Semiconductor Optoelectronics, *Vol. 42 No. 1 (2023), 444-452*
https://bdtgd.cn/

Semiconductor Optoelectronics ISSN: 1001-5868

A NOVEL REVIEW ON WIND ENERGY CONVERSION SYSTEM

S. Karthikeyan[1], Dr. C. Ramakrishnan[2]
Research Scholar[1], Associate Professor and Head[2]
Department of ICE[1], EEE[2], SNS College of Technology (Autonomous) [1&2],
Coimbatore-641035, India.

Abstract

Energy is the complete source of human life. Wind energy is gaining greater importance in today's world. Wind Energy Conversion System (WECS) has a greater concern in recent years towards renewable source of energy in the production of electricity. Enormous research and development are being concentrated today towards the growth of WECS development. In recent years wind turbines plays a major role and a challenging task in the production of energy which is environment friendly with towers to increase the wind turbines above the ground to capture the strongest wind to generate more energy for electricity production. This article gives a review on WECS its growth across the world, general structure and components of Wind Energy Conversion System and an overview of wind turbines respectively.

Introduction

The wind system that presents in the earth surface vary based on the variation of pressure in air due to solar heating variation. Rising and cooling of air are based on the variation of solar heating. The wind pattern in turn change to seasonal variation based on the temperature difference that exist between land, seas, mountains and valleys [1]. Based on the roughness of the feature of ground like vegetation and house the wind speed gradually slows down. The windspeed is normally calculated by wind maps or meteorology departments. Generally, wind speed data is drastically slow in many regions of the world where 4-5 m/s annual wind speed will make up small-scale wind power generation of electricity. Wind energy system has a major role in development of country based of the electrical energy consumption as the population is increasing day by day. Wind energy is the rapidly growing power generation technology from the strength of renewable resources in recent years. Energy extraction is a challenging task in many industrial consumptions due to inadequate resources, pollution issue and high fuel cost etc., The role of renewable energy has a greater impact in present decade in which wind energy is an attractive research area in the present era. The use of wind turbines with control system has a greater penetration in wind energy generation which has a complimentary of minimized cost and maintenance of installation for a long period of time. Recently wind energy utilization has attained a drastic growth in North America, Europe and Asian countries [2][13]. Global Wind Energy Council (GWEC) have presented a report on the capacity of wind energy installed in 2012 which exceeded 44GW globally. The increase in modernization and industrialization leads to high demand of energy process. Effective solution has to be focused to overcome the errors exist in the environment such as insufficient resources of energy used in power generation, emission of carbon dioxide and emission of greenhouse gas results in global warming through renewable energy sources. By the year 2020 nearly 30 percent of excessive growth rate and 12 percent equal foreseeable penetration as excessed which lead into a global electricity demand respectively [3]. Wind energy generation capacity has tripled in last five years in top five countries depicted in figure 1 with greater than 20W of energy source in which China (188GW), Germany (56GW), United States of America (89GW), India (33GW) and Spain (23GW) according to the report gathered by GWEC. Among the report, India as power capacity of 63GW with 19 percent of electricity production with renewable energy [4][6].

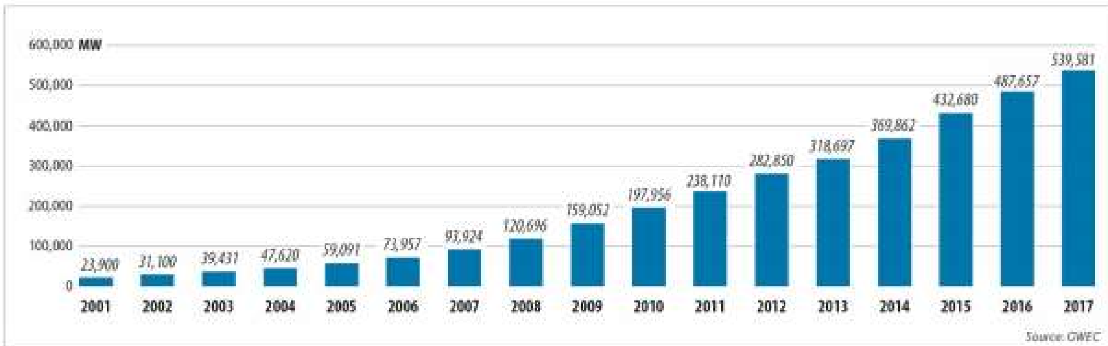


Figure. 1: Wind energy installed across the world [5]

Different Energy sources like hydro power energy, bio-fuel energy, wind energy is the type of renewable energy resources in which wind energy rate is considered to gain higher share rate in the market when compared to other renewable resources [5][7]. Hence future energy challenge demand is highly concentrated on wind energy conversion which are dependent on the country's growth [8].

