Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 162 (2019) 38–47

Energy Procedia

www.elsevier.com/locate/procedia

Special Issue on Emerging and Renewable Energy: Generation and Automation

Wind Energy Conversion System Topologies and Converters: Comparative Review

Kotb B. Tawfiq [a]*, Arafa S. Mansour [a], Haitham S. Ramadan [b,c], Mohamed Becherif [c], E.E.El-kholy[a]
[a]*Electrical Engineering Department, Faculty of Engineering, Menoufia University, Egypt*
[b] *Electrical Power and Machines Department, Faculty of Engineering, Zagazig University, Egypt*
[c]*Femto-ST, FCLAB, University of Technology of Belfort-Montbeliard, France*

Abstract

Sources of renewable energy such as wind energy are indigenous and can help in decreasing the reliance on non-renewable energy sources. After introducing the history of wind energy production in Egypt and worldwide besides its techno-economic importance, this paper presents a comparative review on the wind energy conversion systems (WECS). The horizontal and vertical types of wind turbines with their mathematical dynamic models are discussed. Different types of electrical generators used in WECS in addition to their advantages and disadvantages are illustrated. The various AC-AC converters topologies for WECS are explained with a detailed discussion for their features.

Selection and peer-review under responsibility of the scientific committee of the 6th International Conference on Emerging and Renewable Energy: Generation and Automation, ICEREGA 2018.

Keywords: Wind Turbine, WECS, Matrix Converter, AC-DC-AC Converter, Synchronous Generators, Induction Generators, Doubly Fed Induction Generator.

Nomenclature

A_r	Area of turbine rotor in m^2	VVVF	Variable voltage variable frequency
DFIG	Doubly Fed Induction Generator	WECS	Wind energy conversion system
HAWT	Horizontal axis wind turbine	WT	Wind turbine
IG	Induction generator	c_p	Power coefficient
IGBT	Insulated gate bipolar transistor	v_w	Speed of the wind in m/s
MC	Matrix converter	R_r	Radius of the rotor blade
PMSG	Permanent magnet synchronous generator	P_m	Mechanical power generated from wind in Watt
SCR	Silicon controlled rectifier	ω_r	Angular speed of the turbine shaft in rad/s.
SG	Synchronous generator	ρ	Air density in g/m^3,
SRIG	Slip ring induction generator	λ, λ_i	Tip speed ratio and constant
VAWT	Vertical axis wind turbine	θ	Pitch angle

---

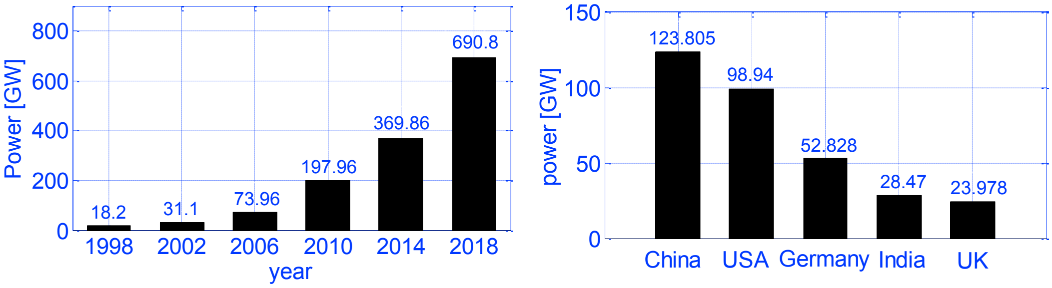
* Corresponding author. Tel.: *Tel: +201066701824, Fax: +20482221848*
E-mail address: kotb.bassem@sh-eng.menofia.edu.eg

1876-6102
Selection and peer-review under responsibility of the scientific committee of the 6th International Conference on Emerging and Renewable Energy: Generation and Automation, ICEREGA 2018.
10.1016/j.egypro.2019.04.005

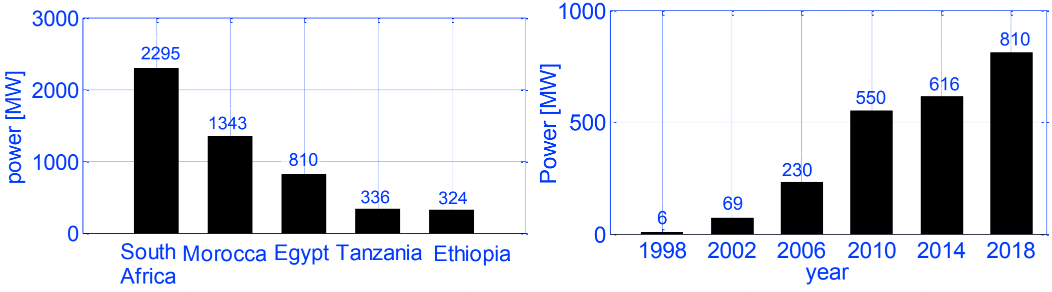
1. Introduction

Worldwide energy demand is rapidly expanding due to the continuous economic progress and the power electronic technologies development. Conversely, traditional petroleum derivatives, for example, coal, oil and flammable gas, which have been the key energy source since the industrial revolution, are confronting rapid consumption. Therefore, the mission to create inexhaustible and clean sources of energy from wind, solar and hydrogen energy becomes more convenient. Among these numerous sustainable assets, wind energy encourages business prospects in substantial power in favor of its safe and naturally sustainable behavior, zero emission, competitive and inexhaustible nature [1, 2].

