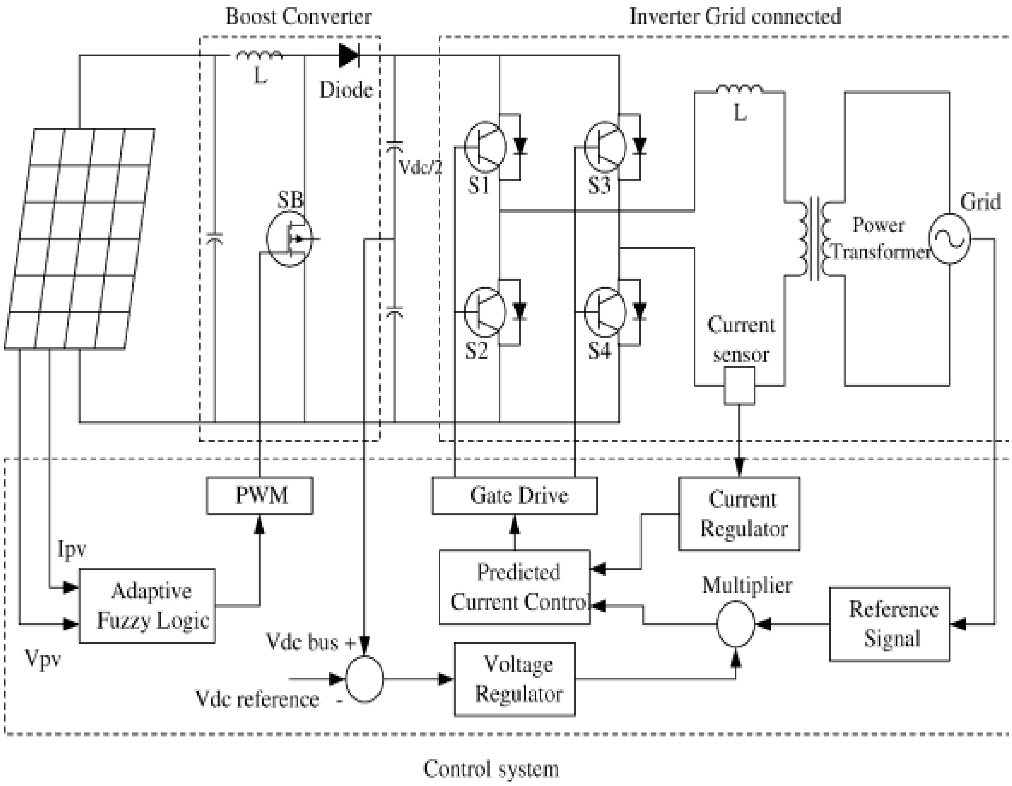

Figure 3.27. Predictive current control for a Single Phase PV Inverter (Patcharaprakiti, Premrudeepreechacharn and Sriuthaisiriwong, 2005)

3.3.2. Maximum Power Point Tracking (MPPT)

A controller that tracks the maximum power point locus of the PV array is known as the MPPT. The points of maximum array power form a curve termed as the maximum power locus. Due to high cost of solar cells, it is necessary to operate the PV array at its maximum power point. (Nayar, Islam, Dehbonei and Tan, 2006).

Several maximum power point tracking (MPPT) algorithms have been proposed from time-to-time. Some of the popular schemes are the hill climbing method, incremental conductance method, constant voltage method, modified hill climbing method, β method, system oscillation method and the ripple correlation method**,** perturb-and-observe method, open- and short-circuit method, fuzzy logic and artificial neural network (Liu,Wu and Cheng, 2004 ; Jain and Agarwal, 2007).

3.3.2.1. Perturb-and-Observe Method

The perturb-and-observe method, also known as perturbation method, is the most commonly used MPPT algorithm in commercial PV products. This is essentially a “trial and error” method. The PV controller increases the reference for the inverter output power by a small amount, and then detects the actual output power. If the output power is indeed increased, it will increase again until the output power starts to decrease, at which the controller decreases the reference to avoid collapse of the PV output due to the highly non-linear PV characteristic. (Liu,Wu and Cheng, 2004).

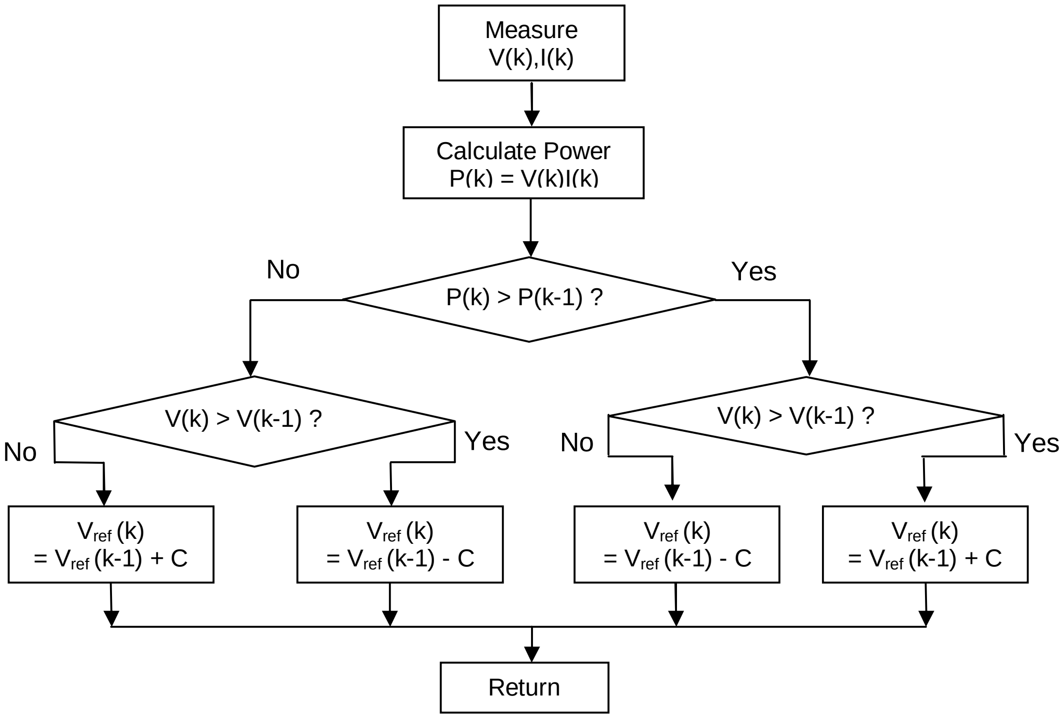

Figure 3.28. Perturb-and-Observe Method flow chart (Liu,Wu and Cheng, 2004)

Figure 3.28 shows the flow chart of the P&O method. The present power P(k) is calculated with the present values of PV voltage V(k) and current I(k), and is compared with the previous power P(k-1). If the power increases, keep the next voltage change in the same direction as the previous change. Otherwise, change the voltage in the opposite direction as the previous one. (Liu,Wu and Cheng, 2004).

3.3.2.2. Incremental Conductance Algorithm

In the incremental conductance method, the MPP is tracked by matching the PV array impedance with the effective impedance of the converter reflected across the array terminals. The latter is tuned by suitably increasing or decreasing the value of 'M'. (Jain and Agarwal, 2007).

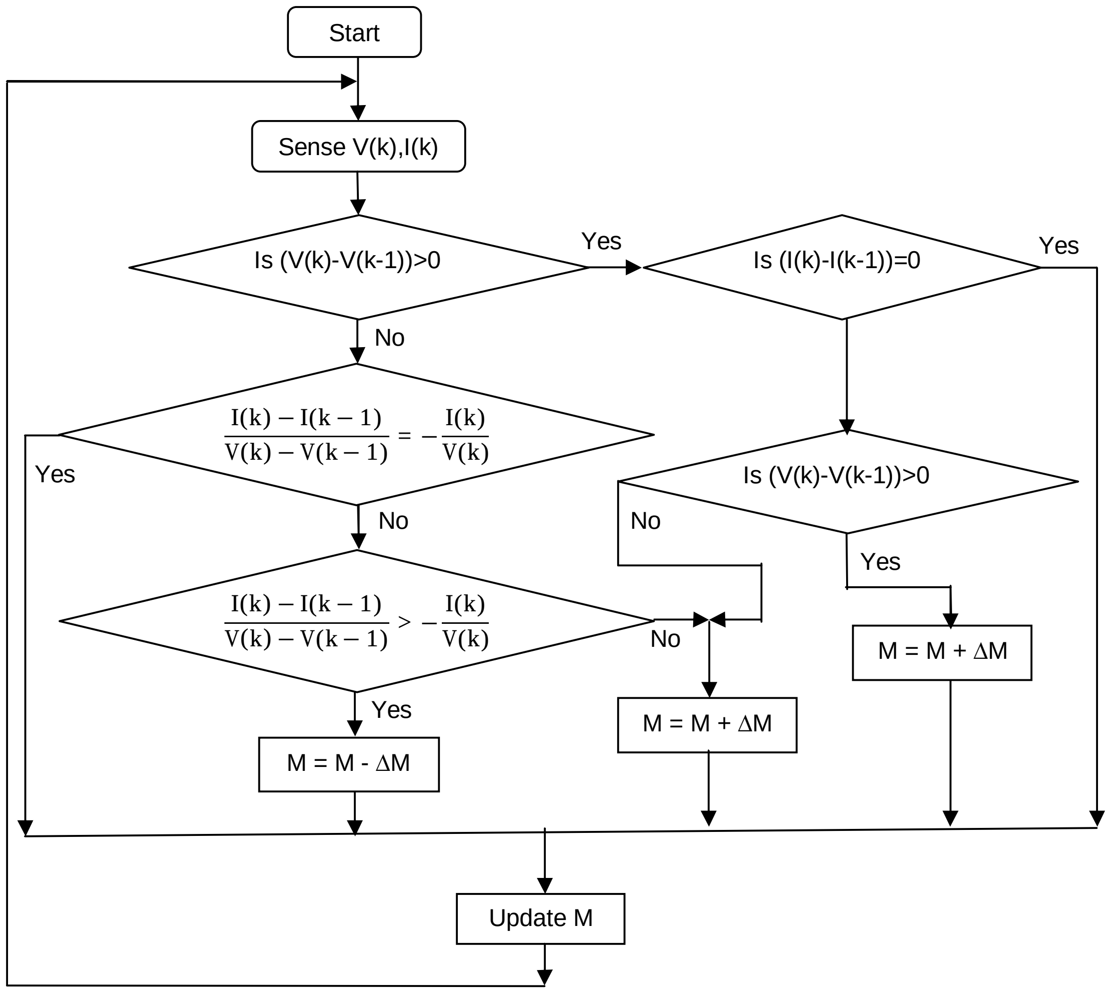

Figure 3.29. Incremental Conductance Algorithm flow chart (Liu,Wu and Cheng, 2004)

The main task of the incremental conductance algorithm is to find the derivative of PV output power with respect to its output voltage, that is dP/dV. The maximum PV output power can be achieved when its dP/dV approaches zero. The controller calculates dP/dV based on measured PV incremental output power and voltage. If dP/dV is not close zero, the controller will adjust the PV voltage step by step until dP/dV approaches zero, at which the PV array reaches its maximum output. The main advantage of this algorithm over the P&O method is its fast power tracking process. However, it has the disadvantage of possible output instability due to the use of derivative algorithm. Also the differentiation process under low levels of insolation becomes difficult and results are unsatisfactory. (Liu,Wu and Cheng, 2004).

3.3.2.3. β method

The other method, based on β tracking, has the advantage of both fast and accurate tracking. It is observed that the value of β remains within a narrow band as the array operating point approaches the MPP. Therefore by tracking β, the operating point can be quickly driven to close proximity of the MPP using large iterative steps. Subsequently, small steps (i.e. conventional MPPT techniques) can be employed to achieve the exact MPP. Thus, β method approximates the MPP while conventional MPPT technique is used to track the exact MPP. Flow chart for the β method algorithm is given in Figure 3.30. (Jain and Agarwal, 2007).

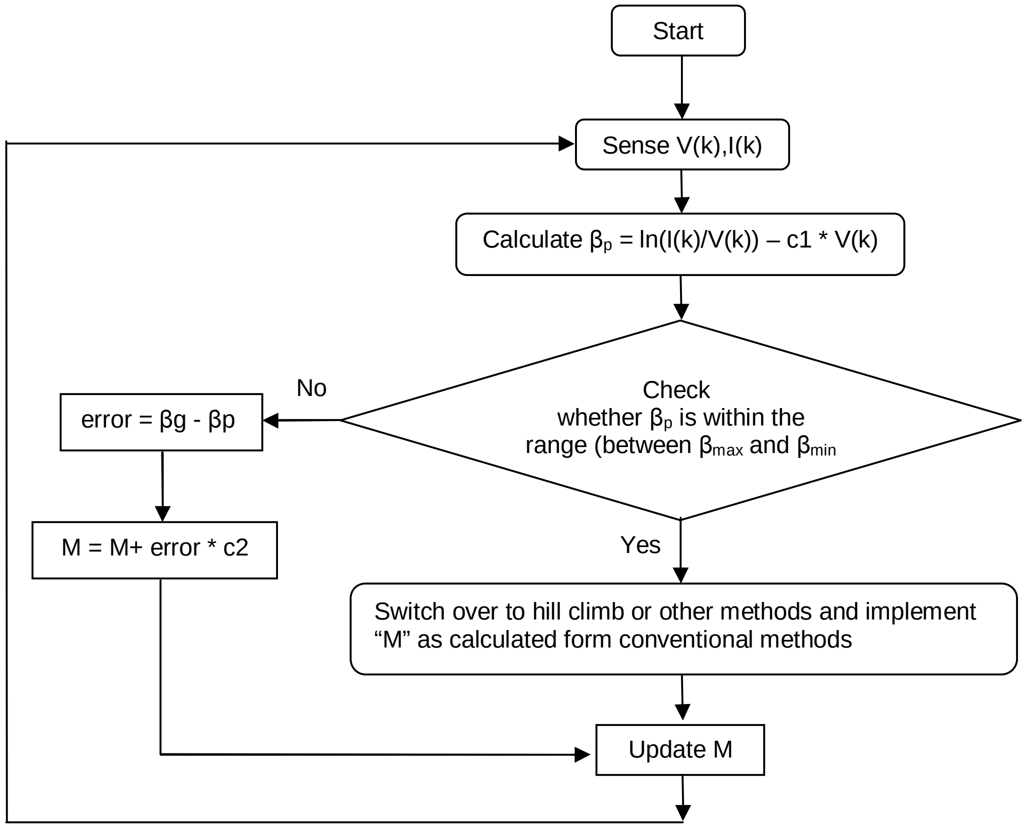

Figure 3.30. β method flow chart (Jain and Agarwal, 2007)

3.3.2.4. Open- and Short-circuit Method

The open- and short-circuit current method for MPPT control is based on measured terminal voltage and current of PV arrays. By measuring the open-circuit voltage or short-circuit current in real-time, the maximum power point of the PV array can be estimated with the predefined PV current-voltage curves. This method features a relatively fast response, and do not cause oscillations in steady state. However, this method cannot always produce the maximum power available from PV arrays due to the use of the predefined PV curves that often cannot effectively reflect the real-time situation due to PV nonlinear characteristics and weather conditions. Also, the online measurement of open-circuit voltage or short-circuit current causes a reduction in output. (Liu,Wu and Cheng, 2004).

3.3.2.5. Fuzzy Logic and Other Algorithms

Since the PV array exhibits a non-linear current-voltage or power-voltage characteristic, its maximum power point varies with the insolation and temperature. Some algorithms such as fuzzy logic or artificial neural network control with non-linear and adaptive in nature fit the PV control. By knowledge based fuzzy rules, fuzzy control can track maximum power point. A neural network control operates like a black box model, requiring no detailed information about the PV system. After learning relation between maximum power point voltage and open circuit voltage or insolation and temperature, the neural network control can track the maximum power point online. (Liu,Wu and Cheng, 2004).

4. OTHER RENEWABLE ENERGY SYSTEMS

4.1. Geothermal Energy

4.1.1. Using of the Geothermal Energy

Geothermal energy is abundant and renewable, but only a very small fraction can currently be converted commercially to electricity and heating value with today's technology. In recent years, the installed geothermal capacity worldwide has more than doubled. The increase in the use of geothermal energy is the result of a multi-disciplinary effort. Highlighted are some production engineering advances that have played a significant part in making geothermal a competitive renewable energy resource. Geothermal energy is going to be an attractive energy source due to rising oil prices and environmental pollution concerns. Since the price of oil has reached its peak and efforts are necessary to find alternative energy resources. Geothermal energy is more attractive when compared to conventional fossil fuel systems. A major focus of production engineering in the geothermal energy industry has been to lower costs sufficient to allow geothermal energy to compete with other energy sources (Yari,2010; Gallup 2009).

Compared to oil, gas, or coal, geothermal power projects are generally classified as clean, renewable energy sources with low or zero greenhouse gas emissions and low to moderate environmental impact in terms of air quality, land use and stability, and water quality. Geothermal fluids do, however, contain gases, mainly carbon dioxide, which can either be released to the atmosphere in the case of dry steam and flash plants or injected back into the reservoir in the case of binary plants. When the gases are discharged to the atmosphere, greenhouse gas emissions are typically an order of magnitude less than that of a coal plant (Williamson,2010).

