



Power Converter Interfaces for Wind Energy Systems - A Review

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Abstract. The paper attempts to bring out a wide-ranging analysis the performance of electronic converter interfaces that assuage to meritoriously control a Wind Energy Conversion System (WECS). The system seems to gather significance in an effort to exploit the natural resources and offer support to associate the generation demand gap. The effective practice of the wind power augurs to carry down the cost of generation and encourage to satisfy the needs of the utilities. The WECS exist in the form of the variable speed generators and the types include the Permanent Magnet Synchronous Generator (PMSG), Doubly-fed Induction Generator (DFIG), Synchronous Generator (SG) and Wound Rotor Induction Generator (WRIG). The DFIG invites a greater attention owing to its smaller requirement of the partially rated converters and enables to regulate the system through a compliance for the transfer the real and reactive power.

Keywords: Power electronics converters · Wind turbines · Power quality
Grid connection

1 Introduction

The wind energy appears to be a fast developing sector surrounded by other renewable sources and be obligated its merits to being clean, green, in naturally available, low cost and particularly beneficial to the rural areas. However, it is intermittent and requirement of initial asset, broadcast aspect, and property area all finds a large amount of cost.

The WECS shown in Fig. 1 relates to a physical system with three main components where the first one shows the rotor connected in blades. As wind goes through blades, it allows the rotor to rotate and therefore generates mechanical energy. The next component describes the transfer energy from the rotor to generator and the electric generator establishes the third to convert the mechanical energy to electric power.

The WECS technique involves, wind tower and a rotor linked with blades then the hub. The furthest designer horizontal-axis (HAWTs) comprises of 3-blades, located windward of the stronghold and contains exactly the mechanical decelerating system, generators, controlling systems and yaw system [1].

The most popular horizontal system converter with two or more blades consist of a yaw machinery that turns the rotor blades to wind sides. The next vertical axis converter consists of blades positioned straight up serves to capture wind freely from wind directions as shown in Fig. 2. However due to lower effectiveness, complex to repairs and

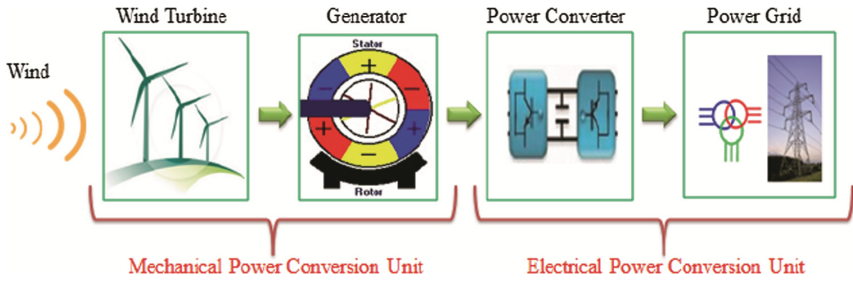


Fig. 1. Main elements of WECS

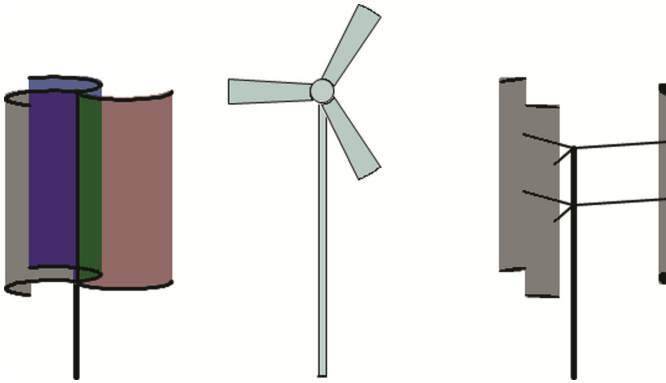


Fig. 2. Various vertical axis winds turbines

huge property occupation, and the application of this converter is deteriorating through the past few spans. The collected power from a wind turbine is particular to every system is given by equation 1 [2]:

Let,

- V_w = Wind Speed (m/s),
- A = Area of Swept Turbine (m^2),
- P_t = Turbine Power (W),
- ρ = Air Density (kg/m^3) and
- C_p = Performance Coefficient.

$$P_t = \frac{1}{2} \rho A C_p V_w^3 \tag{1}$$

Consequently, if constant value of air density, swept area and velocity of wind, the power C_p of turbine is used toward determine the output energy value of wind. The aerodynamic physical appearance of blades is more supportive to healthier power coefficient. The turbine coefficient remains predisposed by TSR. The equation is shown below (2),

Let,

- V_w = wind speed (m/s),
- ω = rotational speed of turbine and
- r = radius of wind turbine.

$$TSR = \frac{\omega r}{V_w} \tag{2}$$

A characteristic curve is shown in Fig. 3, it specifies that there is unique ratio at which the wind turbine performance is greatest. To attain maximum energy, the TSR is required to be set aside at best working point for overall widespread range of the turbine speeds. The turbine output power characteristic is shown in Fig. 4.

