A Comprehensive Study of Converter Control Topologies of Grid Connected DFIG in WECS

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***Abstract*- Conventional sources of power generation are reducing every day there is strong need for sustainable and clean sources of power which could fulfill the demand of electricity. In India context, wind energy power generation play vital role in renewable power generation. Wind energy conversion system (WECS) with control mechanism has become very popular in renewable energy sources power conversion especially in wind energy. Due the development in power electronics devices and advancement in different control techniques and their applicability to extract maximum wind power, doubly fed induction generator (DFIG) has best option as generator in grid connected WECS. This paper presents the different converter control topologies and their comparative study on the basis of type of converter, number of control switches and control schemes of grid connected DFIG in WECS.**

Index Terms- Wind energy conversion system (WECS), Wind turbine (WT), Doubly fed induction generator (DFIG), Rotor side converter (RSC), Grid side converter (GSC).

I. INTRODUCTION

Electricity is the basic need of human being and growth of the nation. Conventional energy based electricity generation is limited due the issues like international oil crisis, limited availability of conventional sources and environmental pollution effect, therefore an alternative source of energy that can be the solution for the theses issues. The renewable energy sources like wind energy, solar energy, tidal energy etc. can be a possible solution. Renewable energy is derived from natural processes that are replenished constantly. All these sources are plentifully available in nature are recyclable and almost available free of cost [1].

In India, renewable power generation 61.3%, 18%, 10.9%, 9.6% and 0.3% are the share of wind, solar, biomass, small hydro and waste materials. Wind energy has the largest contribution in renewable power generation among all the renewable sources. By framing various policies for renewable power generation, India has created positive atmosphere in power sector especially in solar and wind power [2]. With the advancement in power electronics converter variable wind speed power generation has become more popular and more efficient as compare to fixed wind speed WECS. To capture the maximum wind power when wind is variable the wind turbine and generator has great concern. Doubly fed induction generator is efficient and robust machine and widely used in grid connected WECS. DFIG with partial frequency converter based WECS has many advantages like control may be applied at lower cost, allow converter to generate or absorb reactive power and improved efficiency due to low losses in rotor circuit [3, 4].

In this paper, various aspects of WECS are described with their mathematically equations. The grid connected DFIG based WECS with different control topologies employed in rotor side converter, grid side converter and both rotor and grid side converter are elaborated for controlling the essential parameters like electromagnetic torque, active and reactive power, dc-link voltage etc. Also, the comparative study of different converter control topologies are carried out on the base of types, cost and converter control methods.

II. WIND ENERY CONVERSION SYSTEM

The essential aspects of WECS are aerodynamic aspect, mechanical aspect like gears box etc. and electrical aspect such as power converters. The cascaded WECS is shown in Fig.1.

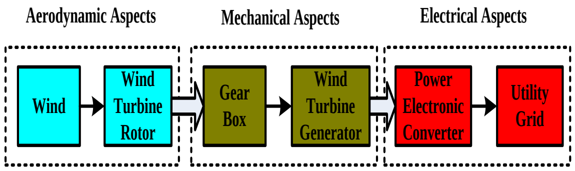

Fig. 1 Wind Energy Conservation System

The different aspects of WECS have been described and elaborated in subsequent sections.

A. Wind Power

Power in the wind is increases as the cube of the wind speed means doubling the wind speed increases the power by eight times [5]. The wind power is given by (1).

$P_{Wind} = 0.5\rho A\upsilon^{3}$ (1)

Where, P_{Wind} power in wind in watts, ρ is the air density in Kg/m^3, A is the area of cross-sectional through which wind passes in m^2 and υ is the wind speed in m/sec nominal to cross-sectional area. The power curve of typical wind profile is shown in Fig.2

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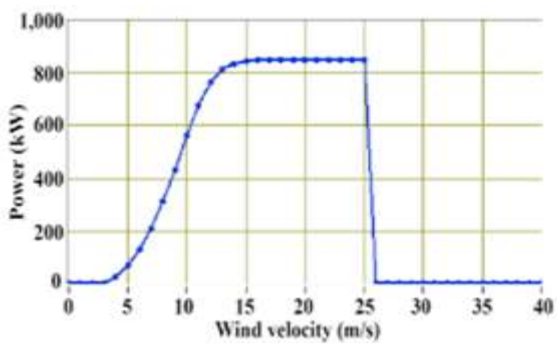

Fig.2 Power Curve of Wind

B. TurbinePower

The aerodynamic power in rotor of wind turbine is given by (2)

$P_{Turbine} = 0.5\rho A C_p\, \upsilon^{3}\lambda$ (2)

Where $P_{Turbine}$ = mechanical power in turbine in watts, C_p = power coefficient and λ = tip speed ratio.