Geothermal Energy can generate electricity by using geothermal resources directly or indirectly methods. The most common way of capturing the energy from geothermal sources is to use hydrothermal systems. Cooler water coming from the rain or water which is used by humanbeing seeps into earth's crust. After this water is heated up by hot crust, it goes up to the surface. When heated water is forced to the surface, steam turbine is used to catch the steam. Resulting power from the steam turbine is used to run generator. Generator generates electricity by using this steam. Used vapour is gathered in the condenser and then it is converted to water. This water is sent to earth crust again. Thus, the loop is maintained by the power plants. Geothermal power plants drill their own holes into the rock to more effectively capture the steam and to send obtained water . This system is shown in Figure 4.1.

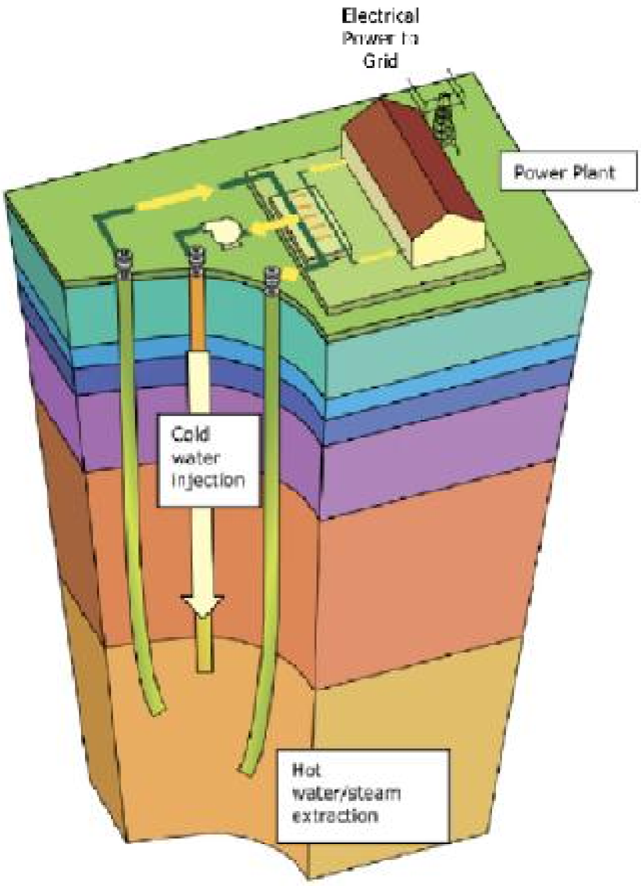

Figure 4.1. Geothermal Energy Generation System (Gallup,2009)

4.1.2. Utilization of Geothermal Energy

Geothermal energy can be utilized as either direct heat or electricity generation, as discussed below:

4.1.2.1. Direct Using of Geothermal Energy

It includes the following applications.

(a) Hydrothermal :

Hydrothermal resources of low to moderate temperature (20° - 150°C) are utilized to provide direct heating in residential, commercial, and industrial sectors. These resources include space heating, water heating, greenhouse heating, heating for aquaculture, food dehydration, laundries,and textile processes.

(b) Agriculture:

Geothermal resources are used worldwide for agricultural production. Water from geothermal reservoirs is used to warm greenhouses to help in cultivation.

(c) Industry:

The heat from geothermal water is used worldwide for industrial purposes. Some of these uses include drying fish, fruits, vegetables and timber products, washing wool, dying cloth, manufacturing paper, and pasteurizing milk. Geothermally heated water can be piped under sidewalks and roads to keep them from icing over in a freezing weather. Thermal waters are also used to help extract gold and silver from ore and even for refrigeration and ice-making (Sheth and Shahidehpour,2004).

4.1.2.2. Electricity Generation (Geothermal Power Plants)

Geothermal power plants use the natural hot water and steam from the earth to turn turbine generators for producing electricity. Unlike fossil fuel power plants, no fuel is burned in these plants. Geothermal power plants give off water vapors but have no smoky emissions. Geothermal electricity is for the base load power as well as the peak load demand. Geothermal electricity has become competitive with conventional energy sources in many parts of the world. The geothermal power plants are listed as follows:

a. Dry steam power plant
b. Flash steam power plant
c. Binary cycle power plant
d. Combined binary/flash power plant

(a) Dry steam power plant

Dry steam power plants are the simplest and most economical technology, and therefore are widespread. The dry steam power plant is suitable where the geothermal steam is not mixed with water. Production wells are drilled down to the aquifer and the superheated, pressurized steam (180 - 350°C) is brought to the surface at high speeds, and passed through a steam turbine to generate electricity. In simple power plants, the low pressure steam output from the turbine is vented to the atmosphere. This improves the efficiency of the turbine and avoids the environmental problems associated with the direct release of steam into the atmosphere. These cycles consume about 15-25 kg of steam per kWh of electricity generated. Dry steam condensing cycles have condensers at the exit of the turbine and cooling towers. The United States and Italy have the largest dry steam geothermal resources in the world. Dry Steam power plant is shown in Figure 4.2 (Sheth and Shahidehpour,2004;Kanoglu,1999).

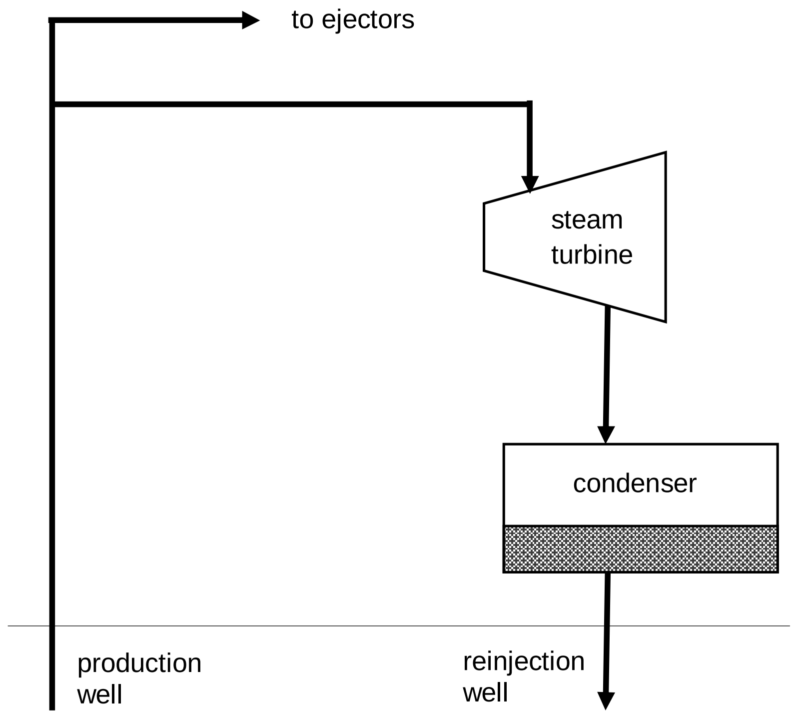

Figure 4.2. Dry-Steam geothermal power plant. (Kanoglu,1999)

(b) Flash steam power plant

Flash steam plants are used to generate power from liquid-dominated resources that are hot enough to flash a significant proportion of the water to steam in surface equipment, either at one or two pressure stages (single-flash or double-flash plants) as shown in Fig. 4.3 and Fig. 4.4.

In a single flash steam technology, hydrothermal resource is in a liquid form. The fluid is sprayed into a flash tank, which is held at a much lower pressure than the fluid, causing it to vaporize (or flash) rapidly to steam. The steam is then passed through a turbine coupled to a generator in dry steam plants. To prevent the geothermal fluid flashing inside the well, the well is kept under high pressure. Flash steam plant generators range from 10 MW to 55 MW; a standard size of 20 MW is used in several countries.

Steam flows through a steam turbine to produce power while the brine is reinjected back to the ground. Steam exiting the turbine is condensed by cooling water obtained in a cooling tower or a spray pond before being reinjected. Steam ejectors are used in all steam condensing cycles to keep vacuum conditions (under atmospheric pressures) in the condensers. Ejectors consume some steam to accomplish their purpose (Sheth and Shahidehpour,2004; Kanoglu,1999).

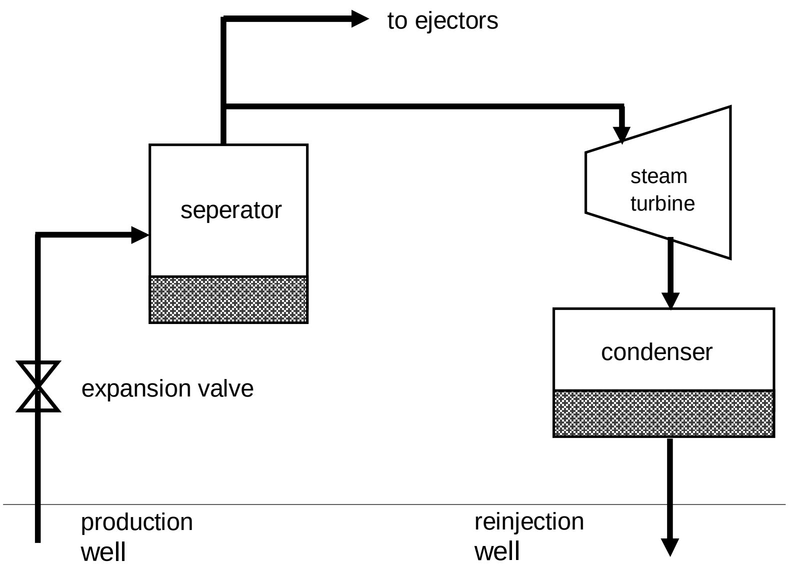

Figure 4.3. Single-Flash geothermal power plant. (Kanoglu,1999)

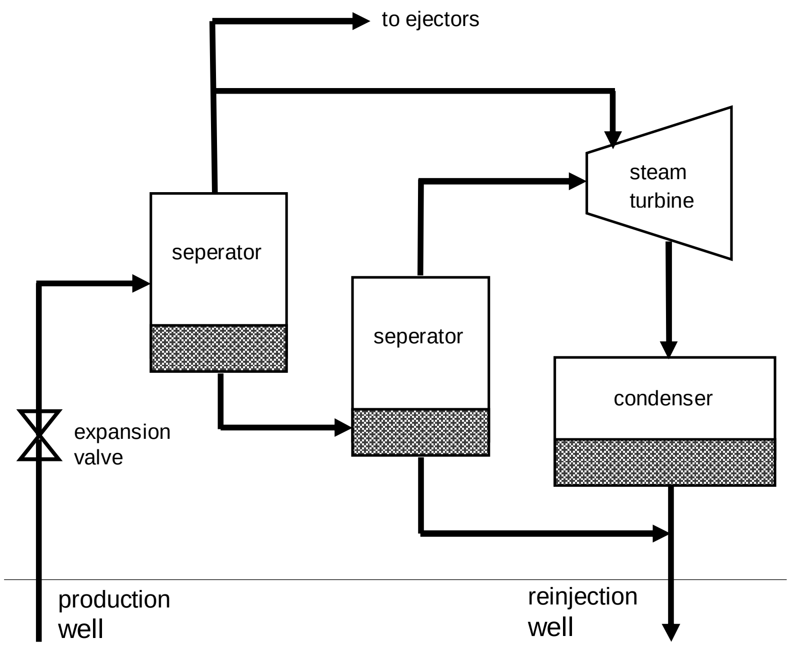

Figure 4.4. Double-Flash geothermal power plant. (Kanoglu,1999)

(c) Binary Cycle power plant

Binary cycle power plants are used where the geothermal resource is insufficiently hot to produce steam, or where the resource contains too many chemical impurities to allow flashing. In addition, the fluid remaining in the tank of flash steam plants can be utilized in binary cycle plants. Binary cycle plants use the geothermal brine from liquid-dominated resources usually below 170°C. In the binary cycle process, the geothermal fluid is passed through a heat exchanger. The secondary fluid which has a lower boiling point than water is vaporized and expanded through a turbine to generate electricity. The working fluid is condensed and recycled for another cycle. All of the geothermal fluid is reinjected into the ground in a closed-cycle system. These plants operate with a binary working fluid that has a low boiling temperature. The working fluid is completely vaporized and usually superheated by the geothermal heat in the vaporizer. The vapor expands in the turbine. It is then condensed in a water-cooled condenser or dry cooling tower before being pumped back to the vaporizer to complete the cycle (Sheth and Shahidehpour,2004; Kanoglu,1999). This system is shown in Figure 4.5

Binary cycle power plants can achieve higher efficiencies than flash steam plants (Sheth and Shahidehpour,2004).

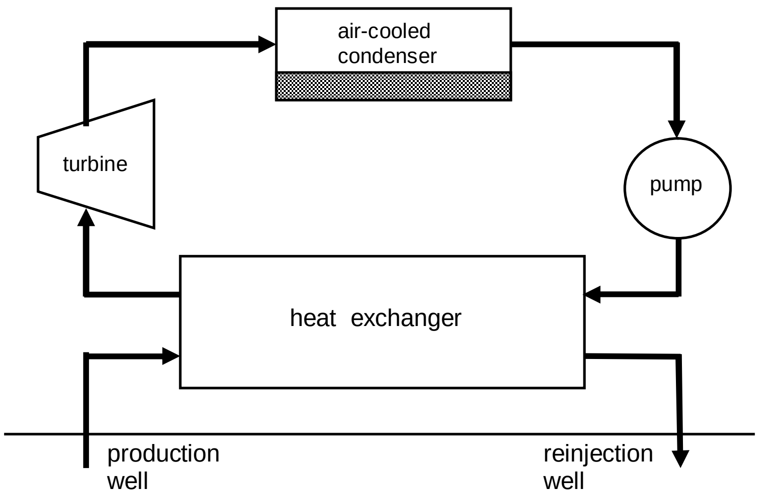

Figure 4.5. Binary-design geothermal power plant. (Kanoglu,1999)

(d) Combined Binary/Flash power plant

Combined flash/binary plants incorporate both a binary unit and a flashing unit to take advantage of advantages associated with both systems as shown in Figure 4.6. The liquid portion of the geothermal mixture serves as the input heat for binary cycle while the steam portion goes through a steam turbine to produce power .

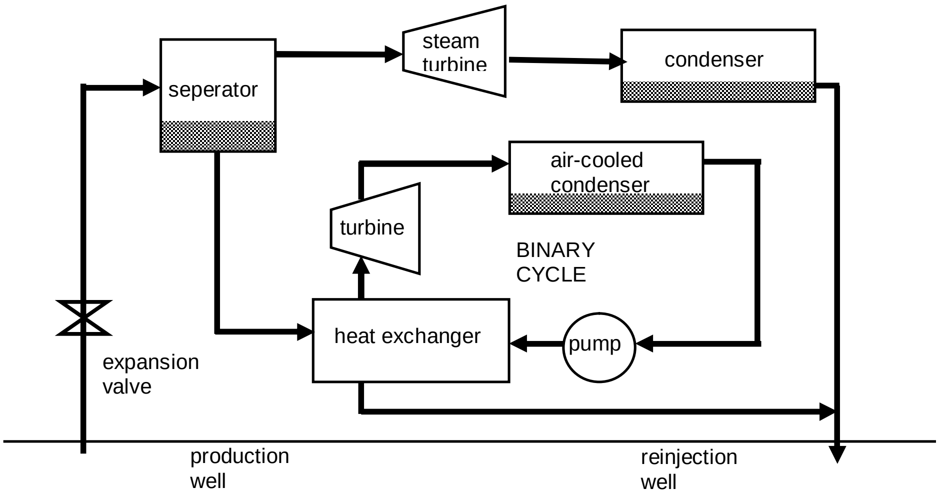

Figure 4.6. Combined binary/flash power plant. (Kanoglu,1999)

4.2. Hydropower Energy

Among all renewable energy sources, hydroelectricity is the most expanded one over the world. It represents almost 94% of the renewable energy production and 20% of worldwide energetic needs. In fact, this is due to high power hydroelectric stations, each of them producing several hundreds of megawatts, which have been built for approximately one century. Nowadays, it is nearly no more possible to settle such a plant in many countries because of suitable site rareness and of environmental concerns. Nevertheless small-scale hydropower has a quite large potential of development because of the increasing interest in renewable energies and dispersed electrical generation. (Ansel and Robyns, 2006).

Hydropower continues to be the most efficient way to generate electricity. Modern hydro turbines can convert as much as 90% of the available energy into electricity. The best fossil fuel plants are only about 50% efficient. Hydro resources are also widely distributed compared with fossil and nuclear fuels and can help provide energy independence for countries without fossil fuel resources. (Yuksek, Yuksel and Kaygusuz, 2006).

4.2.1. Hydropower Stations and Control Methods

The large diversification in behavior of nonlinear plants across its operating points require different control objectives and thus different control actions to be taken for each variation in operating point. The nonlinear dynamic characteristics of hydro plant largely depend on internal and external disturbances, set point changes, leading to shift from its optimum operating point. The schematic of hydropower plant is illustrated in Figure 4.7. (Kishor, Saini and Singh, 2007).