In 2018, wind energy provides around 5% of the total energy consumption of the world [3]. It is anticipated that energy from wind will be about (20 % and 35%) of the total world's energy in (2030 and 2050) respectively [4]. The worldwide wind energy production has reached 690.8 GW in 2018 from around 19057 wind farms and Europe had the first place with 259 GW and 13290 wind farms [6]. Figure 1(a) depicts the global wind power production in the last two decades in 2018[5]. Production of wind power for the top five countries across the world in 2018 is illustrated in Figure 1(b). China has the highest wind production in the world with 123.805 GW [5]. The USA provides the highest wind power in Americas and the second in the world with 98.94 GW [7]. Germany is the highest in Europe and the third in the world with 52.828 GW. Africa has the lower wind energy production in the world continents with 5.7 GW with 87 wind farms as depicted in Figure 1(c) [5]. Wind power in South Africa is the highest in Africa with 2295 MW [5]. Egypt has the third place and produces around 810 MW of wind energy and the potential of this production is expected to reach (1500 MW and 2500 MW) in (2030 and 2050) respectively [5]. The electrical power generation from wind energy in Egypt started in 1997 by 6 MW and increased gradually as shown in Figure 1(d) to reach 810 MW in 2018 [5]. In onshore, the blowing wind from the sea to land is usually less than perfect. In addition to, the tendency of waves increases and short period swell is created [8]. Therefore, there is an increased interest for offshore wind, as the breeze is regularly more grounded and more uniform in surface of ocean than aground and the expected generated power from the planned offshore is 143.36 GW [9]. European nations are the pioneers in offshore wind. For around 20 years, Denmark has been using it to supply power. Offshore wind in the USA and similar nations can possibly turn into a noteworthy energy hotspot for household applications as waterfront wind sources are plenty [10].



(a) Wind energy trend in the world [5]. (b) Top five wind power production in the world [5].



(c) Top five wind power production in Africa [5]. (d) Wind energy trend in Egypt [5].

Figure 1 : Wind energy trend in the world & Africa [5].

The extracted power from WECS meets substantial amount of electrical power demands. For instance, 20% of the whole power utilization in Denmark is given by wind energy. Recently, different power electronic converter procedures have been created for connecting with the electrical network [11]. The utilization of power converters permits the operation with variable wind speed of wind turbine, and upgraded power extraction. The required fixed values for the grid frequency and voltage can be provided with maximum value for the extracted power in variable speed operation via designed control methods for the power converter [12]. Different control structures, differing in complexity and cost, have been considered for all WECS. Developed control plans coordinated with the power converter are proposed to provide maximum extracted energy at all conceivable wind speeds [13].

This paper highlights the difference between the available WECS topologies and converters. Besides, the choice of the most recommended converters for WECS are introduced. This paper is organized as: Section 1 discusses wind turbine types, features of each and their relevant models. Section 2 introduces the different types of electrical generators used in WECS in addition to their advantages and disadvantages and different topologies used in WECS. Section 3 presents the types of AC-AC converters with a comparison to their features. Finally, Section 4 highlights the conclusions and recommendation for the paper.

2. Wind Energy System

Clean and green wind energy system is one of the renewable energy sources that generate electrical power without fossil fuel sources problems. Therefore, the interest about WECS as a suitable source of renewable energy becomes more vital [14]. Wind turbine (WT) is used for transforming the air kinetic energy to mechanical energy for electrical generators to obtain electrical energy. WTs can rotate about either a horizontal or a vertical axis forming either horizontal axis wind turbine (HAWT) or the vertical axis wind turbine (VAWT). HAWTs are commonly used owing to their several merits, simple configuration especially for higher rates besides their high efficiency and low cost [15].

2.1. Horizontal Axis Wind Turbine

In HAWTs, the electrical generator is at the top of the tower as shown in Figure 2(a). Gearbox is used in most of WECS to obtain the suitable speed to drive the electrical generator due to the slower rotation of WT blades. HAWTs configuration produce maximum amount of energy compared to the other type due to its tall tower base. It is observed that when the height of the WT tower increases by 10 meter, the speed of wind increases by 20% that result in an increase in the generated output power by 34% [16].Variable blade pitch is the main advantage of HAWTs which enables the turbine blades to optimally adjust its angle for reaching maximum amount of energy. The HAWT efficiency is relatively high in favour of the perpendicular moving of turbine blades with wind. The drawbacks of this configuration are: (i) higher cost in tower construction to hold the generator, gear box and the heavy blades, (ii) the radar installation is affected in addition to making signal clutter due to the reflections from HAWT's high tower [17]; (iii) HAWTs require additional control mechanism for controlling the direction of the turbine blades [18].

