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Design and Development of Power Converter for Wind Energy Conversion System

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Abstract— *The Control strategy and design of power converter for variable speed wind energy conversion systems (VSWECS) operation in standalone system is proposed. VSWECS consists of PWM inverter IGBT based with LC filter. In VSWECS, power converter is made to convert the output of generator which is variable frequency variable speed to the fixed frequency fixed voltage. Control and dynamic modeling of VSWECS with the proposed converter is performed using MATLAB SIMULINK. In addition to this closed loop control scheme is also simulated.*

Keywords: *Wind energy conversion system, PWM inverter.*

1. INTRODUCTION

Electrical energy nowadays is a very essential and irreplaceable resource in household and industry. Gradually, the utilization of electrical energy has increased and the extraction of energy to produce electrical energy from the traditional resources such as coal, uranium, etc. has become efficient as well. But increased pollution concerns and higher cost requirement to occupy highly efficient equipment for traditional production of electrical energy has drawn the attention of the industry towards unconventional or natural resources to produce electrical energy. Such resources include wind turbine generators, solar panels, hydro power plants and biogas power generators.

In the wind energy scenario, India is the fifth biggest producer of wind energy with a total production capacity of 22GW as per the Global Wind Energy Council report [1]. The contribution of wind energy towards the total energy requirement of India is 3%. And the total infrastructural investment towards this structure is US$ 7.9 bn. The higher land requirement of the wind energy sector is sufficed by Gujarat, Tamilnadu, Rajasthan, Karnataka and Andhra Pradesh due to the states' higher coastal or desert area [2].

2. WIND ENERGY CONVERSION SYSTEM

A WECS utilizes kinetic energy of wind by the rotor blades and then converts it into mechanical energy through turbine. The other components participating in the energy conversion process are: wind turbine generator, gearbox, DC link, inverter, transformer, grid connections, anemometers, mechanical breaks, wind vane, yaw drive, yaw motor and blade pitching machinery.

2.1 Wind speed and Energy

The above mentioned arrangement contributes to convert wind energy into mechanical energy and followed by conversion into electrical energy. An operating and dynamic wind turbine generator also contains defining parameters defines the behavior of the turbine and can perform with specific characteristics by specific control.

The performance of wind turbines is a function of the torque coefficient $C_q(\theta, \lambda)$ and power productivity coefficient $C_p(\theta, \lambda)$, where blade's pitch angle is θ and the speed rate is denoted by λ. The speed of air defines the output of the turbine which after multiplying with the gear coefficient will give the output power of the turbine [3].

The desired operation speed is achieved by coupling the turbine and generator shafts. The mechanical power extracted by the blades involving the air flow rate and blade speed:

$$P = \frac{1}{2} * \rho * A * v^3 * Cp \tag{1}$$

Where, P = mechanical power (watt),

ρ = density of air (kg/m^3),

A = rotor blades' swept area (m^2),

v = wind's velocity (m/sec) and

C_p = power coefficient

The theoretical minimum value of C_p is defined by the Bentz limit i.e. 0.59. The value of C_p varies from 0.20 to 0.40 for low speed turbines having three blades. The controlling the flow condition and the productive area of blades mainly determine the controlling of wind energy conversion system.

The TSR is the proportion of rotor speed to the speed of wind . The ratio is defined by

$$\lambda = (\omega * R)/V \quad (2)$$

Where, ω = angular speed of rotor (rad/sec)

R = radius of rotor blade (m).

Maximum power can be obtained in relation to speed rate of rotor at wind turbine operation point. For keeping the λ optimal the rotor speed must be in synch with the wind speed i.e. high rotor speed at high wind speed and vice versa.