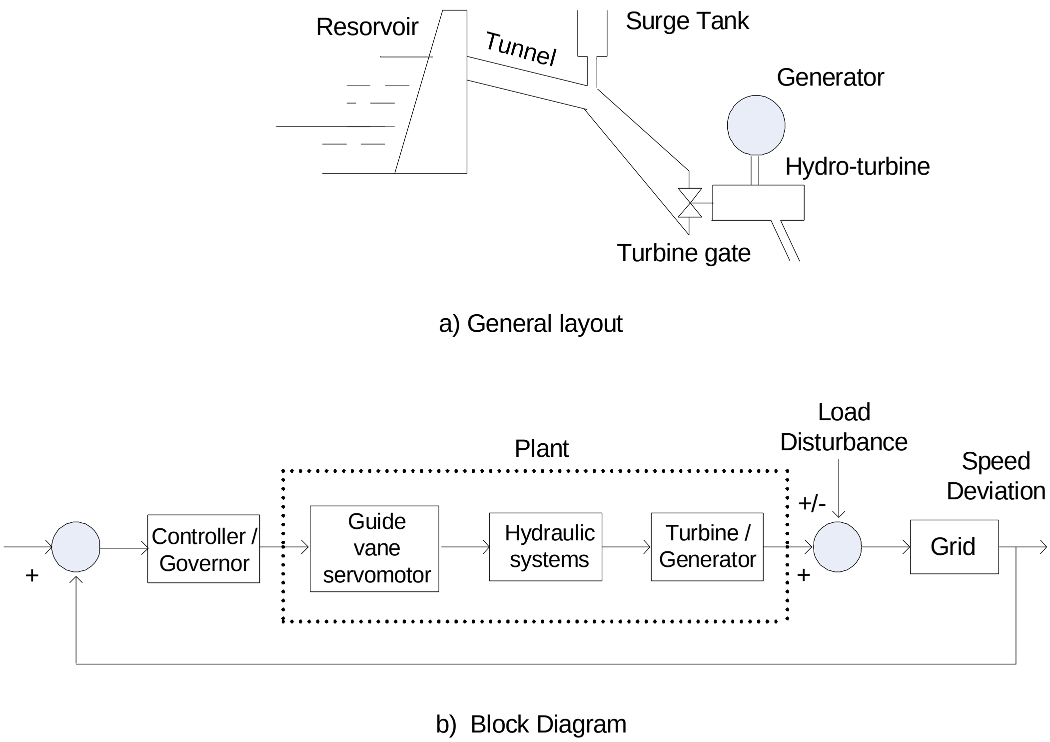

Figure 4.7. Schematic of hydropower plant with its structures and components (a) general layout form (b) block diagram form (Kishor, Saini and Singh, 2007)

A key item of any hydro power plant is the governor. This governing system provides a means of controlling power and frequency. The speed governor includes all those elements, which are directly responsive to speed and position or influence the action of other elements of the speed governing system. The speed control mechanism includes equipment such as relays, servomotors, pressure or power amplifying devices, levers and linkages between the speed governor and governor-controlled gates/vanes. The speed governor normally actuates the governor-controlled gates/vanes that regulate the water input to the turbine through the speed control mechanism. (Kishor, Saini and Singh, 2007)

Conventionally, hydraulic-mechanical governor and electro-hydraulic type with PID controllers are popular in use. The technologies of these governors have developed considerably over the past years. The classical PID is the most common form of controller used in governing. The structure of the PID controller is simple. The three terms of the controller treat the current control error (P), past control error (I), and predicted future control error (D). Its use ensures faster speed response by providing both transient gain reduction/transient gain increase. The derivative term in the control action is important in case of isolated operation. Its use results in excessive oscillation in interconnected system. The transfer function of PID without derivative effect in action is equivalent to that of the hydraulic-mechanical governor. The design is based on linear control theory at one load condition and then de-tuned for worst operating conditions. This controller design does not guarantee the close loop system to remain stable at all operating conditions.

In recent years, digital governors have gradually replaced these analog controllers. Recent developments in the field of control technologies impose a new approach in the turbine control systems with application of artificial intelligence (AI). One of the most discussed applications of artificial intelligence in turbine governing is the replacement of a standard Electro-hydraulic governor with fuzzy logic or neural network or hybrid controller-fuzzy logic and neural network. (Kishor, Saini and Singh, 2007).

4.2.2. Hydropower Station Component Modelling

4.2.2.1. Kaplan water wheel

The turbine model is a basic one i.e. it includes neither blade pitch control nor upstream guide vane one. According to these assumptions, hydraulic turbine behaviour may be taken into account by means of simplified static mechanical characteristics. Indeed the water wheel efficiency depends on this quantity. Turbine torque (T_t) versus speed (Ω) characteristic is assumed to be a straight line. Torque becomes null for a rotating speed value Ω_e , which is the runaway speed i.e. speed when no load torque is applied on the shaft. Ω_e is a turbine parameter and a value of 1.8 times the turbine rated speed Ω_n is assumed. (Ansel and Robyns, 2006).

Torque versus speed characteristic equation under rated water flow and head is given below : (Ansel and Robyns, 2006).

$$T_t = T_n \left(1.8 - \frac{\Omega}{\Omega_n}\right) \quad (4.1)$$

Subscript "n" is used for rated values. Mechanical power (P_m) simplified characteristic is consequently a parabola. This power results from the hydraulic power P_{hyd}, which is expressed as follows:

$$P_{hyd} = pgHq \quad (4.2)$$

where p is the water density, g the gravity acceleration, H the water head and q is the water rate of flow. (Ansel and Robyns, 2006).

4.2.2.2. Shaft

The electromechanical drive speed value leads to the torques applied to the shaft by the turbine and electrical machines according to the fundamental equation:

$$J\frac{d\Omega}{dt} = T_t - T_{ms} - T_{dfig} \quad (4.3)$$

where T_{ms} and T_{dfig} are respectively the PMSM and DFIG torques and J is the moment of inertia of all rotating parts. (Ansel and Robyns, 2006).

4.2.2.3. Permanent magnet synchronous machine

The synchronous machine is modelled using Park method in a reference frame linked to its rotating field. It may be indicated that the transformation chosen does not keep constant power values. (Ansel and Robyns, 2006).

$$v_{dms} = R_{ms} i_{dms} + L_d \frac{di_{dms}}{dt} - w_{ms} L_q i_{qms} \tag{4.4}$$

$$v_{qms} = R_{ms} i_{qms} + L_q \frac{di_{qms}}{dt} - w_{ms}(L_d i_{dms} + \emptyset_f) \tag{4.5}$$

In these equations the subscript “ms” is related to the synchronous machine. Subscripts “d” and “q” refer to direct and quadrature axis. v_{dms} and v_{qms} are PMSM voltage Park components, whereas, i_{dms} and i_{qms} are the current ones. w_{ms} is the voltage and current pulsation. R_{ms}, L_d and L_q represent respectively the machine single phase winding resistance, single phase direct and quadrature axis inductances.

It may be noticed that:

$$e_{dms} = w_{ms} L_q i_{qms} \tag{4.6}$$

$$e_{qms} = w_{ms}\left(L_q i_{dms} + \emptyset_f\right) \tag{4.7}$$

are electromotive forces (emf) resulting from the mathematical coupling between d and q axes. The torque produced by the PMSM is expressed as follows:

$$T_{ms} = \frac{3}{2} p_{ms}\left[\left(L_d - L_q\right) i_{dms} i_{qms} + \emptyset_f i_{qms}\right] \tag{4.8}$$

if p_{ms} is the PMSM number of pole pairs.

This torque acts against the turbine motion when the speed is under synchronism and contributes to drive the DFIG in hypersynchronism mode. That means that the PMSM operates as a generator or a motor according to the rotating speed. (Ansel and Robyns, 2006).

4.2.2.4. Doubly fed induction machine

As the PMSM, the DFIG is modelled using Park method in a reference frame linked to its rotating field (the transformation chosen does not keep constant power values). As a consequence, Equations (4.9) to (4.12) involve the stator pulsation w_s and the rotating magnetic field electric speed relative to the rotor [(w_s - p_{dfig} Ω) p_{dfig}] is the DFIG number of pole pairs.

$$v_{sd} = R_s i_{sd} + \frac{d\emptyset_{sd}}{dt} - w_s \emptyset_{sq} \tag{4.9}$$

$$v_{sq} = R_s i_{sq} + \frac{d\emptyset_{sq}}{dt} - w_s \emptyset_{sd} \tag{4.10}$$

$$v_{rd} = R_r i_{rd} + \frac{d\emptyset_{rd}}{dt} - (w_s - p_{dfig}\Omega)\emptyset_{rq} \tag{4.11}$$

$$v_{rq} = R_r i_{rq} + \frac{d\emptyset_{rq}}{dt} + (w_s - p_{dfig}\Omega)\emptyset_{rd} \tag{4.12}$$

In these equations subscript “s” refer to the stator, whereas, “r” is related to the rotor. Under these conventions, R_s, R_r represent the single phase winding resistances, v_{sd} , v_{sq} , v_{rd} , v_{rq} are voltage components, i_s, i_r, i_d, i_q are current ones.

$$\emptyset_{sd} = L_s i_{sd} + M i_{rd} \tag{4.13}$$

$$\emptyset_{sq} = L_s i_{sq} + M i_{rq} \tag{4.14}$$

$$\emptyset_{rd} = L_r i_{rd} + M i_{sd} \quad (4.15)$$

$$\emptyset_{rq} = L_r i_{rq} + M i_{sq} \quad (4.16)$$

L_s, L_r are cyclic coefficients of self induction, whereas, M is the mutual inductance. (Ansel and Robyns, 2006).

4.3. Wave Energy

The large and growing demand for electrical power and the environmental impact of the current methods of filling that demand are well known. Ocean waves represent a large renewable energy resource which to date is largely unexploited.

Review of existing Wave Energy Converters has found that several general mechanisms have been previously used to absorb wave energy :

1) Oscillating water columns, which use the rise and fall of water within a chamber to drive air through a turbine connected to an electric generator.

2) Oscillating bodies - Buoyant devices, which generate power from the vertical or rotational motion of a float.

3) Overtopping devices, where wave height is increased by focusing and/or shoaling such that the waves will overtop a barrier and fill a reservoir. The reservoir is then drained through a hydro-electric turbine to generate electric power. (Hazlett and Inculet, 2009).

The classification in Table 4.1 is based mostly on working principle. The examples shown are not intended to for man exhaustive list and were chosen among the projects that reached the prototype stage or at least were object of extensive development effort. (Antonio, 2009).

Table 4.1. The various wave energy technologies (Antonio, 2009)

- **Oscillating water column** (with air turbine)
  - Fixed Structure
    - Isolated: **Pico**, **LIMPET**
    - In breakwater: **Sakata, Mutriki**
  - Floating: **Mighty Whale, Ocean Energy, Sperboy, Oceanlinx**
- **Oscillating bodies** (with hydraulic motor, hydraulic turbine, linear electric generator)
  - Floating
    - Essentially translation (heave): **Aqua Buoy, IPS Buoy, FO_3, Wavebob, Powerbuoy**
    - Essentially rotation: **Pelamis, PS Frog, SEAREV**
  - Submerged
    - Essentially translation (heave): **AWS**
    - Rotation (bottom-hinged): **WaveRoller, Oyster**
- **Overtopping** (with low-head hydraulic turbine
  - Fixed Structure
    - Shoreline (with concentration): **TAPCHAN**
    - In breakwater (without concentration): **SSG**
  - Floating Structure (with concentration): **Wave Dragon**

4.3.1. Oscillating water column Systems

The oscillating water column (OWC) device comprises a partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water free surface (Figure 4.8). The oscillating motion of the internal free surface produced by the incident waves makes the air to flow through a turbine that drives an electrical generator. (Antonio, 2009).

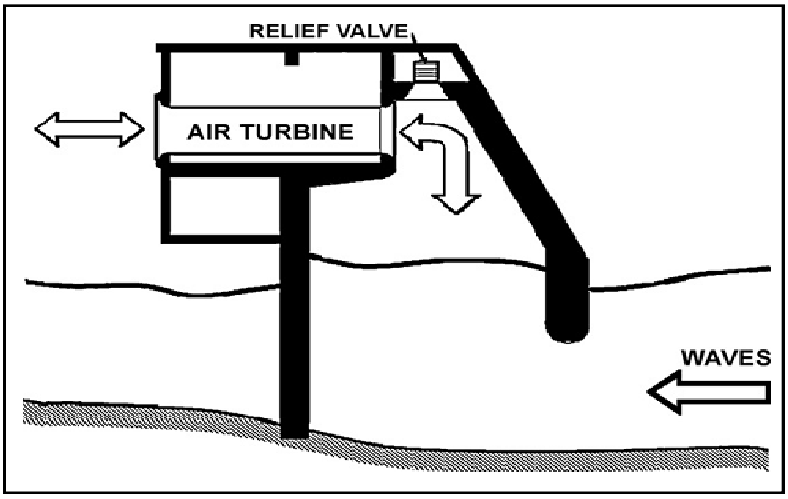

Figure 4.8. Cross-sectional view of a bottom-standing OWC (Antonio, 2009)

4.3.2. Oscillating body systems

Offshore devices (sometimes classified as third generation devices) are basically oscillating bodies, either floating or (more rarely) fully submerged. They exploit the more powerful wave regimes available in deep water (typically more than 40 m water depth). Offshore wave energy converters are in general more complex compared with first generation systems. This, together with additional problems associated with mooring, access for maintenance and the need of long underwater electrical cables, has hindered their development, and only recently some systems have reached, or come close to, the full-scale demonstration stage.

The simplest oscillating-body device is the heaving buoy reacting against a fixed frame of reference (the sea bottom or a bottom-fixed structure). In most cases, such systems are conceived as point absorbers (i.e. their horizontal dimensions are much smaller than the wavelength). (Antonio, 2009)

Figure 4.9. Norwegian heaving buoy in Trondheim Fjord, 1983. (Antonio, 2009)

The system with a heaving buoy driving a linear electrical generator was recently developed at Oregon State University, USA. It consists of a deep-draught spar andanannular saucer-shaped buoy (Figure 4.10). The spar is taut-moored to the sea bed by a cable. The buoy is free to heave relative to the spar, but is constrained in all other degrees of freedom by a linear bearing system. The forces imposed on the spar by the relative velocity of the two bodies is converted into electricity by a permanent magnet linear generator. The spar is designed to provide sufficient buoyancy to resist the generator force inthe downdirection. (Antonio, 2009).

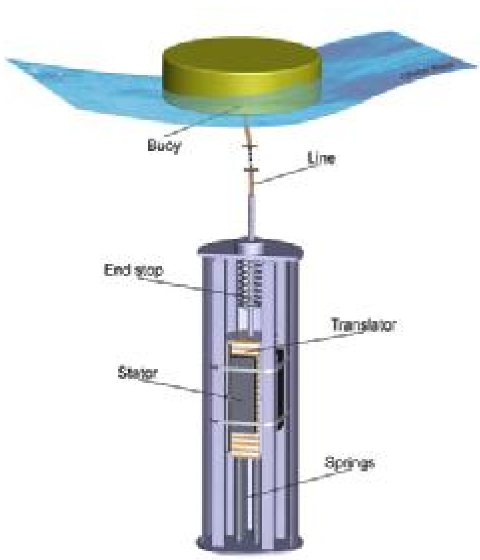

Figure 4.10. Buoy with linear electrical generator (Antonio, 2009)

The generator piston is driven by the motion of the buoy and counteracted by a spring, see Figure 4.10. The whole generator is fixed at the seabed with the help of a massive fundament. During a storm, the buoy will/may at some stage be submerged, limiting the power transmitted to the energy converter. The remaining over power is handled electrically since, this is superior to a mechanical power control.

The design of the linear generator is highly dependent on the local wave climate. Different design options, found through electromagnetic field simulations, have been reported for mild to heavy ocean climates. However, up to now, there has been no report on experimental results from a multisided permanent magnetized three-phase cable wounded linear generator. Each direct wave energy converter will produce a highly irregular altering current (AC), following from the reciprocal wave motion. From a system perspective, this current needs to be rectified into direct current (DC) before the plant is connected to the grid. (Leijon, Danielson, Eriksson, Thorburn, Bernhoff, Isberg, Sundberg, Ivanova, Sjostedt, Agren, Karlsson and Wolfbrandt, 2006).

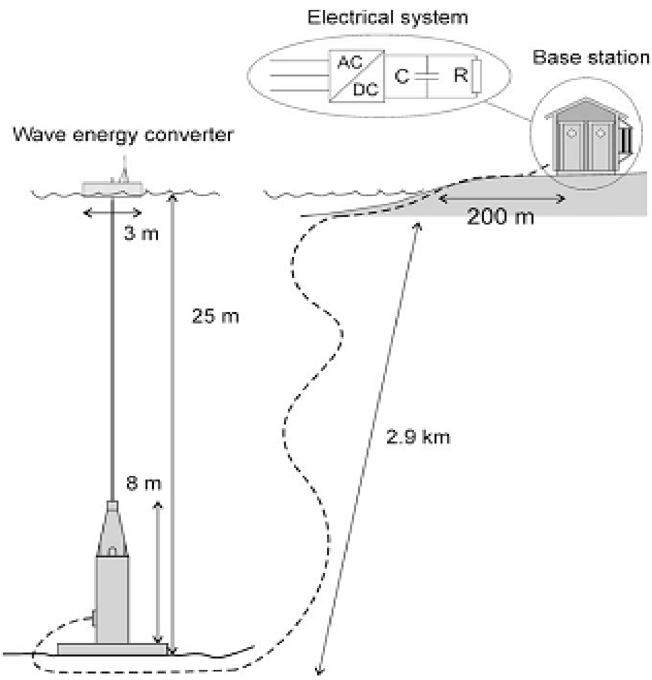

Figure 4.11. Schematic figure of wave energy converter and electrical system (Bostrom, Lejerskog, Stalberg, Thorburn And Leijon, 2009)

There are different options for the electrical interconnection of an array of linear energy converters. Most of these deal with rectification and parallel connection on the DC-side. Rectification can be achieved by, e.g. diodes, thyristors or IGBT's (Insulated Gate Bipolar Transistors). The final choice depends on the actual generator topology. For example, a synchronous linear generator with permanent magnets designed for a low load angle can operate with a diode rectifier, which is cheap, robust and have relatively low losses.