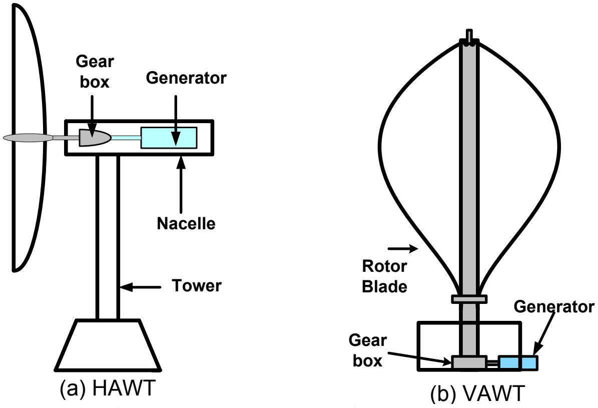


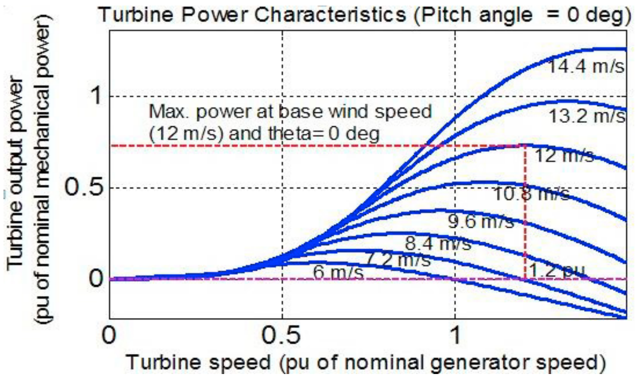
Figure 2: WT types construction [20].

2.2. Vertical Axis Wind Turbine

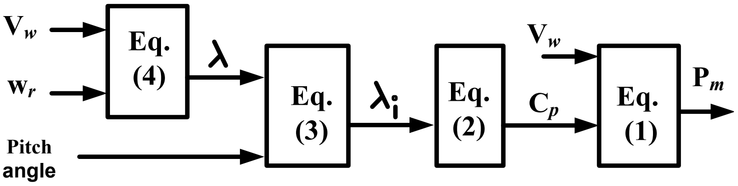
The blades of vertical-axis wind turbines (VAWTs) are rotated around a shaft that is arranged vertically to the ground. One of the advantages of this type is that the wind is perpendicular to the blades all time. Therefore, no additional controller is required compared to HAWTs type [19, 20]. Table 1 illustrates that VAWTs have an easier maintenance process compared to HAWTs. Due to the configuration presented in Figure 2(b), the gearbox and the generator are fixed at the ground. VAWTs have less noise due to their less speed. VAWT type can be carried out in many locations such as high ways and roofs. In contrast to HAWTs, the efficiency of VAWTs is relatively smaller with slower rotation due to shorter towers. Higher speeds could not be achieved with shorter tower. Thus, the generated output power from the VAWT type is smaller compared to the other type [21].

Table 1: HAWTs and VAWTs features [17-20]

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



(a) Mechanical power relation with speed



(b) Mathematical model of wind turbine

Figure 3: Wind turbine generated power and mathematical model.

2.3. Wind Turbine Modeling

The mechanical power produced from either HAWT or VAWT is given in Eq. (1). Equation (2) shows the power coefficient calculation as a function of tip speed ratio and rotor blade pitch angle θ. Figure 3(a) illustrates the variation of the generated power from wind with turbine speed at various wind velocities [22]. Equations (1-4) can be used for modelling the WT either HAWT or VAWT in Figure 3(b).

$$P_m = \frac{1}{2}\rho c_p A_r v_w^3 \qquad (1)$$

$$c_p(\lambda,\theta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\theta - 0.002\theta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \quad (2)$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\theta} - \frac{0.003}{\theta^3+1}} \quad (3)$$

$$\lambda = \frac{\omega_r R_r}{v_w} \quad (4)$$

where v_w represents the speed of the wind in m/s, ρ is air density in g/m^3, ω_r is the angular speed of the turbine shaft in rad/s. P_m is the mechanical power generated from wind (watt), A_r the area of turbine rotor in m^2, ($A_r = \pi R_r^2$, where R_r is the radius of the rotor blade) and, c_p is the power coefficient.