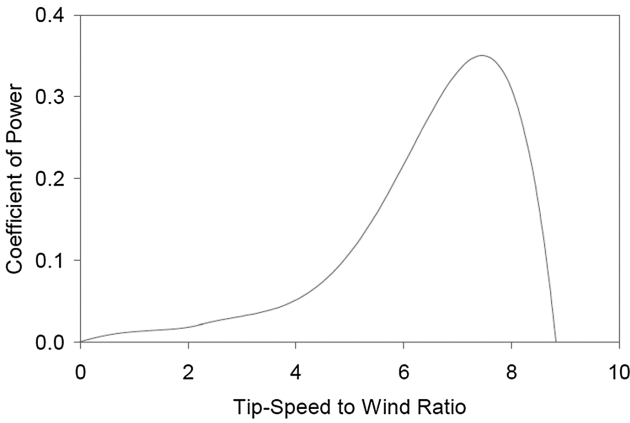


Fig. 3. Typical co-efficient of power curve

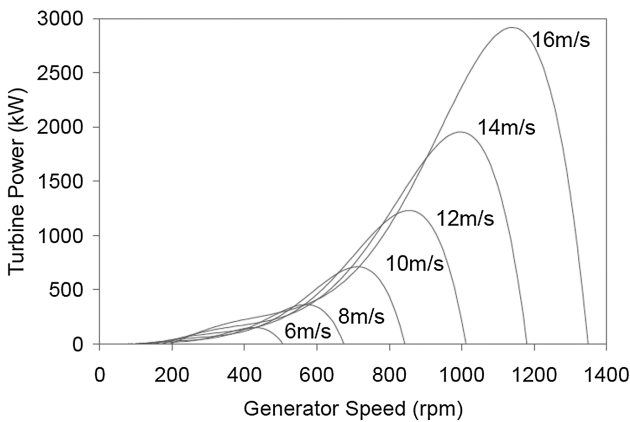


Fig. 4. Turbine output power characteristic

2 Power Converter Interfaces

The power electronic device remains to undergo progress with evolution of self-commutated Insulated Gate Bipolar Transistors (IGBTs), Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFETs) and some more advanced semi-conductor devices are implemented in modern power converter techniques [2]. When interruption of line voltage and the line current carry ability of device is continuing to increase and the significant study strives to explore to alter some other material (silicon carbide), with an emphasis on increasing the value of power density in the power converters.

Besides there exists the variety of power converter topologies to agree with application needs and the directions of power flow. The thyristor converters form the grid commutated power converters through maximum power capability of 6, 12 or more switching pulses. It ingests the inductive power and finds use in maximum voltage and high power systems [3]. The self-commutated converter methods typically operate using Pulse Width Modulation (PWM) method and enable the transfer of mutually active and reactive power. In PWM converters, if switching frequency is maximum, then they will produce harmonics and inter-harmonics up to few kHz and reduce this harmonic spectrum minimum range filters may be used at the inverter output.

In WECS different promising power electronics techniques are available to develop the vibrant and quality output [4]. The major constraint in energy distribution zone transmits to the accurate governor in real and reactive power flow for maintaining system voltage stability. It engages modern power converter and satisfies its ability of converting the electrical energy from ac to dc and reverse process also. The different types of three-phase converter configurations ensemble the conversion process and facilitate to achieve the requirements.

2.1 Voltage Source Inverter (VSI)

The PWM - VSI find an extensive scope in the operation of electrical drives owing to their voltage-buck conversion capability characteristics. Wang, Wu, Dai, Zargari, and Xu brought in a “Low Cost Current Source Converter Solutions for Variable Speed Wind Energy Conversion Systems” in the year 2011 [5] and illustrated that the diode converter with CSI-PWM, it can attain full-range real power regulator but the minimum range of reactive power control over the PWM VSI based topologies, though it slightly increases the rectifier cost the scheme is shown in Fig. 5.