At the same time, the choice and the control of the interconnection scheme will directly affect the mechanical damping of the individual energy converter. Thus the array behaviour will depend not only on the linear generators, but also on the actual interconnection scheme and control algorithms governing the latter. The approach so far has been to rectify the raw power into a DC voltage, as shown in Figure 4.12. The same approach is used for other sources like under water kinetic energy conversion since it is a simple, low cost method with additional benefits regarding DC-transmission. At the grid connection a DC/AC converter suited for the correct voltage has to be implemented. Studies reveal that the DC voltage at different wave climates plays an important role in the optimisation of the whole electric production system. (Leijon, Danielson, Eriksson, Thorburn, Bernhoff, Isberg, Sundberg, Ivanova, Sjostedt, Agren, Karlsson And Wolfbrandt, 2006).

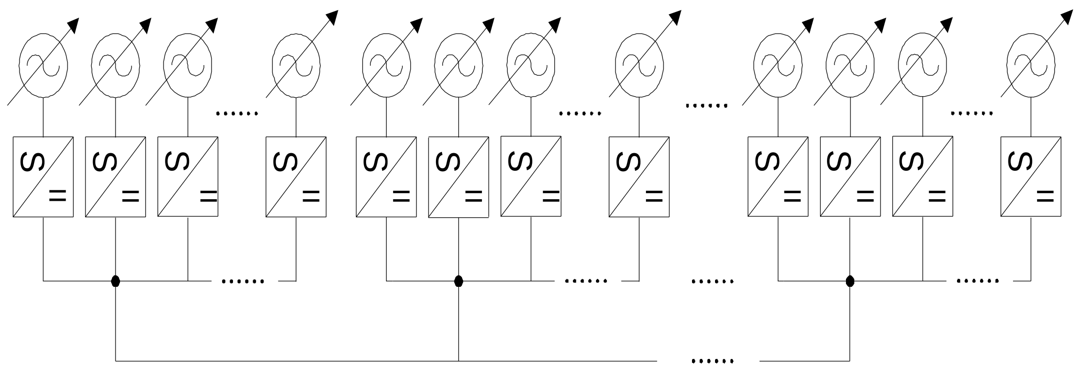

Figure 4.12. An example of cluster configuration. Each circle represents a wave energy converter producing a highly irregular alternating current (AC). (Leijon, Danielson, Eriksson, Thorburn, Bernhoff, Isberg, Sundberg, Ivanova, Sjostedt, Agren, Karlsson And Wolfbrandt, 2006).

4.3.2.1. Rectifier and Filter

The voltage variation in amplitude and frequency from the generator mainly depends upon two things. Primarily, the translator moves in a similar fashion as the buoy. The buoy motion is dependent upon the length, height and shape of the wave. The translator will reach zero speed at the upper and lower turning points of its motion and no voltage will be induced at these points. Secondly, as the dampening of the generator is changed, the translator speed will be changed, and hence buoy motion.

A filter that is made up of capacitors is proposed for this system. It is designed to reduce the fluctuations mentioned above to ensure a smooth DC voltage. If the filter had to be designed to handle the variation in power over an hour time scales, the filterwould have to be unreasonably large. Another problem would be the reduced control of the DC voltage for power output optimization. The value of filter capacitance, C, can be calculated using the fundamental equations.

$$C = \frac{Q}{V} \tag{4.17}$$

$$I = \frac{dQ}{dt} \tag{4.18}$$

$$E = C\frac{V^2}{2} \tag{4.19}$$

Where Q is the electric charge, V is the voltage, I is the current and E is the energy. Assuming that the energy, ΔE is taken from the capacitor:

$$\Delta E = \frac{1}{2}CV^2 - \frac{1}{2}CV_{min}^2 \tag{4.20}$$

The power, P, can be expressed as : (Bostrom, Lejerskog, Stalberg, Thorburn And Leijon, 2009)

$$P = \frac{\Delta E}{\Delta t} \tag{4.21}$$

and finally, by using Equations (4.20) and (4.21) and Ohm's law an expression for the capacitance can be written as :

$$C = \frac{2P\Delta t}{V_{max}^2 - V_{min}^2} \tag{4.22}$$

where P is the generated power, V_{max} is the maximumvoltage, V_{min} is the minimum tolerated voltage and Δt is the acceptable discharge time, the time between V_{max} and V_{min}.

The simulation of the system is described in (Bostrom, Lejerskog, Stalberg, Thorburn And Leijon, 2009). The rectifier used in the simulations and experiments is a six-pulse passive diode rectifier. This choice was made because of their high efficiency and their simplicity compared to active rectifiers. Diodes only let through current in one direction, this prevent the generators from affecting each other during normal operation. (Bostrom, Lejerskog, Stalberg, Thorburn And Leijon, 2009).

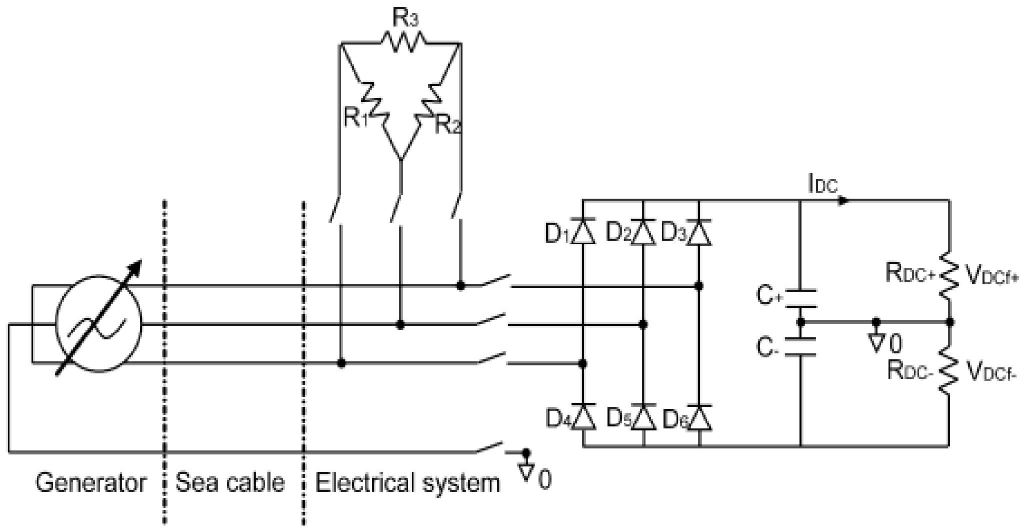

Figure 4.13. Installed electrical system in the measuring station. The generator can either be connected to a delta coupled resistive load or connected to a diode rectifier, capacitor filter and DC-resistors. (Bostrom, Lejerskog, Stalberg, Thorburn and Leijon, 2009)

4.3.2.2. Pitching devices

The oscillating-body wave energy converters briefly described above are nominally heaving systems, i.e. the energy conversion is associated with a relative translational motion. (It should be noted that, in some of them the mooring system allows other oscillation modes, namely surge and pitch). There are other oscillating-body systems in which the energy conversion is based on relative rotation (mostly pitch) rather than translation.

The first versions consisted of a string of Ducks mounted on a long spine aligned with the wave crest direction, with a hydraulic-electric PTO system. Salter later proposed the solo duck, in which the frame of reference against which the nodding duck reacts is provided by a gyroscope (Figure 4.14). Although the Duck concept was object of extensive R&D efforts for many years, including model testing at several scales, it never reached the stage of full-scale prototype in real seas. (Antonio, 2009).

Figure 4.14. The Duck version of 1979 equipped with gyroscopes (courtesy of University of Edinburgh) (Antonio, 2009)

4.3.3. Overtopping converters

A different way of converting wave energy is to capture the water that is close to the wave crest and introduce it, by over spilling, into a reservoir where it is stored at a level higher than the average free-surface level of the surrounding sea. The potential energy of the stored water is converted into useful energy through more or less conventional low-head hydraulic turbines. The hydrodynamics of overtopping devices is strongly non-linear, and, unlike the cases of oscillating body and OWC wave energy converters, cannot be addressed by linear water wave theory. (Antonio, 2009).

4.3.3.1. Power equipment

The electrical to be supplied to a grid, has to be generated in some kind of electrical machine, either a more or less conventional rotating generator (as in small hydro and wind applications) or a direct-drive linear generator. In the former case, there has to be a mechanical interface that converts the alternative motion (of the oscillating body or body-pair or of the OWC) into a continuous one-directional motion. The most frequently used or proposed mechanical interfaces are air turbines, (low and high-head) water turbines and (high-pressure oil driven) hydraulic motors. The power equipment is possibly the singlemost important element in wave energy technology, and underlies many (possibly most) of the failures to date.

Air turbines equipped most of the early (small and large) wave energy converters and are still the favoured PTO for many development teams. Conventional turbines are not appropriate for reciprocating flows, and so new types of turbines had to be devised and developed. Self-rectifying air turbines were probably the object of more published papers than any other piece of equipment for wave energy converters.

More or less conventional low-head hydraulic turbines are used in overtopping devices, whereas high-head (in general Pelton) turbines are an alternative to hydraulic motors in oscillating-body devices.

High-pressure-oil circuits, with rams, gas accumulators and hydraulicmotors, have been used in several oscillating-body wave energy converter prototypes, including the Pelamis. This may be regarded as an unconventional use of conventional equipment. (Antonio, 2009).

4.4. Tidal Energy

4.4.1. General Information

Tidal energy is the energy dissipated by tidal movements, which derives directly from the gravitational and centrifugal forces between the earth, moon and sun. A tide is the regular rise and fall of the surface of the ocean due to the gravitational force of the sun and moon on the earth and the centrifugal force produced by the rotation of the earth and moon about each other .

Tidal currents are experienced in coastal areas and in places where the sea bed forces the water to flow through narrow channels. These currents flow in two directions; the current moving in the direction of the coast is known as the flood current and the current receding from the coast is known as the ebb current. The current speed in both directions varies from zero to a maximum. The zero current speed refers to the slack period, which occurs between the flood and ebb currents. The maximum current speed occurs halfway between the slack periods. These tidal variations, both the rise and fall of the tide and the flood and ebb currents, can be utilised to generate electricity.

4.4.2. Generating Electricity for Tidal

Tidal power production applies the same principles as hydroelectric power generation, except that tides flow in both directions and generators are designed to respond to two directional water flows. Tidal energy consists of potential and kinetic components. Tidal power facilities can be categorised into two main types: tidal barrages and tidal current turbines, which use the potential and kinetic energy of the tides, respectively (Rourke,Boyle and Reynolds,2010 ; Sheth and Shahidehpour, 2005).

4.4.2.1. Tidal Barrages

Tidal barrages make use of the potential energy of the tides. A tidal barrage is typically a dam, built across a bay or estuary that experiences a tidal range in excess of 5 m. Electricity generation from tidal barrages employs the same principles as hydroelectric generation, except that tidal currents flow in both directions. A typical tidal barrage consists of turbines, sluice gates, embankments and ship locks. The turbines that are used in tidal barrages are either unidirectional or bi-directional, and include bulb turbines, straflo or rim turbines and tubular turbines . Tidal barrages can be broken into two types: single-basin systems and double-basin systems. (Rourke,Boyle and Reynolds,2010 ; Rourke,Boyle and Reynolds,2009b)

(a) Single-basin tidal barrages

Single-basin systems consist of one basin and require a barrage across a bay or estuary. There are three methods of operation for generating electricity within a single basin.

- Ebb generation
- Flood generation
- Two-way generation

Ebb generation **–** The simplest generating system for tidal plants in ebb generating system as shown in Figure 4.15. The basin is filled with water through the sluice gates during the flood tide. At high tide, the sluice gates are closed, trapping the water in the basin. At this point extra water can be pumped into the basin at periods of low demand, typically at night when electricity is cheap. The turbine gates are kept closed until the tide has ebbed sufficiently to develop a substantial hydrostatic head across the barrage . The water is let flow out through low-head turbines, generating electricity for several hours until the hydrostatic head has dropped to the minimum level at which the turbines can operate efficiently. (Rourke,Boyle and Reynolds,2010 ; Sheth and Shahidehpour, 2005).

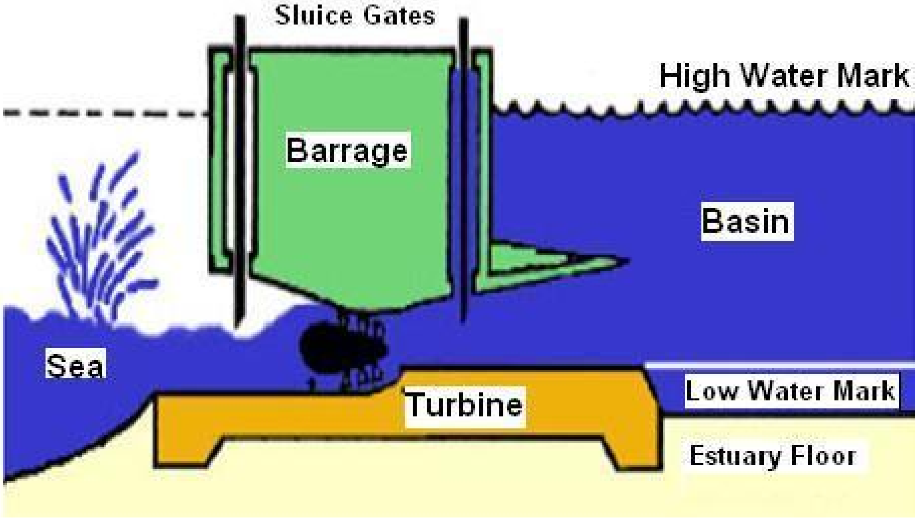

Figure 4.15. Ebb generating system with a bulb turbine (Sheth and Shahidehpour, 2005)

Flood generation - During the flood tide the sluice gates and turbines are kept closed until a substantial hydrostatic head has developed across the barrage. Once the sufficient hydrostatic head is achieved, the turbine gates are opened allowing the water to flow through them into the basin. Flood generation is a less favourable method of generating electricity due to effects on shipping and the environment. These effects on shipping and the environment are caused by the average decrease in sea level within the basin.

Two-way generation - This method of operation utilises both flood and ebb phases of the tide to generate electricity. The sluice gates and turbines are kept closed until near the end of the flood cycle. After this point the water is allowed to flow through the turbines, generating electricity. When the minimum hydrostatic head for generating electricity is reached the sluice gates are then opened. At high tide, the sluice gates are closed and the water is trapped behind the barrage until a sufficient hydrostatic head is reached once again. Water is then allowed to flow through the turbines to generate in the ebb mode. Two-way generation has the advantage of a reduced period of non-generation and a reduction in the cost of generators due to lower peak power.

(b) Double-basin tidal barrages :

Double-basin systems consist of two basins. The main basin is basically the same as that of an ebb generation single-basin system. The difference between a double-basin system and a single-basin system is that a proportion of the electricity generated during the ebb phase is used to pump water into the second basin, allowing an element of storage; therefore this system can adjust the delivery of electricity to match consumer demands.

The major advantage double-basin systems have over singlebasin systems is the ability to deliver electricity at periods of high electricity demand. However, double-basin systems are unlikely to become feasible due to the inefficiencies of low-head turbines. High construction costs of double-basin systems due to the extra length of the barrage may also restrict the development of this system (Rourke,Boyle and Reynolds,2010).

The following types of turbines are used for tidal power generation.

Bulb Turbines **-** water flows around the turbine (Figure 4.16), which makes the maintenance difficult, as the water must be prevented from flowing past the turbine and into the generator. **(**Sheth and Shahidehpour, 2005)

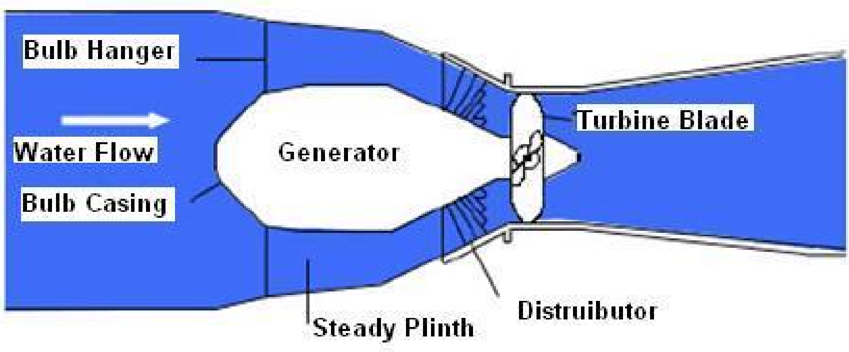

Figure 4.16 Bulb turbine **(**Sheth and Shahidehpour, 2005)

Rim Turbines - Rim turbines (Figure 4.17), also known as the Straflo turbine, reduces the problems encountered by bulb turbine as generator is mounted on the barrage at right angles to turbine blades. Despite that, it is difficult to egulate the performance of Rim turbines which are not unsuitable for pumping either **.**

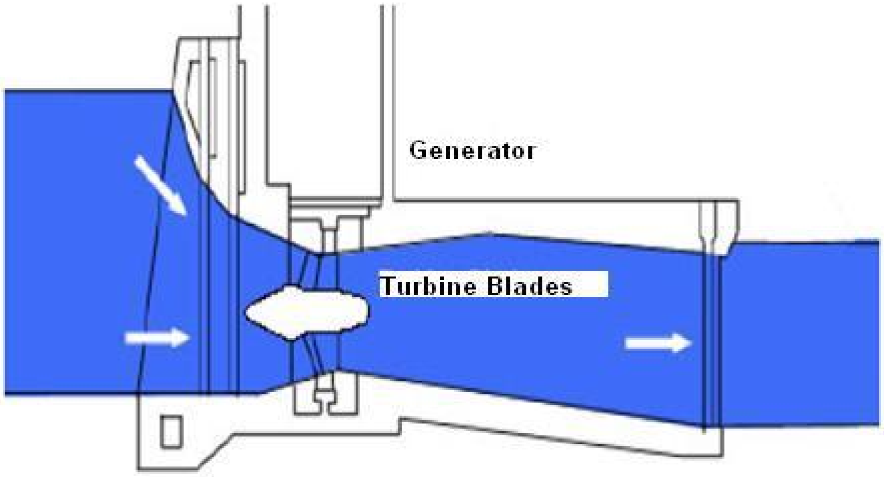

Figure 4.17 Rim turbine **(**Sheth and Shahidehpour, 2005)

Tubular Turbines - In this turbine (Figure 4.18), the generator is on the top of the barrage and the blades are connected to a long shaft.