3. WECS Topologies and Generators

Different WECS are established for various power rates, from few of hundred kilowatts to several megawatts as specified in Table 2. This prompts numerous WECS plans based on numerous criteria as shown in Figure 4. For example, fixed or variable speed wind turbine, the power rate which can be either small or extensive wind turbine or the grid connected wind turbine [23]. Generally, synchronous generators have been utilized for power generation. However, induction generators (IGs) are progressively being utilized nowadays due to their relative worthwhile highlights over conventional synchronous generators, such as low cost, brushless and rugged construction and self-protection against short circuited faults. Moreover, its dynamic response is adequate and able to produce electric power at different speed. This latter enables the operation of IGs in isolated mode to supply remote regions where network expansion is not practical. In conjunction with the synchronous generator, IG satisfies the increased requirement for local power [24-26].

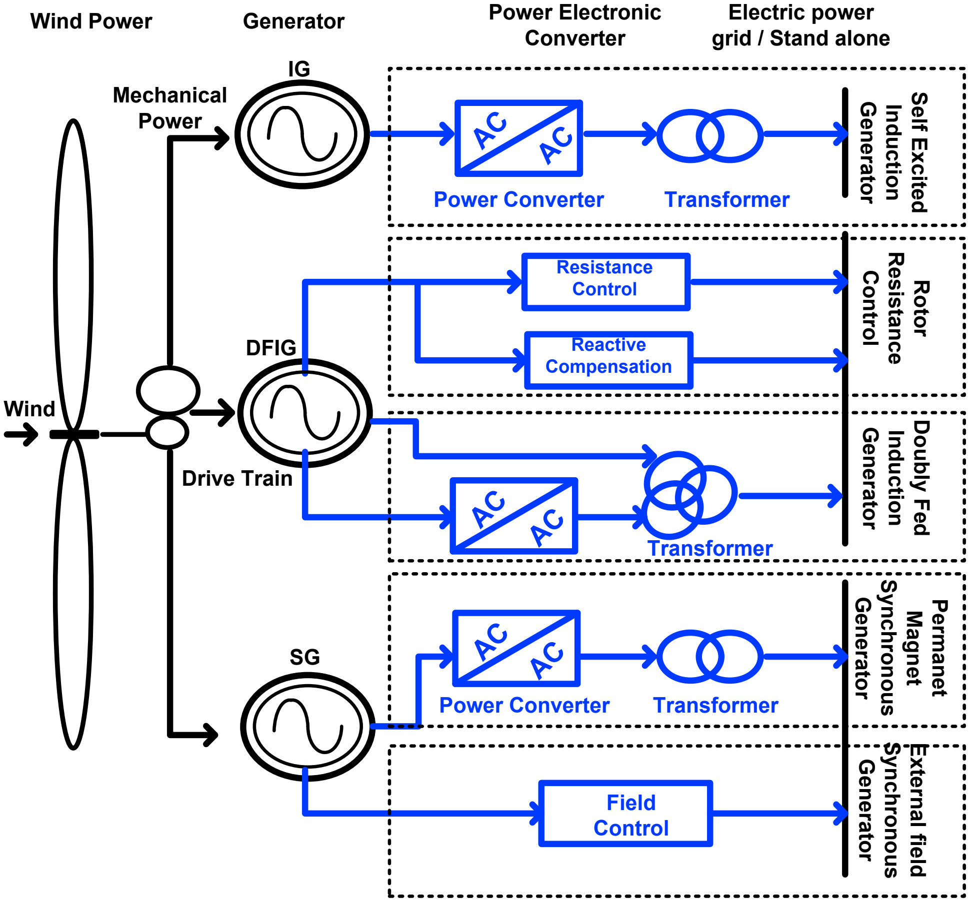


Figure 4 : Synoptic of different WECS schemes.

Table 2 : Size of WECS.

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

3.1. Induction Generator

Using of the induction machines in different applications becomes more acceptable after the recent advancement in power electronic technologies. IGs are utilized for quite a while in a settled speed wind turbines, where the pitch control are managed for control constraint [27]. IGs are generally inexpensive, robust and require low maintenance. Their fundamental disadvantage is the requirement of capacitor bank to supply the reactive power requirement. The use of single capacitor enables providing the reactive power required for the self-excitation of an off grid application when the generator supplies a constant AC load and driven at fixed speed. For variable speeds wind turbine back-to-back PWM inverters are utilized, where the control arrangement of the inverter in the IG side directs the machine torque. Thus, the rotor speed, subsequently keeping the frequency inside characterized limits; then again the inverter in the grid side controls the reactive power at the coupling point. The reactive power can likewise be given by a thyristor-controlled reactor static volt-ampere reactive compensator at the generator terminals to control its voltage when utilizing the IG in a variable speed wind turbine as illustrated in Figure 4 [28].