The efforts of Arunkumaran, Raghavendra Rajan, Ajinsekhar, Tejesvi and Sasi-kumar, offer a “Comparison of Space Vector PWM (SVPWM) and SVM Controlled Smart VSI fed PMSG” containing a 3 ϕ diode bridge converter and 3 ϕ IGBT inverter for Wind Generation System. The Sine PWM system serves to reduce the harmonics with an increase in the switching losses and the SVM method enables to minimize Harmonic distortion to be at 43.23% and to control the switching losses [6].

Davidson, Gitau, Adam and Hamatwi have introduced “Modeling and Control of Voltage Source Converters for Grid Integration of a Wind Turbine System”, in 2016 a pitch angle of blade regulator function on wind model, a rotor speed of field-oriented regulator useful in rectifier for extraction of maximum power in wind system, and vector

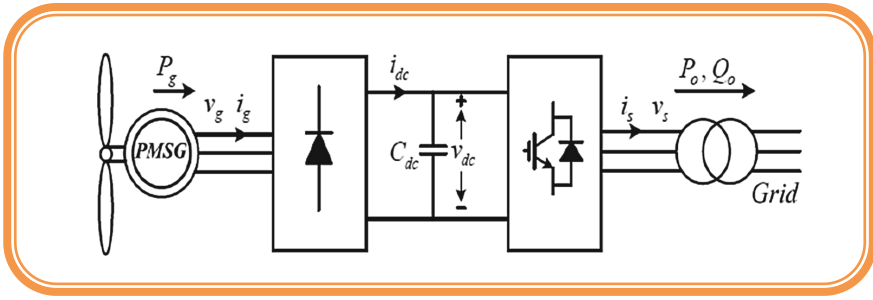


Fig. 5. Diode rectifier and PWM VSI for WECS

based dc link voltage control implemented on the grid-side inverter to maintain the dc-link voltage in constant and to make sure unity power factor.

2.2 Back to Back Converter

“A New Five-Phase to Three-Phase Back-to-Back Current Source Converter Based Wind Energy Conversion System” was introduced in the year 2013 by Massoud, Ahmed, Abdel-Khalik and Elgenedy. The design in WECS experiences challenges on account of amplified perception of wind into the grid due to voltage and frequency variabilities, ripples of generator torque and grid faults to power converter.

While the predictable SVPWM is implemented to regulate the real and injected reactive power in 3ϕ grid side, then 5ϕ generator side converter is well-ordered using SPWM for keeping 1000A of dc-link current. The “Modified back-to-back current source converter” was suggested in 2015 by Holliday, Adam, Abdelsalam, and Williams came up with novel CSC-BTB converter to operate the wind energy conversion system. Though the BTB CSCs suffer from sag voltages are regularly experience via switches in commutation, there is zero switching loss in the inverter side converter. The main advantages accrue to being simple, offer to control is less complex, switching frequency is minimized and controllable grid having maximum power point tracking to collect real power [7] block diagram of modified back to back converter is shown in Fig. 6.

Sumina, Sacic, Mrcela, and Barisa have thought of “A wind turbine two level back-to-back converter power loss study” in 2016, where the WECS is coupled in grid with the support of converter, LC filter with transformer (step-up). In his proposed method, the converter is used to produce the maximum fundamental output voltage with lower harmonics (THD) and to improve the overall system performance [8]. Then the LC filter and step-up transformer are used to minimize the losses in converter switches and as well as the grid voltage/current THD.