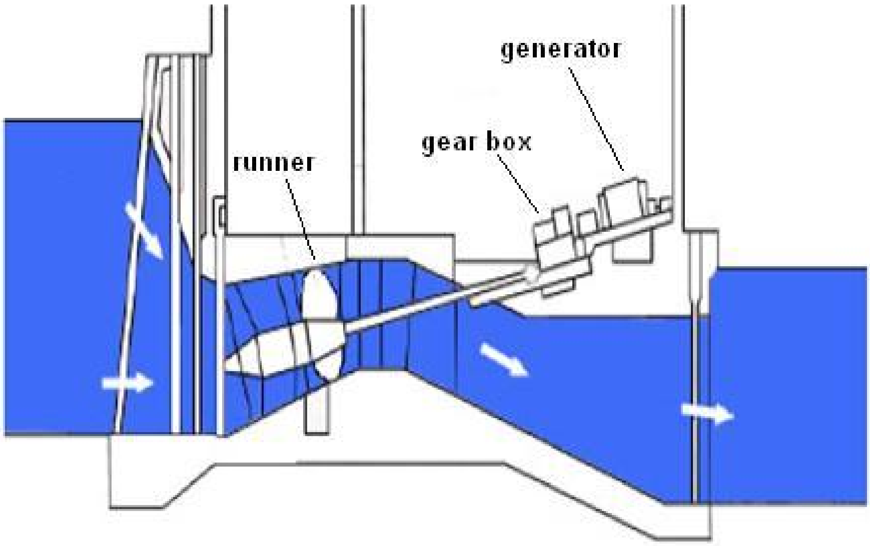

Figure 4.18 Tubular turbine (Sheth and Shahidehpour, 2005)

4.4.2.2. Tidal Current Turbines

Tidal current turbines extract the kinetic energy in moving water to generate electricity. Tidal current technology is similar to wind energy technology. However there are several differences in the operating conditions. Under similar conditions water is 832 times more dense than air and the water flow speed generally is much smaller . Since tidal current turbines operate in water, they experience greater forces and moments than wind turbines. Tidal current turbines must be able to generate during both flood and ebb tides and be able to withstand the structural loads when not generating electricity.

The following two methods of tidal current energy extraction are the most common:

- **Horizontal axis tidal current turbines**. The turbine blades rotate about a horizontal axis which is parallel to the direction of the flow of water.
- **Vertical axis tidal current turbines**. The turbine blades rotate about a vertical axis which is perpendicular to the direction of the flow of water.

In its simplest form a tidal current turbine consists of a number of blades mounted on a hub (together known as the rotor), a gearbox, and a generator. The hydrodynamic effect of the flowing water past the blades causes the rotor to rotate, thus turning the generator to which the rotor is connected via a gearbox. The gearbox is used to convert the rotational speed of the rotor shaft to the desired output speed of the generator shaft. The electricity generated is transmitted to land through cables .

There are three main support structure options when considering installing a tidal current turbine. The first of these is known as a gravity structure which consists of a large mass of concrete and steel attached to the base of the structure to achieve stability . The second option is known as a piled structure which is pinned to the seafloor using one or more steel or concrete beams. The third option is known as a floating structure. The floating structure is usually moored to the seafloor using chains or wire. The turbine in this case is fixed to a downward pointing vertical beam, which is fixed to the floating structure (Rourke,Boyle and Reynolds,2010).

4.4.3. Network Integration

Tidal Turbines can also be used at marines or in a sea . Tidal energy is similar to wave energy. The network integration issues associated with Marine Current Energy Devices (tidal turbines and the similar devices) are similar to onshore renewable energy technologies, such as stability losses and reactive power compensation. Network integration can be separated into three divisions: transmission, grid connections and submarine cables (Rourke,Boyle and Reynolds, 2009a).

4.4.3.1 Transmission

The electricity generated by Marine current energy devices needs to be transmitted to the mainland. This electricity needs to be stepped up to a higher voltage to minimise transmission losses. The size of the step-up transformer is dependent on the distance from the shore and the power capacity of the marine current system. There are two different options available to achieve offshore electrical power transmission: high voltage alternating current (HVAC) and high voltage direct current.(HVDC). The HVAC system basically transmits electrical power as AC at a high voltage. This type of transmission system is a mature and reliable technology. The HVAC system is the most widely used transmission system to transport electrical power.

4.4.3.2. Grid connection

Electricity demand varies with time throughout the day, with peak demand occurring at certain intervals. Matching supply with demand is an important aspect of the integration of renewable energy technologies. Marine current energy has the advantage of being predictable and reliable, unlike other renewable energy sources. For economic exploitation of marine current energy, a reliable grid is essential. Poor grid stability can result in significant losses; this deficiency could limit the generating capacity of even the major identified sites . This will become more critical if the penetration rate is high. For MCEDs load demand is never near the renewable resource, and therefore, transmission losses are unavoidable. A decision also needs to be made if deep reinforcement is required instead of a shallow connection. The deep reinforcement is basically the additional hardware required to the downstream network as a consequence of adding the extra generation capacity.

A definitive time period is required for starting the generators and synchronising with the grid. The fluctuations in the load can be predicted beforehand; therefore a decision can easily be made as to what system is utilised at any given time. The use of asynchronous generators on MCEDs may place a strain on the grid. Asynchronous generators, instead of supplying reactive power to the grid, absorb reactive power from the grid. It is already known from wind turbine technologies that low frequency operation also affects the output power into the grid, as the output frequency has to be maintained relatively close to 50 Hz.

4.4.3.3. Submarine Cable

The type of cable used affects the cost and installation of the system. The fundamental structure of a submarine cable consists of a conductive core, which is a circular section formed with treaded wires carrying the current. For medium and high voltage applications the material used is copper, although, sometimes aluminium is used but it is not as efficient. The cable also consists of electrical insulation which is characterised by the material; either oil impregnated paper or extruded plastic. The use of alternative cross-linked polyethylene cable in submarine cable looks promising. It is cheaper to manufacture, has better bending properties, higher mechanical resistance and lower in weight than other cables.

Another of the major issues associated with submarine cable installation is the decision to bury or lay the cables on the sea floor. The cost of installation can be greater than the cost of the cable in some cases. Special machines are necessary for installing these cables; these machines are able to operate at depths of 1000 m. The Marine current or tidal turbine device needs to be connected to the cable lying in the seabed, whether it is a floating structure or a fixed structure. For floating structures the cable itself is not capable of withstanding the loads it will be subjected to. J-tubes, which are conduits that extend down with large bends to the seafloor, offer protection to the cable (Rourke, Boyle and Reynolds, 2009a).

4.5. Biomass Energy

Energy from biomass is recognized as the renewable energy source with the highest potential towards sustainable development in the near future. Biomass provides already 14% of the world-wide primary energy production. To exploit the full potential of this energy source, new approaches and modern technologies are needed. (Velden, Baeyens and Boukis, 2008).

Biomass includes all organic matter that is available on a renewable basis: energy crops and all kinds of organic wastes. Now and in the near future waste products from agriculture and forestry, easy and cheap to collect, will dominate as source for bio-energy. In the European Union wood waste accounts for 94% of the currently used biomass for energy. In the medium and long term, residues from agriculture and forestry, and energy crops will respectively further develop the bio-energy industry. (Velden, Baeyens, Brems, Janssens and Dewil, 2010).

Biomass can be converted into useful forms of energy using a number of different processes. Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock; the desired form of the energy,i.e. end-use requirements; environmental standards; economic conditions; and project specific factors.

Biomass can be converted into three main products: two related to energy power/heat generation and transportation fuels – and one as a chemical feedstock. Conversion of biomass to energy is undertaken using two main process technologies: thermo-chemical and bio-chemical/biological. (Mckendry, 2002).

4.5.1. Thermo-chemical conversion

Three main processes are used for the thermo-chemical conversion of biomass, together with two lesser-used options.

4.5.1.1. Combustion

The burning of biomass in air,i.e. combustion,is used over a wide range of outputs to convert the chemical energy stored in biomass into heat,mechanical power, or electricity using various items of process equipment,e.g. stoves, furnaces, boilers, steam turbines, turbo-generators,etc. Combustion of biomass produces hot gases at temperatures around 800–1000 ^oC. (Mckendry, 2002).

4.5.1.2. Gasification

Gasification is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperatures, typically in the range 800–900 ^oC. The product gas can be used as a feedstock (syngas) in the production of chemicals (e.g. methanol).

4.5.1.3. Pyrolysis

Pyrolysis is the conversion of biomass to liquid (termed bio-oil or bio-crude), solid and gaseous fracions, by heating the biomass in the absence of air to around 500 ^oC. Figure 4.19 depicts the range and possible yields of pyrolysis energy products. Pyrolysis can be used to produce predominantly bio-oil if flash pyrolysis is used,enabling the conversion of biomass to bio-crude with an efficiency of up to 80%. (Mckendry, 2002).

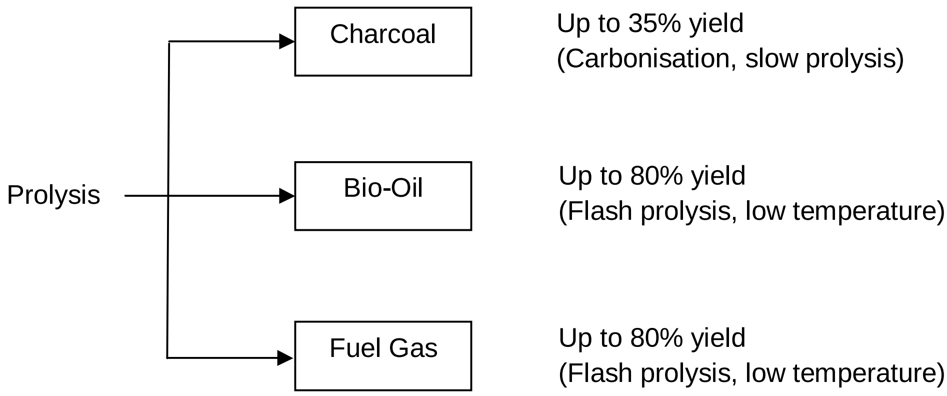

Figure 4.19. Energy products from prolysis (Mckendry, 2002)

Figure 4.20 shows an experimental prolysis process described in (Velden, Baeyens and Boukis, 2008). In the figure, the riser (2) has an internal diameter of 80mm and is 3.8m high. At the bottom a bubbling fluidized bed (1) burns the formed and separated char. The char combustion gas is used as fluidization gas in the riser. Dry spruce (<300 µm) is fed (up to 12 kgh^{-1}) at a height of 1.4 m from the bottom. At start-up, the riser was electrically preheated. After the cyclone (3), the gas and vapours are further de-dusted in an impingement separator (4) and the pyrolysis oil is condensed. The shell-and-tube condenser (6) is cooled with water (at 20 ^{o}C). The residual gas flow is filtered (7) and emitted to the atmosphere. The by-pass (5) is only used in case of operational problems. The downcomer (8) recycles the bed material (sand) and the char via an L-valve to the char combustor. (Velden, Baeyens and Boukis, 2008).

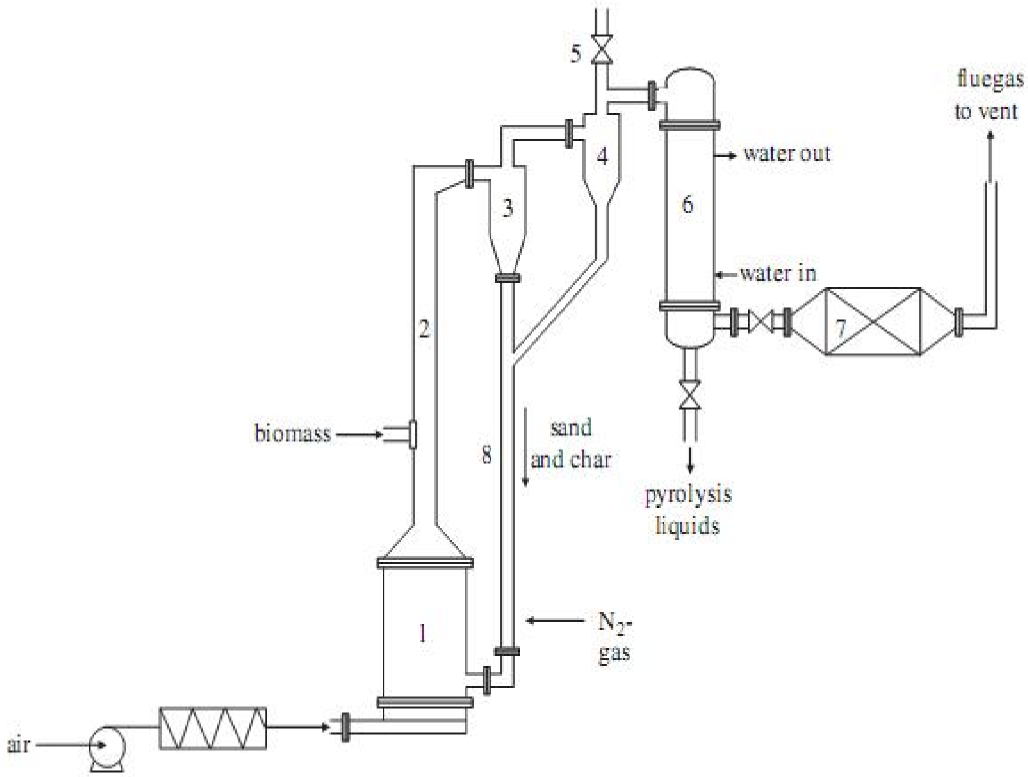

Figure 4.20. Prolysis process (Velden, Baeyens and Boukis, 2008)

4.5.1.4. Other processes

Other processes that produce bio-oils are hydro thermal upgrading (HTU) and liquefaction. HTU converts biomass in a wet environment at high pressure to partly oxygenated hydrocarbons: the process is believed to be almost at the pilot stage. The interest in liquefaction is low because the reactors and fuel-feeding systems are more complex and more expensive than pyrolysis processes.

4.5.2. Bio-chemical conversion

Two main processes used are fermentation and an-aerobic digestion (AD), together with a lesser-used process based on mechanical extraction/chemical conversion.

4.5.2.1. Fermantation

Fermentation is used commercially on a large scale in various countries to produce ethanol from sugar crops (e.g. sugar cane,sugar beet) and starch crops (e.g. maize, wheat). The biomass is ground down and the starch converted by enzymes to sugars, with yeast then converting the sugars to ethanol. Purification of ethanol by distillation is an energy-intensive step,with about 450 liter of ethanol being produced per ton of dry corn. The solid residue from the fermentation process can be used as cattle-feed and in the case of sugar cane, the bagasse can be used as a fuel for boilers or for subsequent gasification.

The conversion of lignocellulosic biomass (such as wood and grasses) is more complex,due to the presence of longer-chain polysaccharide molecules and requires acid or enzymatic hydrolysis before the resulting sugars can be fermented to ethanol. Such hydrolysis techniques are currently at the pre-pilot stage.

4.5.2.2. Anaerobic digestion (AD)

Anaerobic digestion (AD) is the conversion of organic material directly to a gas,termed biogas, a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulphide. The biomass is converted by bacteria in an anaerobic environment, producing a gas with an energy content of about 20–40% of the lower heating value of the feedstock.

4.5.2.3. Mechanical extraction

Extraction is a mechanical conversion process used to produce oil from the seeds of various biomass crops, such as oilseed rape, cotton and groundnuts. The process produces not only oil but also a residual solid or ‘cake’, which is suitable for animal fodder. Three tons of rapeseed are required per ton of rape-seed oil produced. (Mckendry, 2002).

4.6. Hydrogen Energy

Fossil fuels (i.e.petroleum, natural gas and coal), which meet most of the world’s energy demand today, are being depleted fast. Also, their combustion products are causing the global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution, which are posing great danger for our environment and eventually for the life in our planet. Many engineers and scientists agree that the solution to these global problems would be to replace the existing fossil fuel system by the hydrogen energy system. Hydrogen’s combustion will produce no greenhouse gases, no ozone layer depleting chemicals, little or no acid rain ingredients and pollution. Hydrogen, produced from renewable energy sources, would result in a permanent energy system, which we would never have to change.

In comparing the fuels, it is important to take into account the utilization efficiencies at the user end. For utilization by the user, fuels are converted to various energy forms, such as thermal, mechanical and electrical. Studies show that in almost every instance of utilization, hydrogen can be converted to the desired energy form more efficiently than other fuels. When we look at the fuel options critically under the criteria given above, it becomes clear that hydrogen is the best transportation fuel, the most versatile fuel, the most efficient fuel and the safest fuel. In summary, hydrogen is the best fuel. (Veziroglu and Sahin, 2008).