3.2. Slip Ring Induction Generator

Doubly fed induction generator (DFIG) is the broadly utilization of the slip ring induction generator (SRIG). This type requires the immediate coupling of the stator with the framework though the slip ring to be fed by a converter. More recent research interest has focus on the drive engineering side with sub-and super-synchronous cascade by utilizing of cycloconverters on the rotor side. The simultaneous alternative is currently based on full AC-DC-AC as shown in Table 3. This offers a substantial working reach around ± 33 % of the synchronous speed. Likewise the slip values decide the power, which the converter of the DFIG must be intended for [29]. For ± 30 % speed variation from the synchronous speed, the rated power of the converter should be around 30 % of the rated generator, while the converter is dimensioned of the rated generator in the wind turbine with IG, SG and PMSG. The assessment of these well-established certainties prompts the DFIG being the potential competitor of wind vitality generator framework. IGs, either squirrel cage or SRIG require reactive power source, but in the DFIG the reactive power compensation is accomplished by the grid side converter and the DC capacitor, where this subsystem works as a static compensator, another system to guarantee the responsive pay is reactive current injection of a in the rotor [30].

3.3. Synchronous Generator

The industry of power generation solely utilizes substantial SGs because of their variable produced reactive power that helps in voltage control. SG of the wind turbine to the grid back-to-back PWM voltage source inverters are interfaced between the SG and the grid. The grid side PWM inverter takes into account the control of real and reactive power transferred to the grid [31]. The generator side converter is utilized to regulate the electromagnetic torque. The utilization of SG with multiples, therefore, a substantial diameter synchronous generator ring, stays away from the establishment of the gearbox as favorable position after a huge increment in weight will be acknowledged in partner and nearness of the rotor winding [32].

Table 3 Comparison between the different Generators used in WECS [27-30]

Feature	Induction Generator	Synchronous Generator	DFIG
Speed Range	Full	Full	Limited (±30% around N_s)
Energy production	Low	High	Medium - High
Active and Reactive power control	Complete	Complete	Complete
Brushes	No	Yes	Yes
Reliability	High	High	Medium
Cost	Low	Medium - High	Medium
Gear Box	Required	Not Required	Required
Maintenance	Low	High	High

4. Power Converters

AC-AC converters can be divided into two groups voltage regulators and frequency converters as shown in Figure 5. The AC to AC voltage regulators control the rms value of the AC voltage with no change in its frequency. The output voltage from these converters can be provided using either phase control with natural commutation or integral cycle control with forced commutation [33]. These converters are used for voltage stabilizer application to regulate only voltage magnitude. Their applications cannot involve variable speed operation in WECS due to their disability of frequency control [34]. Control of both voltage magnitude and frequency is a significant condition for converters to be used for WECS with variable speed operation. This condition can be achieved using the frequency converters [35].

Frequency converters provide control for both the voltage rms value and frequency. As illustrated in Table 4, frequency converters can be utilized for variable speed drives, WECS and marine applications [36]. These converters can be either direct or indirect form. The indirect converter (AC/DC/AC converter) provides indirect conversion of AC voltage via rectifier stage, DC link capacitor and inverter stage, so it has a massive size construction. The direct type can be classified into the cycloconverter and Matrix converter (MC). Cycloconverter is a naturally commuted direct AC-AC frequency changer which can control the rms value of the load voltage with no real limitation on its size unlike the silicon controlled rectifier (SCR) inverter with commutation elements. As described in Table 4, the main limitations of a naturally commutated cycloconverter are: (i) Limited frequency range for sub harmonic-free and efficient operation, (ii) Poor input displacement power factor, particularly at low output voltages [37] . MC provides a direct AC conversion with no DC link. Therefore it has a simple construction. The advantages of MC are its capability to control the rms value of the load voltage, besides the output frequency that can be greater, equal or less than input frequency, bi-direction power flow control, control the phase angle between the input voltages and the input current and to attain unity input displacement factor [38].

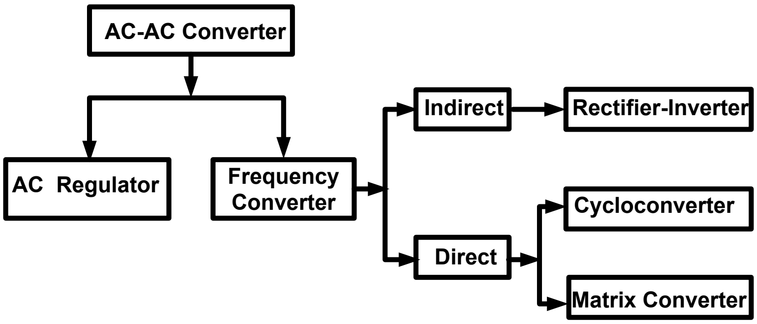


Figure 5: AC-AC Converter

4.1. *AC Voltage Regulator*

Voltage regulators are used for controlling the rms value of the voltage across the load at constant frequency. Voltage control is obtained from AC to AC voltage regulator by two strategies: the phase control under natural commutation using pairs of silicon-controlled rectifiers (SCRs) or triacs; and the on/off control under forced commutation using fully controlled self-commutated switches such as power transistors, gate turn-off thyristors (GTOs), MOS-controlled thyristor and insulated gate bipolar transistors (IGBTs). AC voltage regulators cannot be used in variable speed operation in WECS as the output frequency cannot be controlled [37].