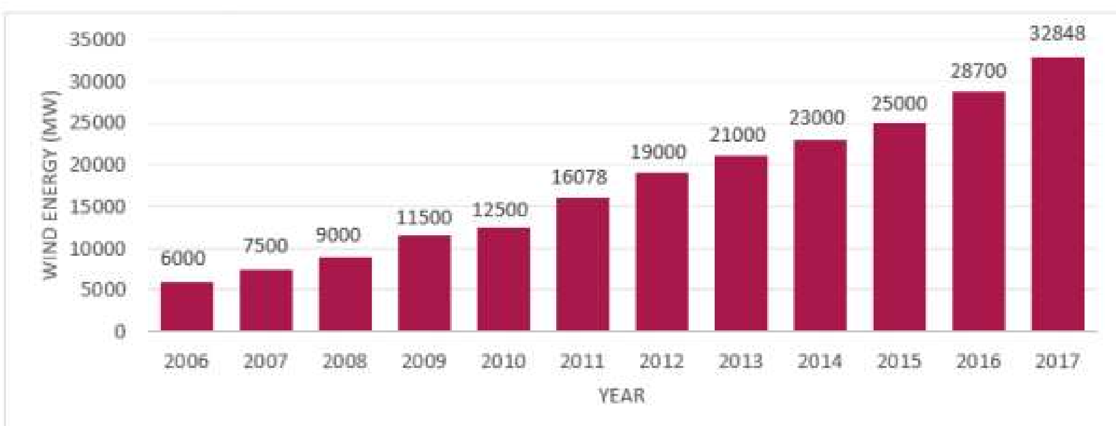


Figure 2: Cumulative wind energy generation installed in India

Figure 2 shows a cumulative wind energy generation installed in India. Nearly 175GW energy generation through renewable energy is targeted by the Government of India by the year 2022 relying with 100GW of Solar Power, 60 GW of wind Power, 10GW of Bio-power and 5GW of small capacity of hydro-power [9]. India is the fourth largest wind power installed with a capacity of 38.124GW which has mainly spread among western, southern and northern regions. In the past decades totally 18 MTOE of primary energy is increased by 1980 and 104 MTOE in 2011 respectively. When compared to other countries India's potential towards renewable resources are vast and remains untapped [10].

Wind Energy Technology

Wind energy acts as a direct mechanical power and indirect electrical power in which WECS plays a major role in conversion of wind power to electrical power. Many sub-systems and components are present in WECS which is a complex electro mechanical energy convertor which plays a crucial role in energy conversion [11].

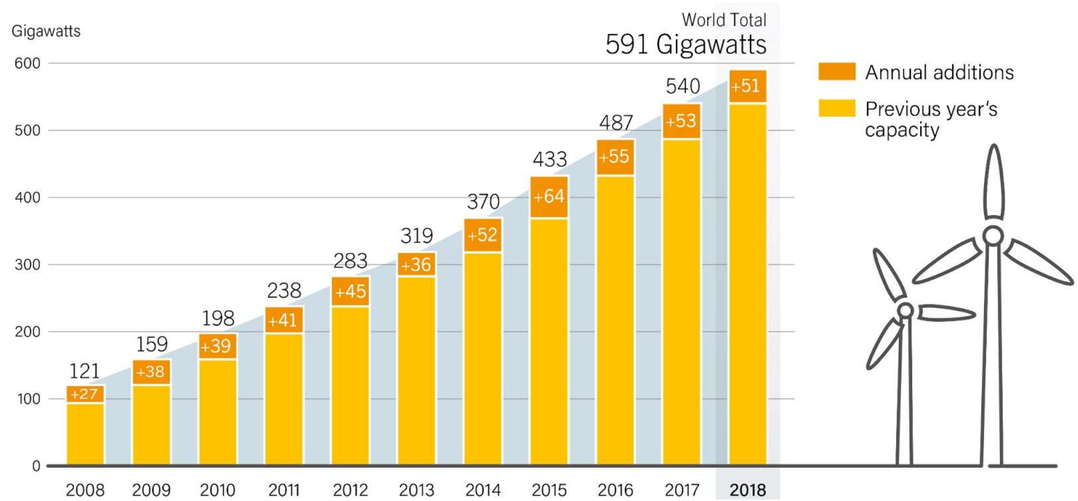
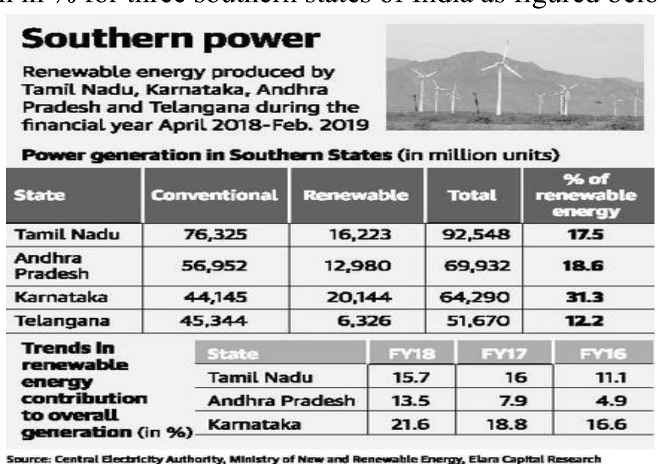