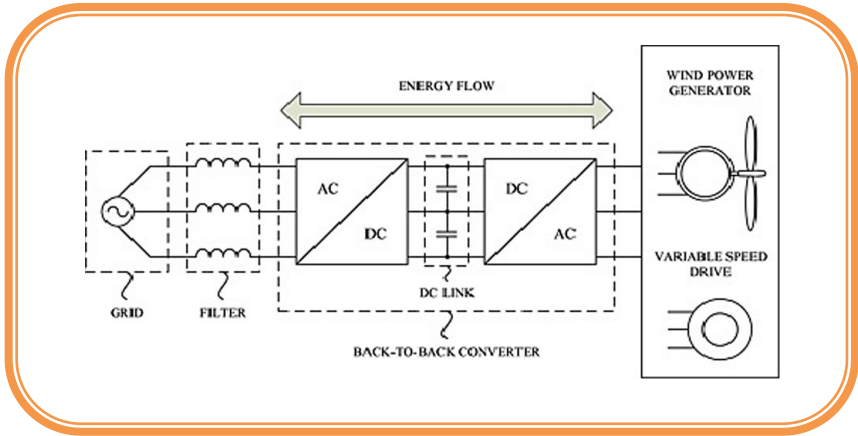


Fig. 6. Block diagram of modified back to back converter

2.3 Matrix Converter

The matrix converter is used for exchanging the variable ac from a fixed ac as seen from the Fig. 7. The bi-directional switches are arranged to any input point possibly will be connected to any output point at any time. The double SVPWM is employed to control the input current and output voltage of the system. The distinct advantages augur due to absence of massive power storing devices and dc-link. However, a larger number of switches is portrayed to be a serious disadvantage.

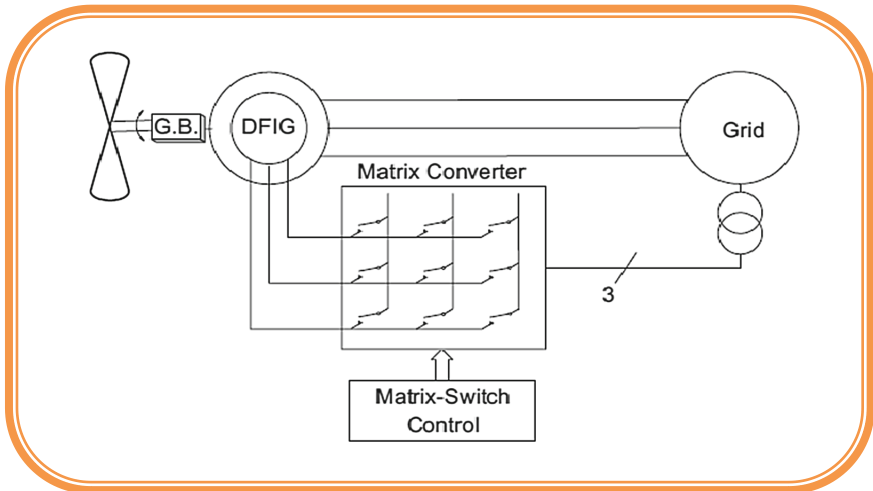


Fig. 7. Block diagram of matrix converter

It occupies a place with the DFIG, where it employs a stator flux based control technic in rotor converter and d-axis current stayed bring into line with stator–flux relation vector. Then the refined d-axis current helps to control the reactive power flow in stator side system and it is also support the real power of stator line. The DFIG output voltage power factor is controlled by rotor winging voltage of DFIG [9].

2.4 Z-Source Converter

The model of a general impedance power converter was attempted in 2003 to stunned the barriers with their limitations of outmoded voltage and current source converters. It is understood to boost voltage and buck voltage, reduce the number of switches, improve the performance with efficiency and function at reduced budget [10].

“The suitability of the Quasi Z-source Inverter for wind power conversion” is studied by Ranjith Babu, Maity and Prasad, it is seen to inherit the advantages of traditional ZSI. The two-port network in Fig. 8 involves the inductors (L_1, L_2) and capacitors (C_1, C_2) are allied in the form of X-shape to arrange for produce quality an impedance coupling. The system is seen to operate with a controller for dynamic and static control of converter through a change in the switching cycle and enhancement of load voltage terminal at the mandatory range and its achieves stability. Though it’s low cost and high efficiency claims its suitability for the wind power generation system [11], its unidirectional nature makes it unpopular in DFIG system.