4.2. *Frequency Converter*

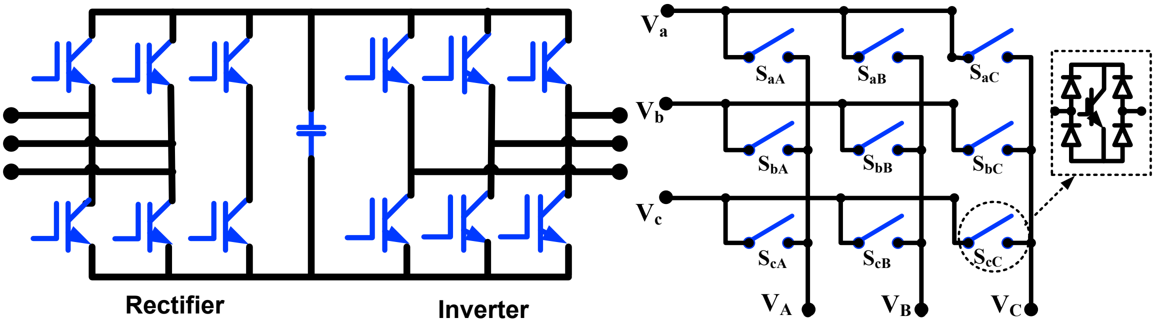
Frequency converters are those converters that can convert the AC voltage signal at certain frequency into AC signal with another desired frequency. The conversion process can be occurred directly either through one stage without using any DC link or indirectly using DC link between the two sides. The converter consists of two stages: rectification and inversion stages.

4.2.1. Indirect AC to AC Frequency Converter (AC-DC-AC)

AC/DC/AC converter is an electrical method to decouple the two frequencies. Two indistinguishable three-phase bridges, one capacitor and inductors make the power circuit. In acceleration mode, the AC/DC/AC converter can be divided into a rectifier and an inverter, as demonstrated in Figure 6(a) [39]. First, forced-commutated three-phase controlled rectifier is required to acquire a coveted voltage in the DC-connect. The AC/DC converter must act like a voltage support keeping in mind the end goal function as a constrained commutated rectifier. In other words, the DC-Link voltage must be more than the peak DC voltage created by the rectifying diodes in passive mode. The inductance L plays the boost voltage operation in combination with the capacitor C and acts at the same time as a low-pass filter for the AC line current. Therefore, the choice of L and C values is the best possible working of the rectifier. Second, the inverter is in charge of driving the wheel motor, controlling its precise speed for various load torques [40].

4.2.2. Direct AC to AC Frequency Converter

The direct frequency converter can be classified into: (i) cycloconverter which operates as a direct AC-AC frequency changer with an output frequency less than input one; (ii) matrix converter which can control the load voltage rms value and can give output frequency that may be greater, equal or less than input frequency [37].



(a) Indirect AC-DC-AC Converter *(b) Direct Matrix Converter*

Figure 6: Indirect converter and MC topologies

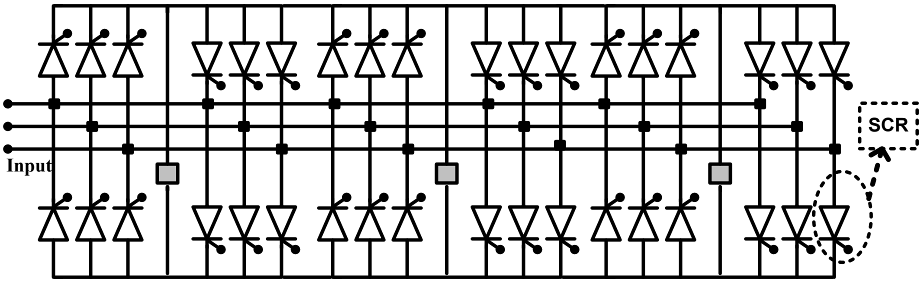


Figure 7: Three-phase 6-pulse cycloconverter with isolated loads.

4.2.2.1. Cycloconverters

The essential standard of cycloconverters to build an alternating voltage wave of lower frequency from progressive sections of voltage waves of higher frequency AC supply. Grid-controlled mercury- arc rectifiers were utilized as a part of these converters introduced in Germany in the 1930s to get 16.667 Hz single- phase supply for ac series traction motors from a three- phase 50-Hz framework while in the meantime a cycloconverter utilizing 18 SCRs providing a 400-hp synchronous motor was in activity for a few years as a power station assistant drive in USA. With the improvement of large power SCRs and microchip based control, the cycloconverter today is a developed down to earth converter for application in large power low-speed variable-voltage variable- frequency (VVVF) AC drives in cement and steel moving plants in addition to factor speed consistent frequency frameworks in flying machine and maritime boats. The primary constraints of the conventionally commutated cycloconverter are: (i) restricted frequency extends for sub harmonic-free and efficient operation; and (ii) poor input displacement power factor, especially at low yield voltages [38].