Figure 3. Installed wind power generation system capacity from 2008 – 2018

Figure 3 depicts wind power generation system capacity installed from the year 2008-2018 shows a remarkable growth of power generation capacity. The latest news from Ministry of renewable energy of India from the central electricity authority, has gave the RE contribution to overall generation in % for three southern states of India as figured below [2][3].



Southern power

Renewable energy produced by Tamil Nadu, Karnataka, Andhra Pradesh and Telangana during the financial year April 2018-Feb. 2019

Power generation in Southern States (in million units)

State	Conventional	Renewable	Total	% of renewable energy
Tamil Nadu	76,325	16,223	92,548	17.5
Andhra Pradesh	56,952	12,980	69,932	18.6
Karnataka	44,145	20,144	64,290	31.3
Telangana	45,344	6,326	51,670	12.2

Trends in renewable energy contribution to overall generation (in %)

State	FY18	FY17	FY16
Tamil Nadu	15.7	16	11.1
Andhra Pradesh	13.5	7.9	4.9
Karnataka	21.6	18.8	16.6

Source: Central Electricity Authority, Ministry of New and Renewable Energy, Elara Capital Research

Figure 4. Power generation in southern states from 2018-19

The wind power installation in India will increase upto 2.07GW in the last financial year of 2019 – 2020 and 31% will increase as compared to 1.58GW in the financial year of 2018 -2019. The overall installation of wind energy in the year of 2019- 20 as 37.69GW as compared to the financial year of 2018- 19 to be 35.63GW [12]. The air can create different two types of dynamic forces when it flows over the surface and another as lift force, were these two forces are responsible for generating the torque power needed for rotation of the turbine blades. The power of wind P_{wind} can be expressed as follows,

$$P_{wind} = 0.5\,\rho\pi\,R^2\,V_w^3 \qquad \text{.....(1)}$$

Where,

ρ is the air density,

R is the turbine blade radius and

V_w denotes air flow speed

Coefficient of turbine power and function of the speed ratio are expressed and the power captured by the turbine blade is expressed as follows,

$$P_{blade} = 0.5\,\rho\pi\,R^2\,V_w^3\,C_p\,(\lambda) \qquad \text{.....(2)}$$

The power coefficient of tip speed ratio is significant tool in the characterization of wind energy converters and the coefficient of power can be varying in the pitch angle. The overall performance control of wind energy conversion system is the most important thing for generation of electric power from the wind energy and the controlling methods are applied to all the various parts of subsystem of WECS [6][7]. One of the most important features in WECS is MPPT control system. It has the ability to operate at maximum power point under the different speed of wind. The MPPT algorithm enable the wind turbine system to maximize the efficiency of energy from wide range of wind speed [8]. The comparison of maximum power point in turbine is compared and discussed in the table 1.