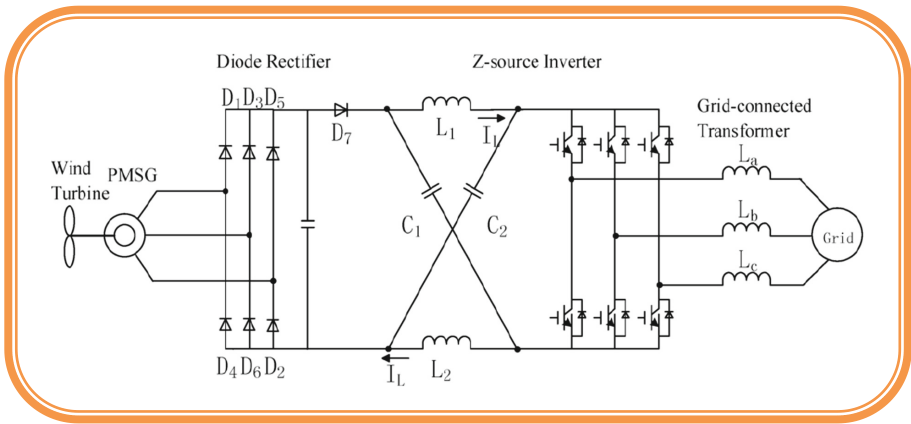


Fig. 8. Block diagram of Z-source converter

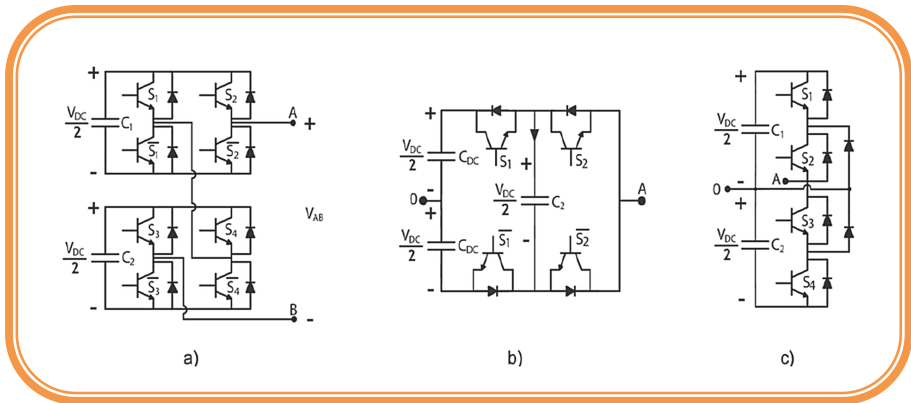


Fig. 9. Block diagram of multilevel converters

2.5 Multilevel Converters

The theory of multilevel converter technic was suggested in past few years; more than a few multilevel converter technics are patented. It is seen to involve the switching devices in series with low level of dc voltage sources to succeed maximum voltage by spending minimum amount of voltage to devices (switches).

The increasing interest in multi-level power converters goes to evolve a mechanism for feeding the wind turbine generator system directly from the prevailing 3- ϕ power grid. There are few different varieties of the multi-level converters frequently executed in maximum energy source and ideal voltage uses. The converters are,

- (a) Series Connected H-Bridge (SCHB) converter method,
- (b) Flying Capacitor (FC) converter method and
- (c) Neutral Point Clamped (NPC) converter method.

as shown in Figs. 9(a), (b) and (c) respectively.

Accumulation to $(N - 1)$ dc link capacitors, the N -level flying capacitor converter have need of secondary capacitors in each power line $[(N^2 - 3N + 2)/2]$, it rises capacity, load, difficulty, and rate of the converter and reduce the performance and lifespan (duration). The NPC method practices, capacitors are connected in series because to split the DC bus voltage keen on static voltage stages. It engages the prospect to bond with neutral line to intermediate power of dc-link point, to form the bi-direction connection in the power converter to reduce the earth drip currents [12].

The bi-direction connection of the NPC converter established WECS generation structure illustrated in Fig. 9(c), it is found to expand the static and transitory action of bi-directional NPC method [13]. On other hand, the amount of holding diodes essential in quadratic ally correlated with number of levels. Where, N is adequately great, more diodes are essential to produce the circuit impossible to execute and more diodes required in each line is $(2N - 4)$ the output voltage waveform of multilevel inverter is shown in Fig. 10.