The power coefficient (C_p) is defined as the power extracted by the wind turbine from available wind stream. The maximum value of C_p is defined by Betz's limit, which state that a turbine can never extract more than 59.3% of power from wind stream. Practically the value of C_p is in range of 25-45% [6, 7].

C. Turbine Rotor Efficiency

Turbine rotor efficiency is the function of Tip Speed Ratio (TSR) of wind turbine (WT). The TSR of WT is the ratio of rotational speed of the tip of the blade (ω) the actual wind velocity (υ) given by (3).

TSR $(\lambda) = \omega * r/\upsilon$ (3)

Where, ω = angular velocity in rad. /sec, r = rotor radius in meter and υ = wind speed in m/s. The C_p versus λ curve at different values of pitch angle (β) of typical wind turbine is shown in Fig. 3

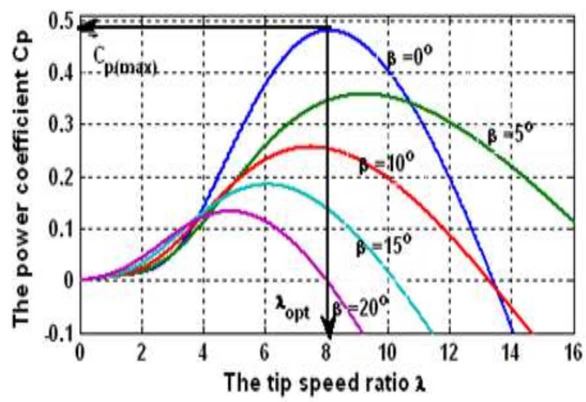

Fig.3 Cp versus λ Curve

III.DOUBLY FED INDUCTION GENERATOR IN WECS

When wound rotor induction machine (WRIM) is used as generator and fed power from both stator and rotor circuit with help of power converter in rotor circuit, it is termed as doubly fed induction generator (DFIG). When DFIG used in WECS electrical energy can be exchanged with stator winding as well as through rotor winding at variable wind speed and also offers a wide range of torque-slip curve depending on the rotor voltage, capture more wind energy, higher reliability and induce high-quality electrical output power which is supplied to the grid [8-11]. The speed of the DFIG can be controlled by adjusting the frequency of the external rotor source of current control. Different power electronics based converters are used as variable frequency source for the rotor. The schematic representation of a DFIG in WECS shown as in Fig. 4

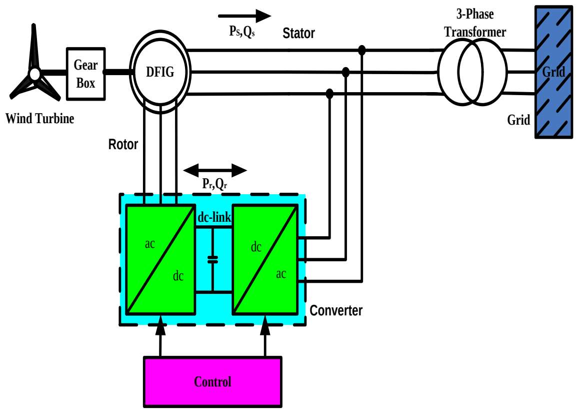

Fig.4 Schematic representation of DFIG in WECS

DFIG are most widely used type of induction generators especially in WECS as these induction generators offer many advantages over other types of generator: the power rating of converter is typically 25-30% of the total system, improved system efficiency, power factor can be controlled and provide a complete control of reactive and active power[12-13]. Due to these advantages, the DFIG can directly be connected to the grid network and remain synchronized at all the times with grid network.

IV. CONVERTER CONTROL TOPOLOGIES

The ability of DFIG to control the rotor currents allows for variable wind speed operation and it also facilitates the various parameters like reactive and active power, electromagnetic torque, dc-link voltage and power factor by stator flux orientation control, voltage vector control, direct power control with help of PI controller, fuzzy controller or some other intelligent controller employed in the converter, which is connected between the rotor circuit of DFIG and grid in WECS[14-19].The different converter control topologies applied to DFIG in WECS have been described and elaborated in subsequent sections.