Table 1. Comparison of various MPPT algorithm [2]

MPPT Algorithm Types	**Complexity**	**Speed**	**Wind speed measurement**	**Performance**
Tip speed ratio control	Simple	Fast	Yes	Very good
Optimal torque control	Simple	Fast	No	Very good
P & O control	Simple	Depended	No	Good
Power signal feedback control	Simple	Fast	Yes	Good

General Structure of Wind Energy Conversion System

Nowadays the main goal of wind energy is to maximize the usage of harvested energy during a specific period of time by power point tracking system. This mechanism can be achieved by functioning maximum power point by keeping the tip speed ratio at an optimal point regardless of the wind gusts. In order to analyse the energy conversion system control structure and strategies has to be aggregated with main controlled variables like power, torque and speed. Testing a wind turbine in a tunnel can be expensive solution where real time emulators can be used in reliable for the production of electricity. The kinetic energy present in the wind can be capable to convert kinetic energy to mechanical energy which in turn can be used directly by various machineries for power supply. This direct power generation are produced with the help of wind turbines coupled with electric generators. Wind energy conversion are considered to be more reliable with a life span of 20-25 years compared to other conventional power production technologies [1][8][9]. Wind technology can rotate on vertical and horizontal axis forming Vertical Axis Wind Turbines (VAWT) and Horizontal Axis Wind Turbines (HAWT [10]

Horizontal Axis Wind Turbines (HAWT)

HAWT depicted in figure 5 (a) are considered to generate maximum amount of wind energy comparable to other tall tower-based wind production type. From the observation of HWAT the WT tower rises by 10 meters, the wind speed increases by 20 percent which results in 34 percent of output power. This is achieved by variable blade pitch that enables the turbine blades to adjust the angles of the blades optimally in order to achieve the maximum amount of energy. As shown in the figure 5 HWAT the electrical generator is present at the top of the tower [4]. Gearbox present in HWAT is used to obtain the appropriate speed to increase the electrical generator due to slower rotation of WT blades. There are certain drawbacks in HWAT where the configuration such as tower construction are high to hold the generator, gearbox with heavy blades, high tower radar installation which causes signal reflection and finally additionally extra control mechanism is required to control the direction of blades present in the wind turbines [9].

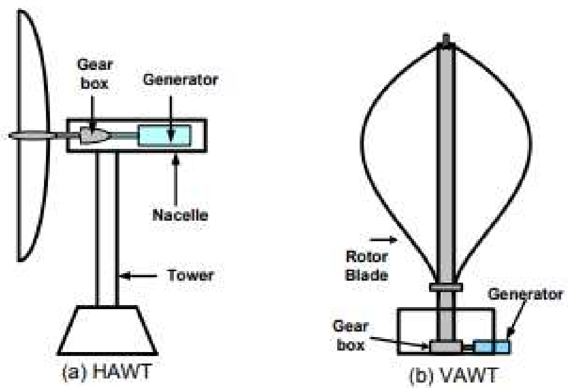


Figure 5: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT)

Table 2: HAWT and VAWTs features [10[12]

Feature	HAWTs	VAWTs
C_p at 12 m/s	0.08	0.05
Efficiency	High (around 70%)	Low (below 60%)
Initial wind speed	High (2.5:5 m/s)	Low (1.5:3 m/s)
Rotation speed	High (5:12 m/s)	Low (3:7 m/s)
Height	Large (around 100 m)	Small (around 10 m)
Rotation area for blades	Large	Small
Direction of wind	Dependant	Independent
Maintenance	Complex	Simple
Noise	5-60 dB	0-10 dB
Effect on birds	Great	Low
Generator location	Top of the tower	The ground
Application	Off shore& On shore	On shore

Vertical Axis Wind Turbines (VAWT)

The diagrammatic representation shown in figure 5 (b) is the vertical Axis Wind Turbines. These turbines do not need any additional controls compared to HAWT. The efficiency of VAWT is relatively smaller with short towers with less rotation speed. As shown in the figure the blades of VAWT are organized vertically to the ground. In VAWT the wind is are perpendicular to the blades frequently which leads to less controllers compared to HAWT. The gearbox and the generator are fixed to the ground region. One drawback is that these type of turbines as shorter towers where high speed cannot be achieved due to shorter towers. This results in smaller output power compared to other types of power production system. A comparative analysis between HAWT and VAWT are represented in table 2 which gives a clear idea about the features and its complexity and simplicity of each turbines [4][13].