An energy system dominated by electrical power has to be as flexible as present fosil fuel systems. (Figure 4.22)

The required new storage and transportation system has to meet the requirements of the customers. The energy carrier hydrogen fits into this system; hydrogen can be used in almost all paths of our energy system for stationary applications and mobile applications. (Figure 4.23)

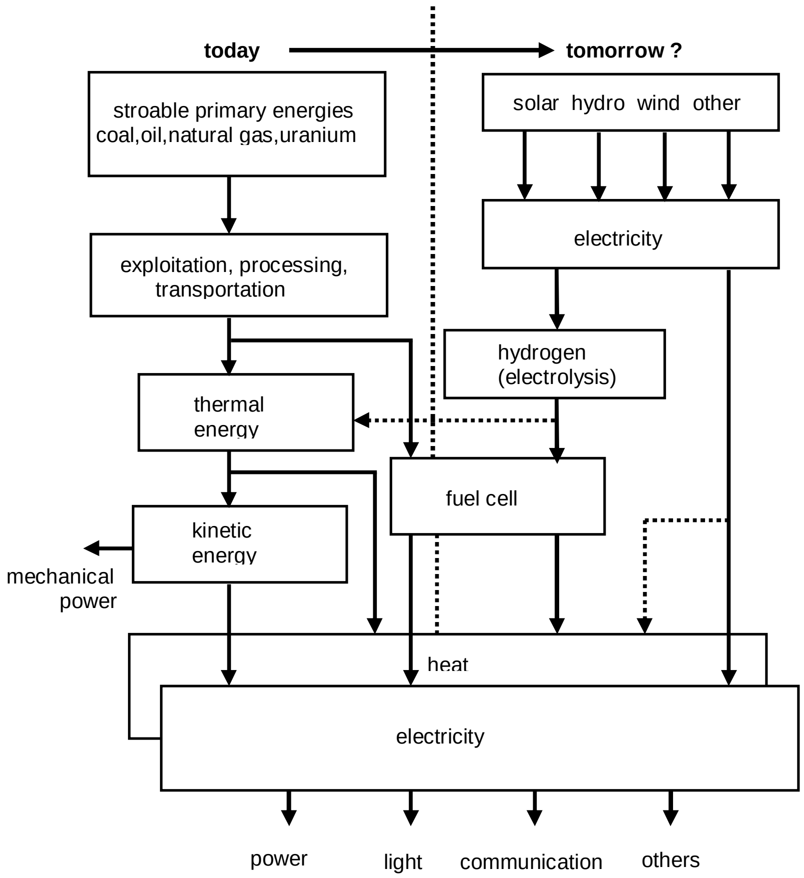

Figure 4.21. Energy Supply Structure (Weinmann,1999)

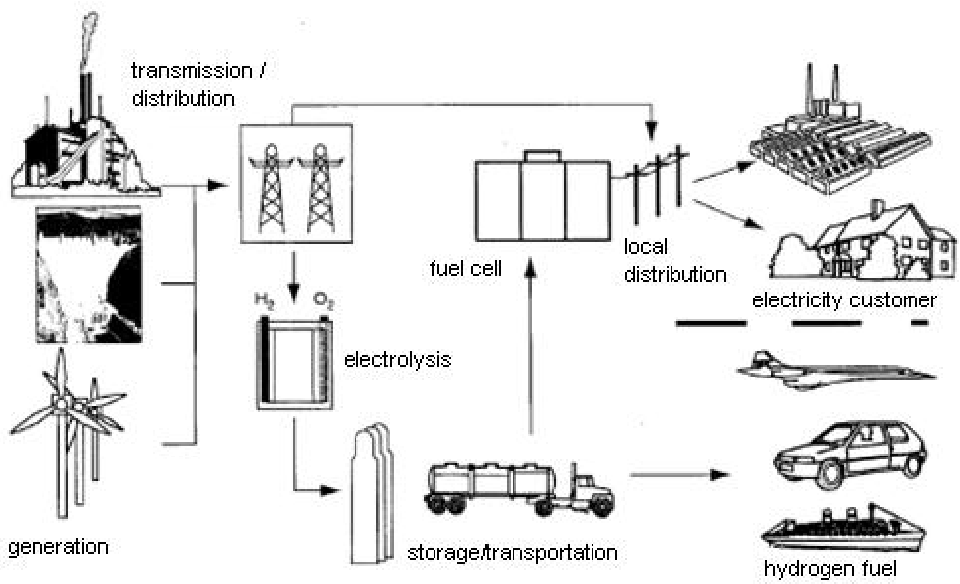

Figure 4.22. A Schematic diagram of the hydrogen power system (Weinmann,1999)

The generation of electricity the production of hydrogen by electrolysis offers some benefits to power utilities: Electrolysers as a load in the electrical network can be used for frequency control or load management, thereby saving reserve capacity, and power plants can be operated at rated power with the best efficiency and highest revenues. Hydrogen can be utilised, for example, in fuel cells with a high efficiency to produce power. Figure 4.23 presents a schematic diagram of the proposed hydrogen energy system. In this system, hydrogen, (and oxygen) is produced in large industrial plants where the primary energy source (solar, nuclear, and even fossil) and water (H_2O), the raw material, are available. For large scale storage, hydrogen can be stored underground in exmines, caverns and/or aquifers. Hydrogen is then transported, by means of pipelines or super tankers, to energy consumption centers. Subsequently, it is used in electricity, transportation, industrial, residential and commercial sectors as a fuel and/or an energy carrier. (Veziroglu and Sahin, 2008; Weinmann,1999)

The oxygen produced in the industrial plant making hydrogen could either be released into the atmosphere, or could be shipped or piped to industrial and city centers for use in fuel cells (instead of air) for electricity generation. This would have the advantage of increasing the utilization efficiency. The oxygen could be used by industry for nonenergy applications, and also for rejuvenating the polluted rivers and lakes, or speeding up sewage treatment.It should be noted that in the hydrogen energy system, hydrogen is not a primary source of energy. It is an intermediary or secondary form of energy or an energy carrier. Hydrogen complements the primary energy sources, and presents them to the consumer in a convenient form at the desired locations and time.

The hydrogen is energy storage not an energy source. Storage of hydrogen in liquid form is difficult, as very low temperatures are required to liquefy hydrogen but it can be stored over relatively long periods of time (Midilli,Aya,Dincer and Rosen, 2005).

If solar energy, in its direct and/or indirect forms (e.g.,hydro, wind, etc.), is used to manufacture hydrogen, then the resulting system is called the ‘‘solar-hydrogen energy system”. In this system, both the primary and secondary energy sources are renewable and environmental1y compatible, resulting in a dean and permanent energy system. Figure 4.24 presents a schematic of the solar-hydrogen energy system .

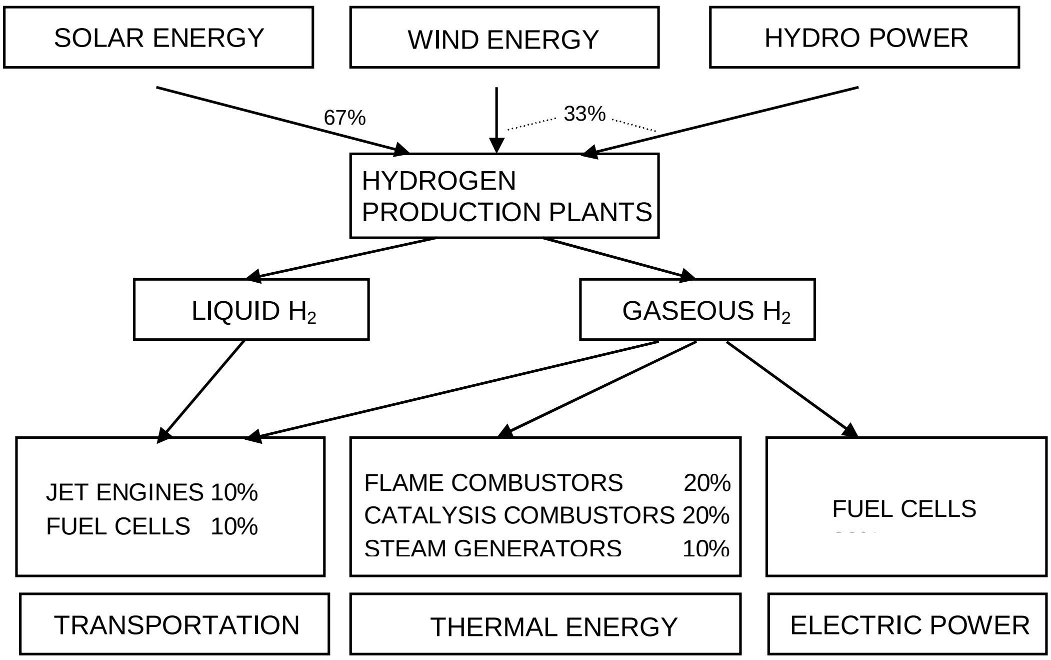

Figure 4.23. Schematic of the solar-hydrogen energy system (Veziroglu and Sahin, 2008)

Below figures show that , the difference between PV system and PV system with hydogen.

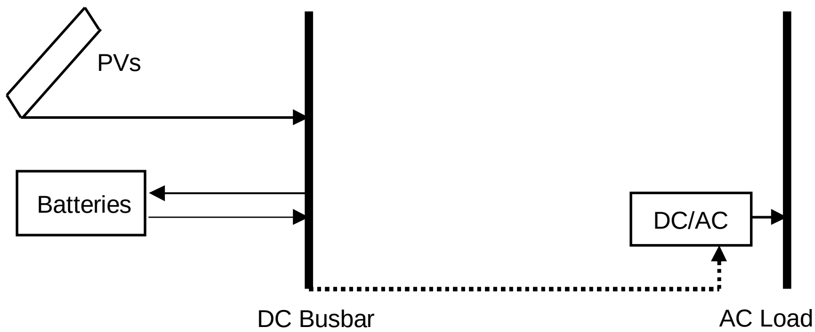

Figure 4.24. PV Path and batteries without hydrogen energy (Cetin,Yilanci,Oner,Colak,Kasikci and Ozturk 2009)

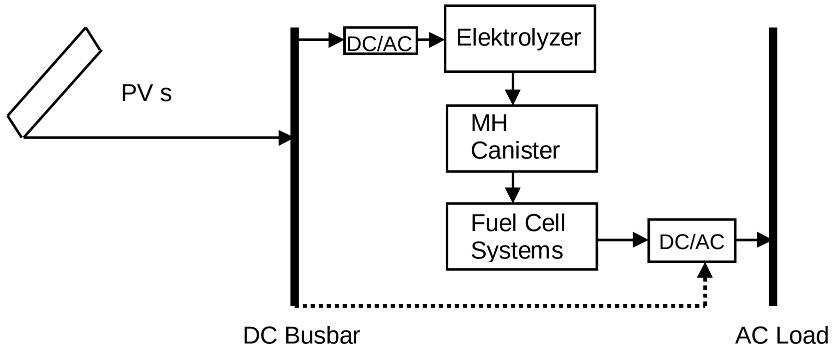

Figure 4.25. PV and Hydrogen path (Cetin,Yilanci,Oner,Colak,Kasikci and Ozturk 2009)

Hydrogen energy can be used to Power Grid Control. (Figure 4.27) Because of its extremely fast regulating behaviour the electrolyser can be used as a variable load which draws power anticyclic to the power production, regulating the needs of a utility and thus replacing some of the necessary regulating and reserve power plant capacity. If such systems are installed on a large scale for future commercial hydrogen production, the following additional advantages could be envisaged for the utility (Weinmann,1999):

- fewer losses in power plant operation
- less wear on power plant regulating components
- improvement of regulating response time and grid stability.

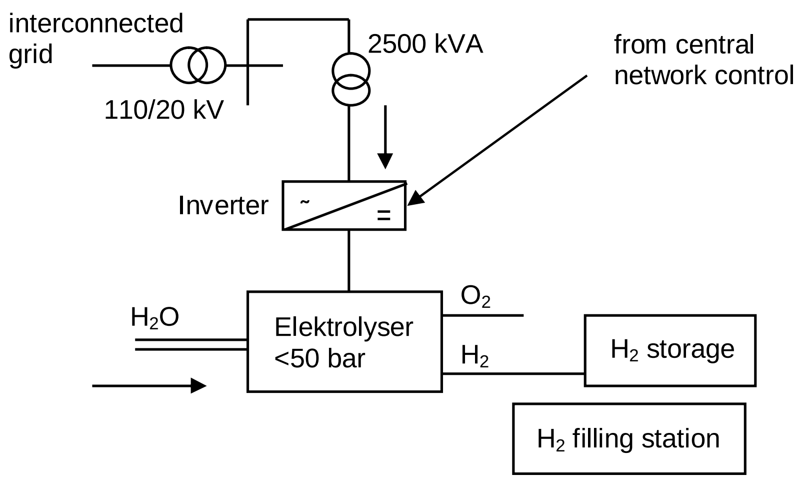

Figure 4.26. Power Grid Control (Weinmann,1999)

5. RENEWABLE ENERGY IN TURKEY

5.1. Wind Energy in Turkey

World's wind resource is estimated as 53 TWh/year, and presently the total installed wind energy power is 40.301 MW. One third of this power is in Germany. The amount of investment necessary for reaching the world wind energy target of 1,245 GW by 2020 is 692 billion Euros. By then, production costs are expected to decrease from 3,79 Euro-cents/kWh to 2,45 Euro-cents/kWh.

Global business volume in wind turbines will increase from an annual 8 billion Euros to 80 billion Euros by 2020. In regions with a total potential of at least 48.000 MW and an annual average of 7,5 m/s, it is possible to make potentially economical investments over present prices.

With Turkey Wind Energy Potential Atlas (REPA), which was realized in 2007, it is calculated that our country has a minimum wind energy potential of 5.000 MW in regions with annual wind speed of 8,5 m/s and higher, and 48.000 MW with wind speed higher than 7,0 m/s (ETKB). Turkey wind map is given in Figure 5.1. Figure 5.2 gives a review of completed and ongoing wind power plant projects in Turkey. In Figure 5.3 views from Bandırma Wind Power plant are given.

Operating at an ideal location, a turbine with a capacity of at least 500 kW can run at maximum 30% efficiency and produce most commercially wind-generated electricity of 1.3 million - kWh year. A 500-kW capacity turbine requires 13,700 ha of land, an initial investment of approximately US$ 500,000, and an annual operating cost of US$ 40,500. The estimated cost of electricity generated by such a system is US$ 0.07 per kWh, with an energy input–output ratio of 1:5 during the 30-year life of the system. (ETKB)

Wind turbines have not yet been the subjects of serious planning legislation in Turkey. The Turkish industry is currently a limited player in the manufacture of turbines and other components. The scale and cost of a wind farm will almost certainly require private investment, with its inevitable demand for an attractive rate of return (Cicek,Ozturk, and Ozek, 2009).

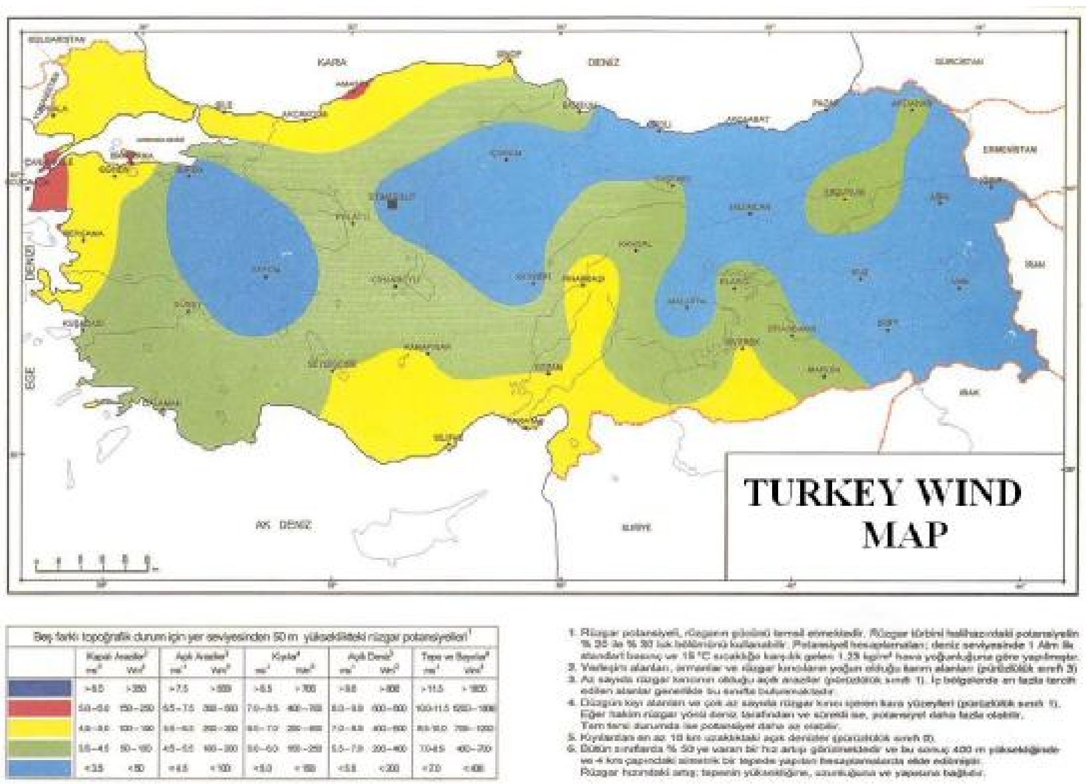

Figure 5.1. Turkey Wind Map (TUREB)