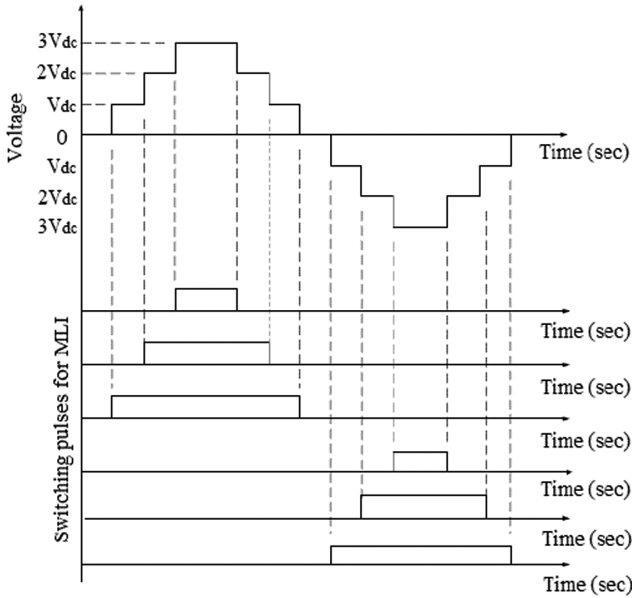


Fig. 10. Output voltage waveform for MLI

2.6 Tandem Converter

The tandem converter contains, the Current Source Converter (CSC) with principal converter and bi-directional PWM-VSI secondary converter. Meanwhile, tandem converter brings about four well-regulated inverters as exposed in Fig. 11 more than a few units of choice is envisaged which qualify sinusoidal input/output Signals.

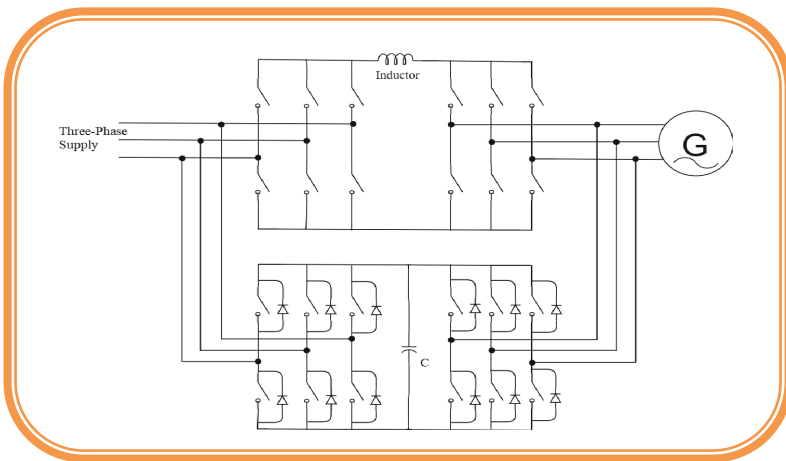


Fig. 11. Block diagram of tandem converter

Dissimilar to the principal converter, the minor converter consumes toward control at a high switching frequency. Benefits of this power converter are, the primary converter requires minimum range of switching frequency, and the secondary converter consume less switching current. It's specified that, the tandem inverter minimize up-to 70% of switching losses. The tandem converter has higher conduction losses in comparison of all other equivalent VSI method but performance efficiency of this converter possibly will increased.

In addition, the main function that relates to reimburse the distortion current both in the source side and the load side converter possibly shall perform similar to an active resistor for providing a restraining action to the main inverter in commercial load circumstances. The increase in the cost and complexity boils down to the maximum volume of apparatuses and measuring device inherent and presented as an obstacle in using the tandem converter is required. The use of the CSI as source side converter shows that, solitary 0.866% of utility voltage is employed and hence the production currents for the tandem converter essentially high to reach the similar energy is observed from the curve as shown in Fig. 12.

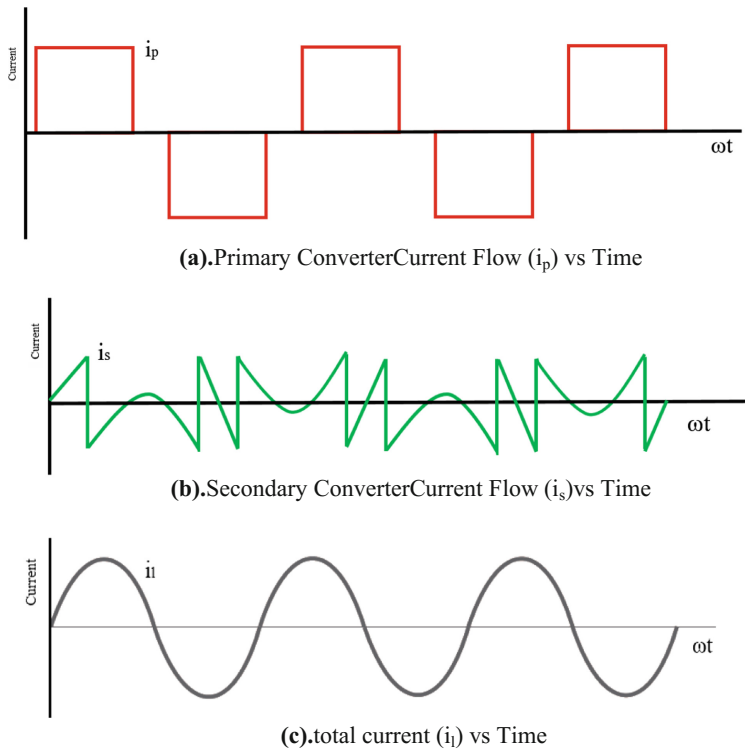


Fig. 12. (a). Primary converter current flow (i_p) vs Time, (b). Secondary converter current flow (i_s) vs Time, (c). Total current (i_t) vs Time