A. Static Kramer Dirve Converter Control Toplogy

The Static Kramer Drive consists of a diode rectifier on the rotor side and the line commutated SCR inverter on grid side [20]. In this converter control topology only grid side converter (GSC) is controlled either by sliding mode control or grid voltage oriented vector control. The schematic representation of Static Kramer Drive Converter Control toplogy is shown in Fig.5

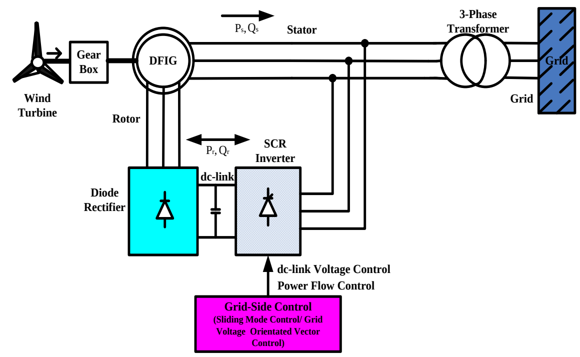

Fig.5 Static Kramer Drive Converter Control Topology

The main objective of controlling GSC is to regulate the voltage across the dc- link, reactive power flow between DFIG and grid, and also to compensate harmonics. This converter control scheme is only able to provide power flow from both stator and rotor circuit in supper synchronous operating mode of DFIG. To solve this problem, other converter control scheme is developed by replacing rotor side diode rectifier by SCR rectifier [21, 22].

B. Thyristor Converter Control Topology

This topology allows the DFIG to reactive power demand to be fulfilled by RSC control and optimum performance of WECS is obtained by adjusting the gear ratio of gear box to its optimum value [22]. In comparison to Static Kramer Drive control topology, this system produce more output power due to the lack of reactive power available with diode rectifier. To obtain the maximum output power from wind the wind speed is optimize between 7.5m/s and 8.5 m/s for sub-synchronous and supper-synchronous mode of operation of DFIG [23]. The schematic representation for Thyristor Control topology is shown in Fig. 6

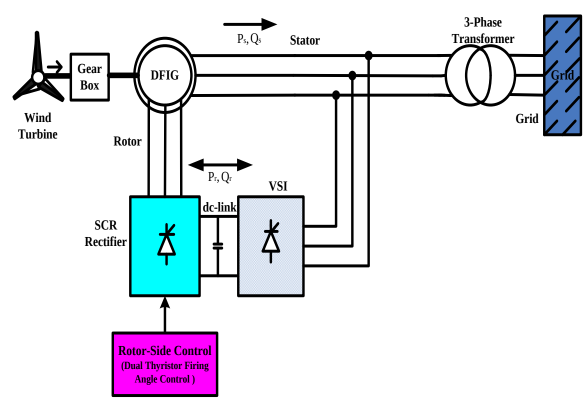

Fig.6 Thyristor Converter Control Topology

The main objective of RSC control is to control stator circuit active power, reactive power and torque. In order to control the three parameters of DFIG either dual thyristor firing angle control or stator oriented vector control scheme is applied. The major drawback of this converter control scheme includes firing of thyristor and commutation problems with RSC and development of harmonic distortion in grid, which are created by grid side inverter i.e. voltage source inverter (VSI) [24, 25].

C. Back-to-Back PWM Converter Control Toplogy

This topology allows the both side converter control i.e. RSC and GSC control. Due to more technologocally advanced methods using back-to-back converters has been developed, which is differ in control strategy and complexity from other previous schemes. The back-to-back converter also reffered as twolevel PWM converter and the most conentational type among all type of converters for variable wind speed turbine WECS. It consist of two converter with a capacitor between, which is often reffered as dc-link capacitor or decoupling capactitor since it also provide a separate control in both converters i.e rotor and grid side [26,27]. The overall cost of this converter is low as compare to other converter. The schematic diagram of back-to-back PWM converter topology is shown in Fig. 7