4.2.2.2. Matrix Converter

MC is an AC-AC direct converter that comprises of nine bidirectional switches which has a simple construction due to the lack of the DC link as depicted in Figure 6(b). MC has the ability of controlling the phase angle between input voltage and the input current and obtaining unity input displacement factor can be obtained [40]. Moreover, it has minimal energy storage requirements, which permits to dispose of massive and lifetime-constrained capacitor. However, MC does not take its proper place in the industry as it has some disadvantages. It has limited input output voltage transfer ratio to 0.866 for sinusoidal input and output waveforms. As a result of the lack of switches that allow the current to flow in both directions, some MC types need more number of switches compared to the conventional rectifier –inverter type. Input filters are needed to reduce high frequency harmonics and clamping circuit are needed to protect switches from over voltages due to energy stored in inductive loads. The main structures of MC are matrix switches, input filter and clamping circuit [40].

Table 4: Three –Phase AC-AC Converter types [36-40]

	AC Voltage Regulator	Frequency Converter		
		Indirect [Rectifier-Inverter]	Direct	
			Cycloconverter	Matrix Converter
Size	Simple	Massive	Simple	Simple
No. of Switches	6	12	9	9
Reactive Capacitor	Non	Exist	Non	Non
Output Frequency	Uncontrolled	Wide range	Less than input	Wide range
Power Flow	Bi-directional	Bi-directional	Uni-directional	Bi-directional
Input Displacement Factor Control	Uncontrolled	Controlled	Un-controlled	Controlled
Commutation	Natural & forced	Forced	Natural	Forced
Reliability	High	Medium	Low	High
Cost	Low	High	Low	Medium
Application	Voltage stabilizer	WECS and Marine	Low speed drive	WECS and Marine

5. Conclusions and Recommendations

This paper provides a comparative review of WECS. The various types of wind turbine and wind turbine modeling are discussed. It presented the different types of electrical generators used in WECS in addition to their advantages and dis advantages. History of wind energy production is displayed in Egypt and across the worldwide. The different types of AC-AC converters strategies are reviewed. Due to the features of matrix converter, this paper strongly recommends using it in WECS application in favor of its ability of bi-direction power flow, wide range of output frequency, control of input displacement factor besides the simple and compact form.

Reference

[1] 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.

[2] Ackermann T, Der LS. An overview of wind energy status 2002. Renewable and Sustainable Energy Reviews 2002; 6(1–2):67–127.

[3] Hepbasli A, Ozgener O. A review on the development of wind energy in Turkey. Renewable and Sustainable Energy Reviews 2004; 8(3):257–76.

[4] Boontome, P., Therdyothin, A., & Chontanawat, J. (2017). Investigating the causal relationship between non-renewable and renewable energy consumption, CO2 emissions and economic growth in Thailand. Energy Procedia, 138(2017): 925–930.

[5] “Wind data”http://www.thewindpower.net/country_list_en.php.

[6] Danish Wind Industry Association, Information Available at:/http://www.windpower.org/en/news050214.htm

[7] Akhmed Hidyatno,Array rahmawan,Bhagas awauf.” A Conceptualization of Renewable Energy-Powered Industrial Cluster Development in Indonesia”, Energy Procedia 156 (2019): 7–12

[8] H. S. Ramdan,A. F. Bendary, S Nagy “Particle swarm optimization algorithm for capacitor systems with wind turbine generators”, Journal of electrical power and energy system; 84(2017):143–152.

[9] Joselin Herbert GM, Iniyan S, Sreevalsan E, Rajiapandian S. “A review of wind energy technologies.”, Renewable and Sustainable Energy Reviews 2007; 11(6):1117–45.

[10] Naruwit thongyai, Kriengkrai,Assawamartbulne.” Wind atlas of Chanthaburi and Trat provinces, Thailand.”, Energy Procedia 141 (2017): 389–393

[11] 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

[12] H. S. Ramdan “Wind energy farm sizing and resource assement for optimal energy yield in Sinai Peninsula, Egypt”,Journal of Cleaner Energy,161(2017): 1283-1293.

[13] Dennis Y.C. Leung, Yuan Yang,” Wind energy development and its environmental impact: A review”, Renewable and Sustainable Energy Reviews 16 (2012) :1031–1039.

[14] M. A. Ebrahim, A. El-Metwally,F. M. Bendary, W. M. Mansour, H. S. Ramadan, R. Ortega, J. Rommero “Optimization of Proportional-Integral-Differential Controller for Wind Power Plant Using Particle Swarm Optimization Technique”, International Journal of Emerging Technologies in Science and Engineering, 2 (2010):1-6.

[15] Tawfiq K B, Abdou A F, E.L-Kholy E E, and Shokrall S S, "Application of matrix converter connected to wind energy system," in Eighteenth International Middle East Power Systems Conference (MEPCON), (2016): 604-609.