2.7 Resonant Converter

The resonant converter well-looked in this segment, this type of converter model is designated as Natural Clamped Converter (NCC), its shown in Fig. 13. In this converter, the inductance is coupled in middle of the system to retain the resonance and controls the current from the supply grid by make better dc link voltage.

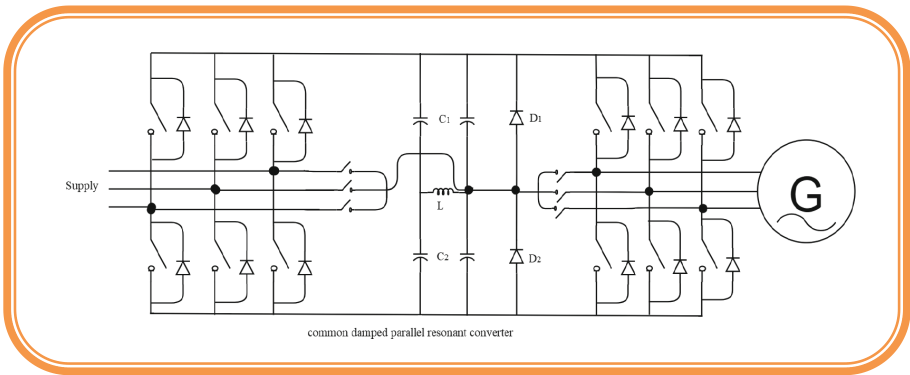


Fig. 13. Block diagram of resonant converter

In NCC method, the modulation could be either PWM or Direct Pulse Modulation (DPM) and its allow the possibility of the use of a various modulation approach in generator side and grid side inverter. In every commutation the voltage difference/

Table 1. Wind energy conversion systems

Generator with range	Converter possibilities	Control methods
PMSG (kW)	Diode Bridge/SCR Inverter SCR Rectifier/Inverter Hard Switching Inverter DC Boost Inverter Back to Back Hard Switching Inverters	- Simple Firing Angle Control - Maximum Power Point Tracking (MPPT) - Vector Control - Pulse Width Modulation (PWM)
DFIG (kW–MW)	Diode Bridge/SCR Inverter SCR Rectifier/SCR Inverter Back-to-Back Hard-Switching Inverters Matrix Converter	- Dual Thyristor Firing Angle Control - Sliding Mode Control - PI controllers
IG (kW–MW)	Back-to-Back Hard-Switching Inverters	
SG (kW–MW)	Diode Bridge/DC Boost/Hard-Switching Inverter Back-to-Back Hard-Switching Inverters	

inequality is established in the main capacitors (C_1 and C_2), then any one of this capacitor will discharge their stored energy. In the situation, the irregular commutations will affect the switching characteristics in very tiny variations.

The various converter topologies are offered for WECS is presented in the Table 1. To increase the efficiency of the converters, the advanced modern controllers are required. Then the overall cost of the system is also will increase and the complication of converter are also increases. If to minimize the control complexity of the inverter, the boost inverter is coupled to the system but the cost is some more high. Now, to expand the benefits of WECS, a finding the middle ground between efficiency and cost is essential.

3 Conclusion

A brief evaluation of the several WECS are articulated with possible converter topologies that can be implement in different combination of PMSG, DFIG, IG and SG. An insight has been thrown on the suitability of the different control schemes and their benefits detailed. The control methods have been focussed with try to achieve extreme output power pass from the wind turbine to the utility grid. The all those efforts are focused on to produce efficient control schemes for the converter and cost minimization in the perspective to address economically feasible solution and overcome aggregate eco-friendly problems. The wind generation has been seen to grow at startling level in earlier era and motivation is carry on to experience leaps and bounds with the advances in the power electronic technology. The drive has been ordained to nurture an enviable progress and ensure the wind energy contributes to arrive at an energy balance economy for the nation.

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