**CHAPTER 2: REVIEW OF WIND ENERGY CONVERSION(WEC) SYSTEMS**

In this chapter, detailed survey of wind energy fundamentals and general overview of wind energy conversion systems will be summarized. To accomplish this, this chapter is divided into four main parts. In fist part wind turbine power equations and wind equations will be given and discussed. This data especially used in wind turbine investment calculations and wind potential estimation techniques. In next part, current wind turbine systems will be classified and evaluated according to their mechanical and electrical aspects. Then three main flux orientations in PM based systems will be shown and explained. Finally importance of modularity in wind energy conversion systems and axial flux advantages and disadvantages will be evaluated.

1. **Power Equations**

The available shaft power(output power) P from a wind turbine can be expressed as a function of the wind speed as follows :

where,

ρair is the mass density of air

Cp(λ,β) is the power coefficient, a function of the tip speed ratio λ and the pitch angle β

r is the blade length

v is the wind velocity

**Power Coefficient**

Power coefficient(sometimes called performance coefficient) is basically can be defined as the ratio between captured wind power by the wind turbine and the available input power of the wind.Therefore it tells us how efficiently we utilize the wind turbine.Its value is sometimes taken from look up tables or can be assumed by nonlinear computations.[25]

In [[1](http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6226866&isnumber=6331663)] Power coefficient  is defined as a nonlinear function of TSR(λ) and pitch angle  as follows,

Where

These coefficients shown above depends on the turbine characteristics.

**Tip Speed Ratio**

Tip speed ratio  (TSR) is defined as a ratio of tip speed of turbine blade to speed of the wind. This ratio is very useful when designing a wind turbine.

where,  V is the wind speed

wm  is the rotational rotor speed

R is the rotor radius

TSR is a kind of measurement of how speedy turbine blades turn. This topic is very important because of the efficiency issues. If turbine blades turns too slow then incoming air to the turbine is not used efficiently (Remember Betz limit!). If turbine blades turns too fast, blades act like a solid wall to the turbine and then efficiency decreases again.To avoid bad consequences(low efficiency, physical breakdown) of turbulence issue,choosing optimal TSR is really important.

Approximate optimal TSR’s for a system:

for TSR value ~6-7 Number of blades=2

for TSR value ~5-6 Number of blades=3

for TSR value ~2-3 Number of blades=5

**Betz Limit**

Theoretically maximum 59% (theoretical maximal of Cp ) of energy carried by the wind can be extracted by a wind turbine. This result is concluded by German physicist Albert Betz. Generally imperfections and in blade manufacture reduces the actual energy yield of the turbine less than the useable energy.

**Weibull Distribution and other issues**

Time dependent nature of the wind determines the production scheme of the WECs(Wind Energy Conversion Systems). There are some approaches for estimate the wind profile at given place. Wind profile at any given area is generally measured 10 meters above the ground level and estimated by 1/7 “Power Profile Law” as given follows[25] :

where,

v is desired wind speed,

v0 is reference wind speed,

h is the desired height,

h0 is the reference height

α value in the equation above can be calculated as follows[25],

this value is approximated as "1/7" in calculations.

One remote sensing tecnique of the wind profile is LIDAR(Light Detection and Ranging) which is based on Doppler Effect to determine wind characteristics. In another method, ANFIS(Adaptive Neuro-fuzzy interference system) based clustering algorithm is used to predict wind speed.

Weibull distribution is used to determine the wind distribution and gives an indication of what percentage of time a certain wind speed occurs in a given site. Weibull distribution is given as follows:

where,

v is the wind speed

k is the shape parameter

α is the scale parameter

Therefore energy yield over a period of time T can be defined as follows,

where, P is the generated power

f(v) is the Weibull function

T=8760 hours (1 year)

Minimum wind speed that is needed to start to rotate the turbines' blade is cut-in wind speed.

1. **Current Wind Turbine Systems**
2. **Mechanical Aspects**
3. **Electrical Aspects**
4. **Flux Orientations in PM based systems**
5. **Importance of modularity in WEC systems**

**References**

[1] Y. Xia, K. H. Ahmed and B. W. Williams, "Wind Turbine Power Coefficient Analysis of a New Maximum Power Point Tracking Technique," in IEEE Transactions on Industrial Electronics, vol. 60, no. 3, pp. 1122-1132, March 2013.