Components of WECS [1-7]

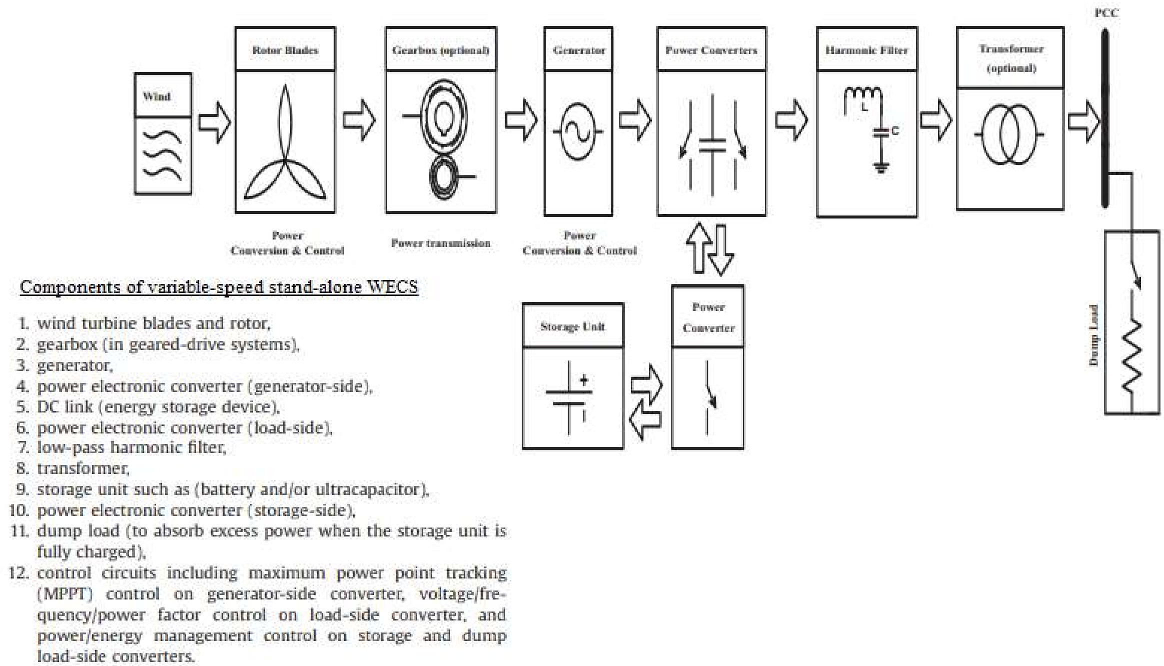


Figure 7: Components of variable -speed and stand-alone WECS

Wind turbine represented in figure 7 consists of various components and -subsystems namely roto hub and blade, generator, tower and gearbox which is discussed in detail in the following sections.

Rotor Hub and Blade: The integration of wind and the rotor produces power generation based on wind turbine. The rotor has turbine blades and hub in which blades are arranged as a set of wings like an aeroplane. The rotational speed of the blades is controlled by pitch drive present in the rotor because the speed of the blade ranges from 1000-3600 RPM respectively [2].

Gearbox: Two major components namely bearings and gear are the main components in which the turbines rotation speed is around 100 RPM. For the production of electrical production, the speed range should be around 1000-3600RPM. The maximum speed for the production electricity is produced with the help of Gearbox [2][3].

WECS topologies and Generators

Generally, WECS are established with different power rates based on kilowatts to megawatts specified in table 3.

Table 3: Different power range with size and applications

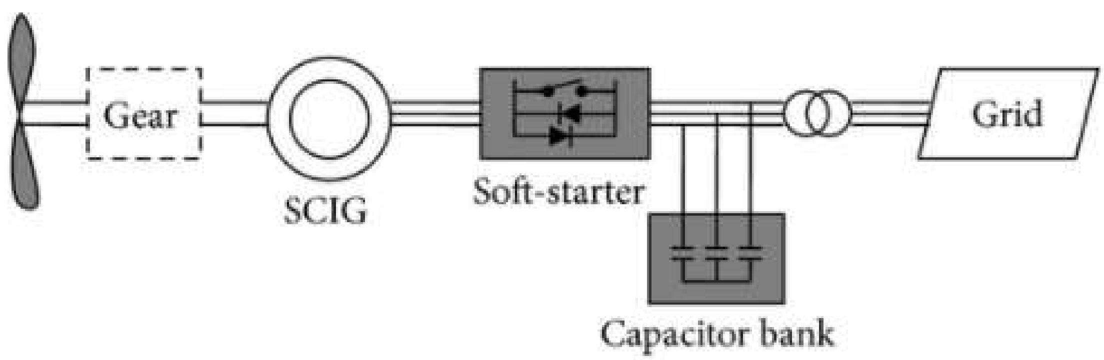
WT power range	Size	Applications
Micro wind turbines	3 kw	Stand alone
Small wind turbines	10 to 100 kw	Hybrid system
large wind turbines	500 to 1500 kw	Grid connected
Offshore wind turbines	Greater than 2000 kw	Wind power stations