[16] M. Zemamou et al. ,” Review of savonius wind turbine design and performance “, Energy Procedia 141 (2017) 383–388

[17] Tawfiq K B, Abdou A F, EL-Kholy E E, Shokralla S S“, "Performance analysis of a matrix converter interfaced wind energy conversion system for static load application,”" "ICNEEE 2016", Cairo, Egypt 1(2016.), :11 – 14

[18] Polinder H, Van Der Pigil Ffa, De Vilder gj, e al.: '”Comparison of direct-drive and geared generator concepts for wind turbines”', IEEE Trans. Energy Convers, (2006).

[19] Chondrogiannis S, Barnes M, Aten M. “Technologies for integrating wind farms to the grid.” New and Renewable Energy Programme, Department of Trade and Industry, February (2006).

[20] Raju AB, Chatterjee K, Fernandes BG, “A simple maximum power point tracker for grid connected variable speed wind energy conversion system with reduced switch count power converters.” In: Proceedings of IEEEPESC’03, 2 (2003):748–53.

[21] Tan K, Islam S. Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors. IEEE Trans Energy Convers 2004; 19:392–9.

[22] Chen Z, Spooner E. “Grid power quality with variable speed wind turbines”. IEEE Trans Energy Convers ;16 (2001):148–54.

[23] Muller S, Deicke M, De Doncker RW.” Doubly fed induction generator systems for wind turbines”. IEEEIndustry applications magazine 2002; 8(3):26–33.

[24] Grabic S, Katic V. “A comparison and trade-offs between induction generator control options for variable speed wind turbine applications”. In: Procedings of IEEE international conference on industrial technology, vol. 1, (2004), 564–8.

[25] Schiemenz I, Stiebler M, “Control of a permanent magnet synchronous generator used in a variable speed wind energy system.” In: Proceedings of IEEE IEMDC’01, (2001), 872–879.

[26] A.Guoliang Yang and B.Huiguang Li,”Application of a Matrix Converter for PMSG Wind Turbine Generation System”IEEE2009, (2009):619-623

[27] Song SH, Kang S, Hahm N, “Implementation and control of grid connected AC-DC-AC power converter for variable speed wind energy conversion system.” In: Proceedings of IEEE APEC’03, 1(2003):154–8.

[28] H. Li Z. Chen, “Overview of different wind generator systems and their comparison,” IET Renewable Power Generation ,(2007).

[29] Janakiraman R and Paramasivam S,”Modelind and Simulation of Self Excited Induction Machine for Wind Power Generation”ACEEE Int.J.on Electrical and Power Engineering, 4(2013) ,2

[30] De Battista H, Puleston PF, Mantz RJ, Christiansen CF. “Sliding mode control of wind energy systems with DFIG-power efficiency and torsional dynamics optimization.” IEEE Trans. Power Systems;15(2000): 728–34.

[31] Higuchi Y, Yamamura N, Ishida M, Hori T, “An improvement of performance for small-scaled wind power generating system with permanent magnet type synchronous generator.” In: Proceedings of IEEE IECON’. 2(2000):1037–43.

[32] HuangH, Chang L,” Energy-flow direction control of grid-connected IGBT inverters for wind energy extraction. “In: Proceedings of IEEE canadian conference on electrical and computer engineering, 1(2000):535–539.

[33] Cadirci I, Ermis M. “Double-output induction generator operating at sub-synchronous and super-synchronous speeds: steady-state optimization and wind-energy recovery.” IEE Proc B Electric PowerApplications, 139 (1992):429–42.

[34] Svensson J. “Simulation of power angle controlled voltage source converter using a linear quadratic method in a wind energy application. “In: Proceedings of IEEE workshop on computers in power electronics, (1996):157–63.

[35] Abdelazeem A. Amin , Kotb B. Tawfiq , HossamYoussef , E. E. EL-Kholy ,(2016) " Performance Analysis of Inverter Fed From Wind Energy System," in Eighteenth International Middle East Power Systems Conference (MEPCON), (2016): 678-683.

[36] J. Rodriguez, M. Rivera, J. W. Kolar,and P. W. Wheeler,” A Review of Control and Modulation Methods for Matrix Converters,” IEEE Transactions on Industrial Electronics , 59 (2012.):58-70,

[37] Pena R, Clare JC, Asher GM. “Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation.” IEE Proc Electric Power Applications ;143 (1996)::231–41.

[38] Bin Wu, “Current-Source Converter and Cycloconverter ,”Topologies for Industrial Medium-Voltage Drives”, IEEE Transactions on Industrial Electronics, 55, (2008):534-544.

[39] Marques J, Pinheiro H, Grundling H, Pinheiro J, Hey H. “A survey on variable-speed wind turbine system.” In:Proceedings of Brazilian conference of electronics of power, 1, (2003):732–8.

[40] 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.