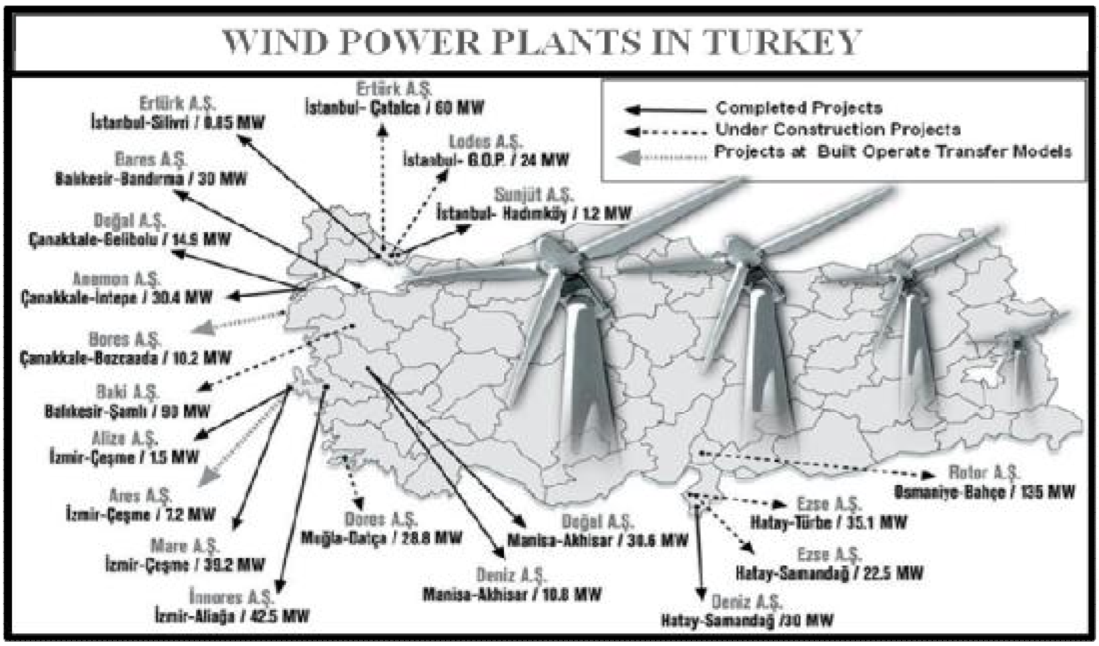

Figure 5.2. Wind Power Plants in Turkey (Radikal,22.06.2008)

Figure 5.3. Bandırma Wind Power Plant (Bilgin Energy)

5.2 Solar Energy in Turkey

Being a natural source of energy, solar energy is the most popular one among sources of renewable energy. Having a high potential for solar energy due to its geographical position, Turkey's average annual total sunshine duration is calculated as 2.640 hours (daily total is 7,2 hours), and average total radiation pressure as 1.311 kWh/m^2-year (daily total is 3,6 kWh/m^2). Solar energy potential is calculated as 380 billion kWh/year. While varying considerably in terms of methodology, materials and level of technology used, solar energy technologies may be divided into two main groups :

- Thermal Solar Technologies and Concentrating Solar Power (CSP): In these technologies, whereby solar energy is used to generate heat, heat can be used either directly or for generating electricity. CSP power plants use different mirror positions to generate electricity by converting solar energy into high-temperature heat. Since they can be built at desired power ratings, they are typically used for powering signaling equipment, meeting rural electricity demand, etc.

§ Solar Cells:Semiconductors which are also called photovoltaic cells transform sunlight directly to electricity .

Greatest disadvantage of solar cells is that their production is incredibly costly due to use of silicon crystals and thin film technology. With the decrease in the cost of using solar cells and increase in their efficiency, solar cell dependent energy generation is expected to increase in Turkey. Furthermore, using Turkey Solar Energy Potential Atlas and the CSP technology, it is calculated that an annual production of 380 billion kWh is possible

The amount of solar collectors installed in our country is roughly 12 million m^2 with a technical solar energy potential of 76 TEP, and annual generation volume is 750.000 m^2, part of which is exported. Such amount indicates that 0,15 m^2 of solar collectors are used per capita. Annual amount of solar-based heat generation is around 420.000 TEP. This data suggests that Turkey is a significant manufacturer and user of solar collectors among world countries .

In our country, installed solar cell capacity, which is used mostly in public bodies for supplying small amounts of power and for research purposes, has reached 1 MW. Work in the area of solar and hydrogen energy holds a great importance for the future of our country including our defense industry and military use (ETKB).

At present, Turkey does not have an organized commercial and domestic photovoltaic (PV) programme, because the government has no intention in PV technology. On the other hand, there is a good potential for PV applications in the local market since the country is enormously suitable due to high rates of solar radiation and available land for PV applications. (Cicek,Ozturk, and Ozek, 2009).

5.3 Hydraulic Energy in Turkey

Among various sources of energy, hydroelectric power plants are preferred because they are environment-friendly and have a low potential risk. Hydroelectric power plants are an environment-friendly, clean, renewable, lasting and efficient domestic resource with low operational costs and no fuel cost, which is not externally dependent and also serve as a fuse for energy prices.

Turkey's technically feasible hydroelectric potential is 36.000 MW. 150 hydroelectric power plants (HEPP) that are presently in operation correspond to an installed power of 13.830 MW and 38% of the total potential . 16,77% of electricity generated in 2008 came from hydroelectric power plants. Recent draughts have substantially limited the contribution of hydroelectric power plants to electricity generation .

In 2004, hydroelectric power plants generated 46 billion kWh of energy. Although a new 600 MW hydroelectric power plant was commissioned between 2004-2008, our hydroelectric production for 2008 remained at the level of 33 billion kWh.

Due to reasons like failures, maintenance/repair works, operational policy, draughts, etc., overall capacity utilization in energy generation is around 73%. Capacity utilization is 68% in thermal power plants, and 94% in hydroelectric power plants .

We aim at utilizing in electricity generation all hydroelectric potential that is technically and economically viable by the year 2023. The scope of Law no. 5346 on Renewable Energy Resources (YEK) has been expanded to include wave, stream and tidal energy, and all other sources for generating energy which are suitable for building canal- or river-type hydroelectric power plants, or hydroelectric power plants with a reservoir area of less than 15 km^2 (ETKB).

5.4 Hydrogen Energy in Turkey

It is hydrogen that fuels the heat emitted by Sun and other stars to thermonuclear reaction, which is the main energy source of the universe. Among all fuels known to man, hydrogen has the highest energy content per unit mass (higher heating value is 140,9 MJ/kg, and lower heating value is 120,7 MJ/kg). 1 kg of hydrogen contains an amount of energy that is equal to that of 2,1 kg of natural gas or 2,8 kg of petroleum. But its volume per unit energy is high.

In energy systems where hydrogen is used as a clean and easy-to-use fuel wherever heat and explosion energy is required, the only emission to the atmosphere is water and/or water vapor. As a fuel, hydrogen is averagely 33% more efficient compared to petroleum-based fuels. During energy generation using hydrogen, no gas or harmful chemical substances with the potential to pollute the environment or to aggravate the greenhouse effect is produced. Research shows that hydrogen is presently three times more expensive that other fuels, and that common spread used of hydrogen as a source of energy will depend on technological advances that can reduce the cost of hydrogen production. On the other hand, it could still be a viable alternative, under present conditions, to store excess electricity generated over daily or seasonal periods as hydrogen. Common spread use of such stored energy -say, for mass transportation purposes- will depend on advances in fuel cell based automobile technologies .

Presently, an annual amount of 50 million tons of hydrogen is produced, stored, transported and used around the world. The highest number of users is to be found in chemical industry, particularly in the petrochemical industry. In Turkey hydrogen is used in industry and is not used for energy production purposes. At present Turkish Government does not have an official policy related with hydrogen energy. (ETKB)

5.5. Geothermal Energy in Turkey

World's installed geothermal power is 9.700 MW with an annual production of 80 billion kWh, and the first 5 countries in geothermal electricity generation are USA, Philippines, Mexico, Indonesia and Italy. Non-electricity utilization is 33.000 MW. The first 5 world countries in geothermal heating and spa practices are China, Japan, USA, Iceland and Turkey (ETKB).

Turkey is located on the Alpine-Himalayan organic belt, having one eighth of the world’s geothermal potential. Turkey has 170 geothermal fields over 400 8C temperature and around 1000 hot and mineralized natural self-flowing springs and they are located mainly on West, North-west and Central Anatolia. Turkey is ranked as fifth biggest geothermal energy user for heating and hot spring purposes after China, Japan, USA and Island. Turkey’s geothermal fields are more available to direct-use applications, since 95% of geothermal fields are low-medium enthalpy resources. Gross geothermal potential of Turkey is given as 31,500MWth, corresponding to 5 million residences heating whereas the economic potential for heating purposes is estimated to be 2843MWth but the share of geothermal energy production, both for electrical and thermal uses is 1229MWth. Aydin-Germencik, Denizli-Kizildere, and theoretically Nevsehir-Acigol fields have the highest enthalpy among all and can be used both for electricity generation and district heating applications**.** These fields may be evaluated if the government offers the financial and/or institutional support that is required for successful development. Electricity generation projections of Turkey are also 500MWe from Germencik, Kizildere, Tuzla and several of the other fields by the year 2010 and 1000MWe by 2020 (Cicek,Ozturk, and Ozek, 2009).

5.6. Bio Energy in Turkey

Having a total fuel-oil consumption of 22 million tons, 3 million tons of which is benzene, Turkey has an installed bio-ethanol capacity of 160 thousand tons. Reserving of lands for biodiesel and bio-ethanol production, which poses a global threat against food security, is the strongest criticism against bio-fuel oriented agriculture. Biogas technology allows us both to obtain energy from organic wastes, and also to bring wastes back into the soil. The amount of biogas that can be produced in Turkey, considering its animal waste potential, is reported as 1,5 to 2 MTEP (million tons equivalent of petroleum). Our biomass sources include agriculture, forests, animals, organic urban waste, etc. While our waste potential is around 8,6 million tons equivalent of petroleum (TEP), 6 million TEP is used for heating. In 2007, the total amount energy obtained from biomass sources was 11 thousand TEP (ETKB).

For heat and electricity production, there are existing projects, mainly using combustion. Policy support has been and is directed at combustion systems, but has tended to favor potentially more efficient and cleaner advanced Technologies such as gasification and pyrolysis. Innovation is focused on the development of these technologies, which are at the demonstration stage but are commercial in niche markets.

The biomass fuel cycle has near-zero net emissions of CO_2 since CO_2 are fixed by the plants as they grow. The land area to replace a significant portion of the electricity currently generated by coal limits the use of biomass. In case of biomass, the following links are clearly weak),

- Resource compatibility,
- User support,
- Needs assessment,
- Using wastes for fuel may degrade soil quality.
- Sugar plantations, sawmills, etc. often owned by rural elite.
- Could results in competition between land uses for feed/fuel.

It is difficult to collect large quantities of biomass wastes due to their disperse nature. The availability of some types of biomass is seasonal. In addition annual productions of most biomass fluctuate from year to year depending on climatic conditions. Biomass is also difficult and costly to transport. The costs of biomass wastes fluctuate widely, depending crop the productions and economic condition (Cicek,Ozturk, and Ozek, 2009).

5.7. Renewable Energy Policy in Turkey

Energy development in Turkey has been dominated by public investment and management since independence in 1923, although several waves of liberalization have been launched since 1983, leading to a gradual opening of the Turkish energy market and improving the situation. Turkey has made early and extensive use of financing models such as build-own-operate (BOO) and build-own-transfer (BOT). As yet, however, no decisive breakthrough has been achieved. In the last two years, several encouraging steps have been taken towards greater liberalization. The notion of privatization has been introduced into the Turkish constitution for the first time. Legislation was adopted in February 2001 to allow competition in the electricity market and adapt Turkey’s legislation for European Union (EU) membership. A new Gas Market Law was adopted in May 2001 for the same purposes.

The main objectives of energy policy including renewable are : (Cicek,Ozturk, and Ozek, 2009)

- To meet demand using domestic energy resources as the highest priority. In the medium and long term, this is to occur through a mix of public, private and foreign capital.
- To develop existing sources while acceleration the penetration of new and renewable sources.
- To diversify energy sources and to avoid dependence on energy imports from a single source or country.
- To encourage private sector investment and to accelerate capacity construction and privatization in the power industry. Preparations are to be made for the introduction of nuclear power.
- To improve the reliability of electricity supply through upgrades in the power transmission and distribution grid.
- To improve energy efficiency in end use and transformation, e.g. through reduction of losses in energy production, transmission and consumption.
- To protect the environment and public health.
- To make use of Turkey’s geopolitical location to establish the country as a pivotal transit area for international oil and gas trade (‘Eurasia energy corridor’)

5.7.1. Renewable energy policy institutions

The Ministry of Energy and Natural Resources is the main body for the formation and implementation of energy policy in general and renewable energy in particular (Energy Policies of IEA Countries, 2001). The Electric Power Resources Survey and Development Administration (EIE) carry out investigations and surveys to identify the energy potential of water, wind and solar energy resources. If big hydropower generation is regarded in the renewable group, Directorate-General of State Hydraulic Works (DSI) is the main implementing organization.

The main institutions operating under Ministry of Energy and Natural Resource have responsibilities for implementing energy policy are (Energy Policies of IEA Countries, 2001):

- Directorate-General for Energy Affairs
- EUAS, Electricity Generation Company
- TEIAS, Turkish Electricity Transmission Company
- TEDAS, Turkish Electricity Distribution Company
- TETAS, Turkish Electricity Trading and Contractor Company
- DSI, Directorate-General of State Hydraulic Works
- TPAO, Turkish Petroleum Company
- Directorate-General of Petroleum Affairs
- Directorate-General for Mining Affairs
- EIE, Electric Power Resources Survey and Development Administration
- BOTAS, Turkish Pipeline Corporation
- TKI, Turkish Coal Enterprises
- Turkish Hard Coal Enterprises (TTK)

The main state organizations having responsibility for planning the energy policy in Turkey are given in Table 5.1.

Table 5.1. The main state organizations having responsibility for planning the energy policy in Turkey

Organization Name	Under the fold of
DPT, State Planning Organization	Prime minister
TUBITAK, Scientific and	Prime minister
Council of Turkey	
Research, planning and Co-ordination Board	Ministry of Energy and Natural Resources
Directory-General for Energy Affairs	Ministry of Energy and Natural Resources
Directory-General of Mineral Affairs	Ministry of Energy and Natural Resources
Directory-General of Petroleum Affairs	Ministry of Energy and Natural Resources

The above general directorates are operating under Minister and his Undersecretary. Therefore, main body responsible from energy policy is Ministry. All groups get or receive directives from ministry and implement the policy accordingly. As it was stated above, there is a separate Department of Energy Directorate General, which reports to Minister and his Undersecretary. Minister reports to Prime Minister.

There are also some non-Ministerial agencies responsible for various aspects of energy policy (Table 5.2).

Table 5.2. Non-Ministerial agencies responsible for various aspects of energy policy (Meda Project, 2002)

Organization name and/or rgulation	Functions
Energy Policy and/or regulation	Energy Market Regulatory Council
Nuclear Power	Turkish Atomic Energy Authority (state organization)
Energy Efficiency	ESÇAE/MAM/TUBITAK Marmara Research Center (state organization) some universities (presenting reports, Organizing meetings and courses)
Energy standards	TSE, Turkish Standardisation Institute IEC, International Electrotechnical Comission
R&D	
	Energy Systems and Environmental Research Institute/ Marmara Research Center
Renewable	
	Clean Energy Foundation
	Turkish Wind Energy Association
	International Solar Energy Society Turkish Section
	Geothermal Energy Association

5.7.2. Renewable policy instruments

In Turkey's case, where government expenditure has to be tightly controlled, it is important that the most cost-effective resources to be developed. Therefore, the government should attempt to develop competitive renewable energy supplies first, and provide base support for renewable energy, if necessary, on cost-effectiveness.

All, the Ministry of Energy and Natural Resources (MENR), the State Planning Organization (DPT) and the Electric Power Resources Survey and Development Administration (EIE) are involved in renewable energy promotion policies. Some promotions and related policies exist with respect to the development and implementation of renewable energy systems. geothermal heat and solar thermal energy production. Low-interest loans up to 45% of the capital cost are applicable to appropriate investments.

Until recently, Free Market Law of Electricity, the price of energy was decided as a result of negotiations between energy production company and the state which is buyer. This was a kind of incentive. Now, the price of the renewable energy will have to obey the market conditions.

The Energy Efficiency Law (EE Law), numbered 5627 and published in official gazette on 2 May 2007 Wednesday, aims to increase the efficient use of energy and energy resources for reducing the burden of energy costs on the economy and protecting the environment. This law comprises the organisation, principals and procedures for increasing energy efficiency in industry, electrical power plants, transmission and distribution systems, building, service and transport sectors. It sets the rules for energy management in industry and in big buildings, project supports, energy efficiency consultancy companies, voluntary agreements and so on .

This law covers principles and procedures applicable to increasing and promoting energy efficiency in energy generation, transmission, distribution and consumption phases at industrial establishments, buildings, power generation plants, transmission and distribution networks and transport, raising energy awareness in the general public, and utilizing renewable energy sources.

Outside the scope of this Law are those buildings which would have to change characteristics or appearances at an unacceptable level upon the implementation of measures for increasing energy efficiency, are used for operation and production activities in the industrial areas, are used as worship places, have less than two years of scheduled period of utilization, are used less than 4 months in a year, have less than fifty square meters of usable area, those buildings or monuments under protection, agricultural buildings and workshops .