Variable or fixed speed wind turbines can either be small, extensive or grid based connected wind turbines based on the power rates. Basically, synchronous generators are normally used for power generation in which induction generators are progressively used nowadays due to low cost, brushless, self-protected against faults on short circuits. Moreover, induction generators are adequate due to its dynamic response for the production of electricity at different speed [11][12].

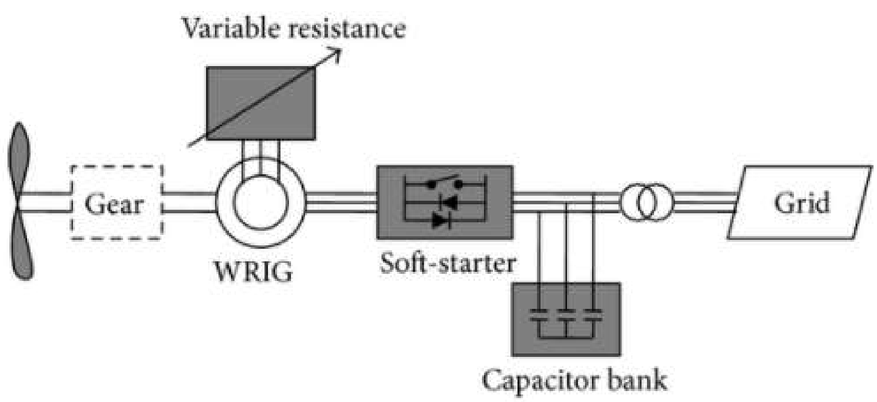
Asynchronous or induction generator:

Induction generators are matured technology with low cost, low maintenance and better dynamic response with simple control operations. These generators are robust in nature with best protection construction against short circuit. In order to generate continuous voltage and active power supply source of continuous reactive power is required either through external VAR source like power electronic converter and switched capacitors respectively. These types of external support are called as self-excited induction generators (SEIG). Induction generators are classified into two bases on the rotor type namely wound-rotor induction generator (WRIG) and Squirrel-cage induction generator (SCIG) depicted in figure i and ii. In WRIG the rotor consists of three phase winding whereas SCIG contains short circuit conducting bars in shape like a squirrel cage. The highlight of WRIG where it can be reconfigured as brushless doubly fed induction generator (BGFIG) and doubly fed induction generator (DFIG) [11][12].

(i) Squirrel cage induction generator (SCIG) [11, 12]



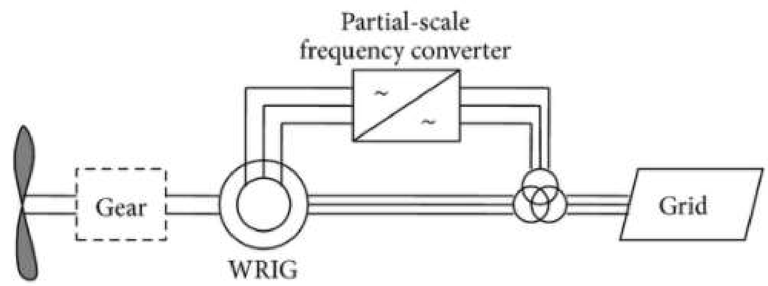
(ii) Wound rotor induction generator (WRIG) [11, 12, 13]



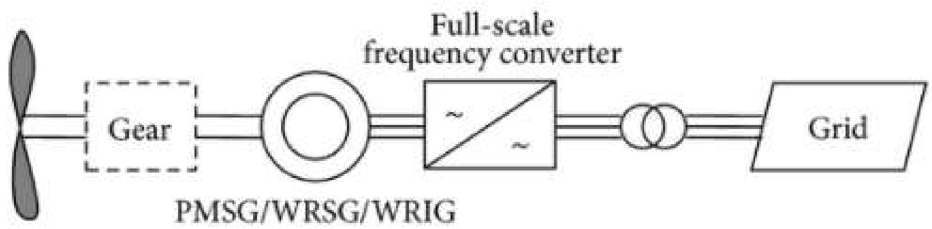
Synchronous generator:

Synchronous generator (SG) is designed as similar to induction generator. The main advantage of SG based WES compared to induction generator is elimination of gearbox with reduced maintenance requirements with increased system reliability and efficiency. Wind turbine systems using SG are also known as direct-drive or gearless wind turbines high number of poles, the salient-pole rotor SGs are usually used for low-speed applications [6]. Synchronous generator has two further applications i.e., wound-rotor synchronous generator (WRSG) and permanent-magnet synchronous generator (PMSG) which is described in upcoming figures [11][12].