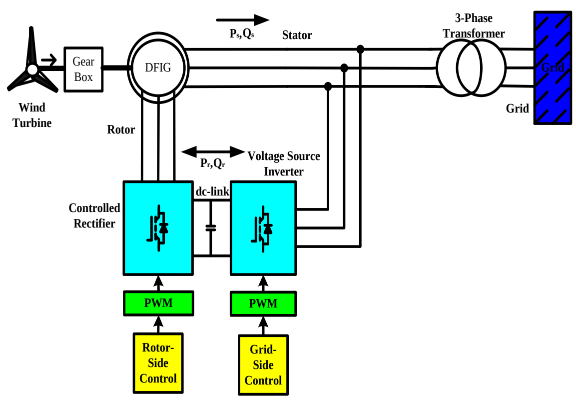

Fig. 7 Back-To-Back PWM Converter Control Topology

This control scheme is combination of RSC control and GSC control scheme. In this combined control scheme all the essential parameters like dc-link voltage, active power, reactive power and torque of DFIG are completely controlled. One option is to apply stator flux vector control on RSC with help of d-q reference theory to providing maximum power transfer, control the electromagnetic torque, power factor [26-30]. To maintain dc-link voltage constant and to control reactive power through converter a stator voltage orientation control with help of d-q reference theory is applied to GSC [28, 29]. Both side controls are employed by the use of PI controller. Pulse width modulation (PWM) or space vector modulation (SVM) switching techniques are used in order to achieve a better modulation index. The back-to-back PWM converter control scheme of DFIG in WECS uses the information like shaft speed, turbine power, estimate wind speed and optimal TSR with in specified range [27]. The main drawback of this control scheme is that it decreases the life of capacitor bank and overall lifetime of system. One more disadvantage of this control converter includes switching losses and emission of high frequency harmonics which results in additional cost of filters [29, 30].

D. Matrix Converter Control Toplogy

This converter control topology is capable of converting the variable ac from the DFIG into constant ac to the connected grid in single conversion stage. This convert control topology has two advantages: no requirement of bulky energy storage device or dc-link capacitor and converter control is implemented in one stage by single converter. The stator flux orientated control was employed on the matrix converter which is connected in rotor side of DFIG. A simple PI controller with employed to control d-q axis currents. The regulation of the d-axis and q-axis currents allows for control the stator reactive and active power respectively [31, 32]. The schematic representation of Matrix Converter Control topology is shown in Fig.8

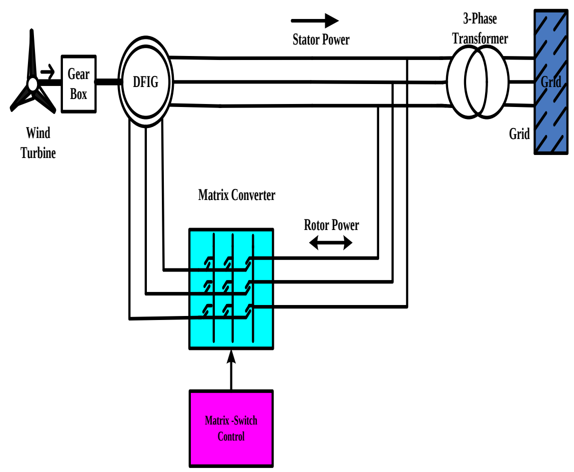

Fig. 8 Matrix Converter Control Topology

The matrix converter consists of nine bi-directional switches (18 total), arranged in a manner that any input phase is connected to any output phase at any time. Each switch is capable for rectification or inversion [31]. The matrix converter is controlled by using double space vector PWM, employing the use of input current and output voltage SVM. The drawback of this control scheme is that it required 18 switches, which increase the converter cost.

V. COMPARISON OF DIFFERENT CONTROL TOPLOGIES

The comparison between different control topologies on the basis of type of converter, number of semiconductor devices, cost and control schemes are shown in Table1.

TABLE1. COMPARISON OF DIFFERENT CONTROL TOPLOGOIES

Control Topology	Convertor Type	No. of Semiconductor Device	Cost of Converter	Control Method
Static Kramer Drive Control	Diode bridge/ SCR inverter	dc-link capacitor, 6 controllable switches	Low	Sliding mode control
Thyristor Converter Control	SCR rectifier / SCR inverter	dc-link capacitor, 12 controllable switches	Moderate	Dual thyristor firing angle control
Back-to-back PWM Converter Control	Back-to-back hard switching inverter	dc-link capacitor, 12 controllable switches	Moderate	Vector control for RSC or SVM, PWM and space vector control for GSC.
Matrix Converter Control	Matrix Converter	18 controllable switches	High	Vector control for RSC with PWM switching

VI. CONCLUSION

Renewable energy sources has significant role in power generation especially wind energy and DFIG is best choice in grid connected WECS system due to advantages such as reduce the power rating of converter, control active power, reactive power, and power factor. A cosine comparative study of various converter control topologies has been achieved through this paper. All the converter control topologies are described to control power flow between DFIG and grid and extract maximum power from wind. Also, in this paper comparative study of different control topologies are carried out which are economically viable solution in the field of wind power generation. Wind power generation has growth at alarming rate due to continue advance technologies in power electronics converters.

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BIBLOGRAPHICAL NOTES

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