The EE Law also amended Law no.5346 dated 10.05.2005 on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy. Renewable electricity receives a fixed purchase price of between EUR cents 5 and 5.5/kWh for 10 years. The price is valid for plants installed until end of 2011, though the government can extend this date for two years. The Electricity Market Law of 2001 was also modified by the EE Law, exempting certain categories of power plants from the obligation to obtain licenses and establish companies. The exemption applies to: renewable energy plants with installed capacity of maximum 500kW; cogeneration plants with at least 80% overall efficiency; micro cogeneration plants with 50 kW installed capacity .

The Law on Utilization of Renewable Energy Resources For The Purpose Of Generating Electrical Energy, numbered 5346, aims to expand the use of renewable energy sources for generating electrical energy by establishing the necessary legal and regulatory framework while ensuring increase in the use of renewable energy sources without disturbing free market conditions. In fostering renewable energy, the Turkish government seeks to benefit from these resources in a secure, economic and qualified manner, to increase the diversification of energy resources, to reduce greenhouse gas emissions, to assess waste products, to protect the environment and to develop the manufacturing sector for renewable-energy related products .

The Law encompasses the procedures and principles for conservation of renewable energy resource areas, utilisation of these sources, and certification of the energy generated from these sources.

The Law on Geothermal Resources And Waters Containing Natural Minerals, numbered 5686 was published in official gazette on 13 June 2007, sets forth the rules and principles for exploring, producing and protecting geothermal and natural mineral water resources. Geothermal and natural mineral waters belong to the state. A special licence is required to carry out exploration activities. The licence may be issued according to the procedure regulated by these provisions and shall be valid for three years. An operational licence is also necessary to exploit geothermal resources.

The integrated use of geothermal energy, the re-injection of geothermal energy after use, efficiency and environmental protection are all also regulated by the Law.

The purpose of this law, geothermal and natural mineral water resources in an efficient way to search, development, production, conservation, over these resources be entitled to and transfer of rights, the environment in accordance with the economic evaluation and abandonment related principles and procedures are regulated.

This law specified or determined geothermal and natural mineral water and geothermal resources of gases between the origin and operation stages, resources on the rights of owner, transfer, abandonment, use of resources to be tender, termination, supervision, resources and catchments protection and related procedures The principles include the sanctions (EIE).

5.8. Research and development on renewable energy in Turkey

Financing of R&D projects are offered via national funds by State Planning Organization (DPT), TUBITAK-TEYDEB and research funds of universities. International co-operation is sought not only in terms of funds but also in terms of know how exchange.

The Technology and Innovation Support Program (TEYDEB) of TUBITAK is a R&D assistance program for industrial companies. This includes a financial contribution by the Scientific and Technical Research Council of Turkey and by the Undersecretary of Foreign Trade for up to 60% of the total eligible cost incurred over the duration (up to 36 months) of an individual R&D project.

There are a lot of industry projects supported by TEYDEB. Most of these projects are done in cooperation with universities. Subjects of R&D projects on renewable energy may be listed as follows:

- Wind turbine technology
- Pumping systems using wind power
- Solar ovens for heating
- Photovoltaic cells
- Solar glasses
- High efficiency solar collectors
- Heating systems using geothermal power
- Hydrogen storage systems

Projects are concentrated mostly on wind power and solar power. Wind turbines up to 1500 kW are manufactured in Turkey by Soyut Wind. Projects on manufacturing of photovoltaic cells is ongoing by the big glass manufacturer of Turkey.

Low-interest loans are provided by the Technology Development Foundation of Turkey (TTGV) for innovative renewable energy R&D projects.

Another fund for R&D studies are provided by the State Planning Organization to relevant university departments for infrastructure developments. Some support is also provided to industry by Electrical Power Resources Survey and Development.

Technology and Innovation Support Program Board (TEYDEB) of TUBITAK, Electrical Power Resources Survey and Development Administration (EIE) and DPT act as implementing agencies. The applicable ministries have some actions as well. At present, about 15 types of legal and administrative incentives exist to promote R&D, including above mentioned. The main renewable energy resources being supported are solar, geothermal, and wind. Other R&D on the demonstration of advanced bio-fuels technology, such as electricity generation from biomass and liquid bio-fuel production are also underway.

Turkey has joined European Union (EU) Seventh Framework Program. There are also many project opportunities in this program about renewable energy.

6. CONCLUSIONS

This dissertation presents renewable energy resources and Turkey's current situation, current technologies, ongoing R&D projects, Turkey's current policies, economics and the barriers of utilization for all means of renewable energy sources.

On our growing world, renewable energy sources have become indispensable due to the increasing population, and decreasing nonrenewable energy resources. During the dissertation, it is understood that the main advantage of usage as energy source is coming from its definition: "Renewable"

There are many advantages of renewable energy conversion. On the other hand there are also some disadvantages like the unstable resources, wind rate in wind, heat rate in geothermal, bio mass supply irregularity etc… The supply could be unstable when it is compared to the other supplies like coal and natural gas. But there is a fact, these sources are limited and will be exhausted.

With the development of technologies for the renewable energy conversion, investing costs of renewable energy plants are decreasing, however it is still not a good choice for energy conversion when it is compared to old means of conversions. Although it is still expensive, that is certain that our unique world is warning us with the global warming issues.

Our country, Turkey has a big potential for renewable energy conversion; 53.000MW for wind, 45000MW for solar, 36000MW for hydro and etc… This potential with strong feasibilities and investments will have great economical and environmental benefits.

Turkey's current situation is promising for renewable energy resources however; there are some financial, political and technical barriers. Besides, there is another issue, that is some failed projects which makes companies hesitate with renewable. Despite the few failures, there are good investments with reliable feasibility and have to be taken into consideration. The government is supporting the projects for renewable energy sources, although it is still not enough to increase the percentage of renewable energy conversion in total. Universities should be supported more for new technologies for increasing total percentage of renewables in total energy conversion. There are still researches for the development of renewable energy conversations supported by Tubitak. Researches are mainly concentrated on solar and wind. There are also a lot of rejected project proposals due to lack of R&D content, inadequate planning or other reasons. Most of the companies who are interested in renewable energy systems are importing technologies instead of forming their own R&D departments. That increases the cost of investment so the cost of conversion. R&D projects should be supported more and more by the government to encourage local companies. Companies should also cooperate with universities to perform successful projects with good planning, R&D content and qualified personnel.

Renewable energy conversion is making a big step in 21th century and it is a fact that our world needs it. Our country has a big potential and with good feasibilities the sources could be used for benefits.

REFERENCES

ABD, R.N., SELVARAJ, J., 2009. Multi-String Five-Level Inverter with Novel PWM Control Scheme for PV Application. IEEE Transactions on Industrial Electronics.

AKHMATOV, V., KNUDSEN, H., 2002. An aggreate model of a grid-connected, large-scale, offshore wind farm for power stability investigations-importance of windmill mechanical system.Electrical Power and Energy Systems 24, Page(s) 709-717.

ANSEL, A., ROBYNS, B., 2006. Modelling and simulation of an autonomous variable speed micro hydropower station. Mathematics and Computers in Simulation, Page(s): 320–332.

ANTONIO F., 2009. Wave energy utilization: A review of the Technologies. Renewable and Sustainable Energy Reviews.

ARABIAN-HOSEYNABADI, H., ORAEE, H., TAVNER, P.J., 2010. Wind turbine productivity considering electrical subassembly reliability. Renewable Energy 35, Page(s) 190–197.

ARANDA, E.D., GALAN, J.A.G., SIDRACH D. M., MARQUEZ, J.M.A., 2009. Measuring the I-V Curve of PV Generators. Industrial Electronics Magazine IEEE, Volume 3, Page(s): 4 – 14.

BILGIN ENERGY (Bilgin Energy Investment Holding) http://www.bilgin.com.tr/bandirma.htm

BOSTROM, C., LEJERSKOG, E., STALBERG, M., THORBURN, K., LEIJON, M., 2009. Experimental Results of Rectification and Filtration from an Offshore Wave Energy system. Renewable Energy, Volume 34, Page(s): 1381-1387.

CASPER, J., 2007. Natural Resources Energy Powering The Past, Present and Future.Chelsa House Publishers, 210s.

CETIN, E., YILANCI, A., ONER, Y., COLAK, M., KASIKCI, I., OZTURK, H.K., 2009. Electrical analysis of a hybrid photovoltaic-hydrogen/fuel cell energy system in Denizli,Turkey. Energy and Buildings 976 41, Page(s): 975–981.

CICEK, B., OZTURK, N., OZEK, M., 2009. Renewable energy market conditions and barriers in Turkey. Renewable and Sustainable Energy Reviews 13, Turkey, Page(s) 1428–1436.

CHEN,Z.,BLAABJERG,F.,2009.Wind farm-A power source in future power systems, Renewable and Sustainable Energy Reviews 13, Page(s) 1288–1300.

CHEN, Z., GUERRERO, M. J., BLAABJERG, F., 2009. A Review of the State of the Art of Power Electronics for Wind Turbines. IEEE Transactions on Power Electronics, Vol.24, No.8, Page(s) 1859-1874.

DAHER, S., SCHMID, J., ANTUNES, F.L.M., 2008. Multilevel Inverter Topologies for Stand-Alone PV Systems. IEEE Transactions on Industrial Electronics, Volume 55, Page(s): 2703 – 2712.

EIE (General Directorate of Electrical Power Resources Survey and Development Administration)http://www.eie.gov.tr/english/announcements/EV_kanunu/EnVer_kanunu_tercume_revize2707.doc

ENERGY POLICIES OF IEA COUNTRIES, 2001, Turkey Review. Paris, France: International Energy Agency.

ETKB (Rebuplic of Turkey Ministry of Energy and Natural Resources) http://www.enerji.gov.tr/harita/santral.html

GALLUP,D.L.,2009. Production engineering in geothermal technology. Geothermics 38, Page(s) 326–334.

HAZLETT, B. D., INCULET, I., INCULET, D.R., November 2009. Electric Power Generation by 'Surfing' Water Waves. Renewable Energy, Volume 34, Page(s): 2510-2514.

IEA (International Energy Agency) http://www.iea.org/Textbase/pm/?mode=re&id=2457&action=detail

JAIN, S., AGARWAL, V., 2007. Comparison of The Performance of Maximum Power Point Tracking Schemes Applied to Single-Stage Grid-Connected Photovoltaic Systems. IET Electr. Power Appl., Page(s): 753-762.

KANOGLU,M.,1999. Desing and Optimization of Geothermal Power Generation, Heating and Cooling. UMI No:9934146, 150s.

KJAER, S. B., PEDERSEN, J. K. P., BLAABJERG F., 2005. A Review of Single Phase Grid-Connected Inverters for Photovoltaic Modules. IEEE Transactions on Industry Appl., Volume 41, Page(s): 1292-1306.

KIM, S., 2006. Sliding mode controller for the single-phase grid-connected photovoltaic system. Applied Energy. Page(s): 1101–1115

KISHOR, N., SAINI, R. P., SINGH, S.P., 2007. A review on hydropower plant modelsand control. Renewable and Sustainable Energy Reviews, Page(s) 776–796

LIU, C., WU, B. and CHEUNG, R., 2004. Advanced Algorithm For MPPT Control of Photovoltaic Systems. Canadian Solar Buildings Conference Montreal.

LI, H., CHEN, Z., 2008. Overview of different wind generator systems and their comparisons.IET Renewable Power Generation,Vol.2,No.2,Page(s):123–138.

MAFFEZZONI, P., D’AMORE D., 2009. Compact Electrothermal Macromodeling of Photovoltaic Modules. IEEE Transactions on Circuits and Systems, Volume 56, Page(s): 162-166.

MARIS, T.I., KOURTESI, S., EKONOMOUC, L., FOTIS, G.P., 2007. Modeling of a single-phase photovoltaic inverter. Solar Energy Materials and Solar Cells, Volume 91, Page(s): 1713-1725.

MEDA PROJECT, Diagnostic Study, Questionnaire, 2002.

MCKENDRY P., 2002. Energy Production From Biomass (part 2): Conversion Technologies. Bioresource Technology, Page(s): 47-54.

MIDILLI, A., AYA, M., DINCER, I., ROSEN, M.A., 2005. On hydrogen and hydrogen energy strategies I: current status and needs. Renewable and Sustainable Energy Reviews 256 9, Page (s): 255–271

NAYAR, C. V., ISLAM, S. M., DEHBONEI, H. and TAN, K., 2006.Power Electronics for Renewable Energy Sources Chapter 27 of Power ElectronicsHandbook. Editor RASHID Muhammad H. , Elsevier Publishing.

OZAKTURK, M., 2007. Rüzgâr Enerjisinin Güç Kalitesi Açısından İncelenmesi. Sakarya Üniversitesi Fen Bilimleri Enstitüsü, 81s.

PARK, S., CHA, G., JUNG, Y. and WON, C., 2009. Design and application for PV generation system using a soft-switching boost converter with SARC. IEEE Transactions on Industrial Electronics, Volume 56.

PATCHARAPRAKITI, N., PREMRUDEEPREECHACHARN, S., SRIUTHAISIRIWONG, Y., 2005. Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system. Renewable Energy, Page(s): 1771-1788.

RADIKAL (Radikal Newspaper), 22.06.2008. http://i.radikal.com.tr/150x113/2008/06/21/fft16_mf22243.Jpeg

REGA (Republic of Turkey Official Newspaper) http://rega.basbakanlik.gov.tr/eskiler/2007/06/20070613-1.htm

ROURKE, F. O., BOYLE, F., REYNOLDS, A., 2009. Marine current energy devices: Current status and possible future applications in Ireland. Renewable and Sustainable Energy Reviews, Article in Press.

ROURKE, F. O., BOYLE, F., REYNOLDS, A., 2009. Renewable energy resources and Technologies applicable to Ireland. Renewable and Sustainable Energy Rev 13(8), Page(s) 1975–1984.

ROURKE, F.O., BOYLE, F., REYNOLDS, A., 2010. Tidal Energy Update 2009. Applied Energy 87, Page(s) 398–409.

SAHIN, A.D., 2004. Progress and recent trends in wind Energy. Progress in Energy and Combustion Science 30, Page(s) 501–543.

SALA, S. V., OLIAS, E., BARADO, A., LAZARO A., 2006. Review of the Maximum Power Point Tracking Algorithms for Stand-Alone Photovoltaic Systems. Solar Energy Materials & Solar Cells, Page(s) : 1555–1578.

SANDROLINI, L., ARTIOLI, M., REGGIANI, U., 2010. Numerical Method for the Extraction of Photovoltaic Module Double-Diode Model Parameters Through Cluster Analysis. Applied Energy, Page(s) : 442–451.

SHETH, S., SHAHIDEHPOUR, M., 2004. Geothermal Energy in Power Systems.Power Engineering Society General Meeting,Vol.2, Page(s) 1972-1977.

SHETH, S., SHAHIDEHPOUR, M., 2005. Tidal Energy in Electric Power Systems. Power Engineering Society General Meeting,Vol.1, Page(s) 630-635

SHIREEN, W., SRINIVAS, V., NENE, H., 2007. DSP based inverter control for alternate energy systems. Journal of Power Sources, Page(s): 445-449.

TSAI, H., TU, C., and SU, Y., 2008. Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK. Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA

TUREB (Turkish Wind Energy Association) http://www.ruzgarenerjisibirligi.org.tr/bilgibank-ruzgar-atlas.htm

VELDEN, M., BAEYENS J., BOUKIS I., 2008. Modeling CFB biomass pyrolysis reactors. Biomass and Bioenergy, Page(s): 128-139.

VELDEN, M., BAEYENS, J., BREMS, A., JANSSENS B., DEWIL R., 2010. Fundamentals, kinetics and endothermicity of the biomass pyrolysis reaction. Renewable Energy, Page(s): 232-242

VEZIROGLU , T.N., SAHIN, S., 2008. 21st Century's energy: Hydrogen energy system. Energy Conversion and Management 49, Page(s): 1820–1831.

VILLALVA, M. G., GAZOLI, J. R., and FILHO, E. R., 2009. Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays.PowerElectronics, IEEE Transactions, Volume 24, Page(s): 1198-1208.

WEINMANN, O., 1999. Hydrogen-the flexible storage for electrical energy. IET Power Engineering Journal, Volume 13, Issue 3, Page(s): 164 – 170.

WIKIPEDIA ENCYCLOPEDIA, http://en.wikipedia.org/wiki/Renewable_energy_ in_the_European_Union# General_European_Union_Energy_policy

WILLIAMSON,K.H.,2010. Chapter 11: Geothermal Power: The Baseload Renewable. Elsevier, Page(s) 303-321.

XUE, J., YIN, Z., WU, B., PENG, J., 2009. Design of PV Array Model Based on EMTDC/PSCAD. Power and Energy Engineering Conference, Page(s): 1-5.

YARI,M.,2010. Exergetic analysis of various types of geothermal power plants. Renewable Energy 35, Page(s) 112–121.

YUKSEK, O., KOMURCU, M. I., YUKSEL, I., KAYGUSUZ K., 2006. The role of hydropower in meeting Turkey’s electric energy demand. Energy Policy,Page(s):3093–3103.

BIOGRAPHY

Cemal ZERAY was born in Konya, Turkey, at 15.02.1966. He has completed high school education in 1983 at Ali Tufan Bilgin Industrial Vocational High School. He recieved the B.S degree in Electrical and Electronics Engineering, Middle East Technical University in 1989. His interest areas are Energy Management, Energy Efficiency, Renewable Energy Sources and Power Quality.