(i)permanent magnet synchronous generator (PMSG) [11]



(ii)wound rotor synchronous generator (WRSG) [12]



(3) Other types of potential interest:
(i)high-voltage generator (HVG) [11, 12],
(ii)switch reluctance generator (SRG) [11, 13],
(iii)transverse flux generator (TFG) [11]

Conclusion

The review article is mainly focused and discussed about wind energy system which highlighted about electrical technologies, wind energy conversion system with its future direction. WECS was discussed briefly with its components namely converter, generators and storage technologies. Wind energy installed across the world is discussed in detail. Analytical review of various stand-alone WECS generator types and the general structure of Wind Energy Conversion System and different wind turbines is explained in detail. Wind energy as a permanent key solution for present global energy concern and it is an evident that wind energy is not only environment friendly but also socially profitable in financial point. Finally, it is mandate to move with further research concentrating potential environmental research.

References:

1. G.S. Mario. Wind turbines: New challenges and advanced control solutions. International Journal of Robust and Nonlinear Control, 2009,19:1-3.
2. Zuher Alnasir, An analytical literature review of stand-alone wind energy conversion systems from generator viewpoint, Renewable and Sustainable Energy Reviews 28 (2013) 597–615.
3. Sharma P., Bhatti T.S., K.S.S. Ramakrishna. Control of reactive power of autonomous wind-diesel hybrid power systems. In: Proceedings of the joint international conference on power electronics, drives and energy systems and power, India 2010. p. 1–6.
4. Olivares DE, Canizares CA, Kazerani M. A centralized optimal energy management system for microgrids. IEEE Power and Energy Society General Meeting 2011:1–6
5. Polinder H., van der Pijl F.F.A., de Vilder GJ, Tavner P. Comparison of direct drive and geared generator concepts for wind turbines. In: Proceedings of the IEEE international conference on electric machines and drives 2005. p. 543–50.
6. Kendouli F., Abed K., Nabti K., Benalla H., Azoui B. High performance PWM converter control based PMSG for variable speed wind turbine. In: Proceedings of the 1st international conference on renewable energies and vehicular technology 2012. p. 502–7
7. Liserre M, Cardenas R, Molinas M, Rodriguez J. Overview of multi-MW wind turbines and wind parks. IEEE Trans Industr Electron 2011;58(4): 1081–95.
8. Abdullah M.A., Yatim A.H.M., Tan C.W. A study of maximum power point tracking algorithms for wind energy system. In: Proceedings of the IEEE 1st conference on clean energy and technology 2011. p. 321–26.
9. PengfeiLi, WeihaoHu, RuiHu, QiHuang, JunYao, ZheChen," Strategy for wind power plant contribution to frequency control under variable wind speed", Renewable Energy, 130, (2019):1226-1236.
10. Abdullah Al-Faruk and Ahmad Sharifi ," Flow field and performance study of vertical axis Savonius type SST wind turbine," Energy Procedia 110 (2017): 235 – 242.
11. Kotb B. Tawfiq, A. M. Mansour and E. E. EL-Kholy,"Ultra-Modified Control Algorithms for Matrix Converter in Wind Energy System ", Journal of Physical Science and Application, 6 (2018), doi: 10.17265/2159-5348.
12. J. J. Rubio, M. Figueroa, J. Pacheco, and M. Jimenez-Lizarraga, "Observer design based in the mathematical model of a wind turbine," International Journal of Innovative Computing, Information and Control, vol. 7, no. 12, pp. 6711–6725, 2011.
13. I. Pourfar, H. A. Shayanfar, H. M. Shanechi, and A. H. Naghshbandy, "Controlling PMSG-based wind generation by a locally available signal to damp power system inter-area oscillations," European Transaction on Electrical Power, 2012.