The relationship between output power and torque is given by

$$T_t = \frac{P_{out}}{\omega_t} \quad (3)$$

2.2 Operating Region of Variable Speed Wind Turbine Generator

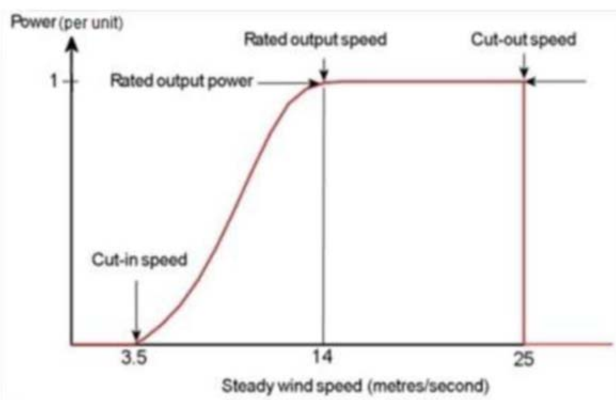

Fig. 1: Operating region of VSWT generator

The fig.1 Shows a wind speed - power curve[3]. The curve which denotes the regulated power the wind turbine can achieve wind speed of 3.5 m/s is denoted as cut-in wind speed, the generated utilizable power is very low. Typically this speed is the starting speed of the wind turbine. From the cut-in speed to the rated speed the relation between the speed of the turbine and the power produced is directly proportional. Hence, with increase in speed the output power increases in proportion. When the speed of wind exceeds the predefined speed limit, the cut-out wind speed, which is typically 20 to 25 m/s, the wind turbines are generally brought to standstill to avoid high mechanical loads on the turbine elements.

Permanent Magnet Synchronous Generator

PMSG consists of permanent magnet in the place of rotor field winding. The advantages of this configuration are: increase in power density, rotor inertia, elimination of copper losses and high robustness. Loss of field control, demagnetization and cost are the demerits of the configuration.

When assumptions like hysteresis losses, sinusoidal distributed winding, eddy currents and neglecting saturation are considered than mathematical model of standard synchronous machine becomes similar to the PMSG.

In a permanent magnet synchronous machine (PMSG) model there are two frames: stationary frame and synchronous frame.

3. PMSM MODEL IN STATIONARY FRAME

The stationary frame consists of the stator. It is also known as abc frame where the a b and c axes, the phases of the machine, form an angle of 120° among them.

$$V_{abc} = R_s I_{abc} + \left(\frac{d\varphi_{abc}}{dt}\right) \quad (4)$$

$$R_s = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \qquad \bar{V} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\bar{I} = \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\varphi_{abc} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \varphi_m \begin{bmatrix} \sin(p\theta) \\ \sin(p\theta - 2\pi/3) \\ \sin(p\theta + 2\pi/3) \end{bmatrix}$$

(5)

Where, $V_{a,,b,c}$= phase Voltage

$I_{a,,b,c}$= phase Current

p= poles

θ=mechanical position of rotors $\O_m$=amplitude of flux linkage in PM

L_{xx}= phase to phase inductances

4. PMSM MODEL IN SYNCHRONOUS FRAME

The control of PMSM is done by translating abc frame into dq frame i.e. reference frame or synchronous frame [5]. The d-axes and q-axes have DC current for normal operations of machine. The transformation between two frames, i.e. Park Transformation, requires status of the rotor position. The switching of frames is done by the below matrices:

$$[T'] = [T_{dq\text{-}abc}] = \frac{2}{3}\begin{bmatrix} \sin(p\theta) & \sin(p\theta - 2\Pi/3) & \sin(p\theta + 2\Pi/3) \\ \cos(p\theta) & \cos(p\theta - 2\Pi/3) & \cos(p\theta + 2\Pi/3) \\ 0 & 0 & 0 \end{bmatrix} \quad (6)$$

$$[T'] = [T_{dq-abc}] = \begin{bmatrix} \sin(p\theta) & \cos(p\theta) & 0 \\ \sin(p\theta - 2\pi/3) & \cos(p\theta - 2\pi/3) & 0 \\ \sin(p\theta + 2\pi/3) & \cos(p\theta + 2\pi/3) & 0 \end{bmatrix} \quad (7)$$

In this model with respect to the direction of rotation d axis rotates behind q axis by 90 degree. Stator voltage equations based on the reference frame theory in d q synchronous reference frame are presented.

$$V_d = R_s i_d + \frac{d\varphi_d}{dt} - \omega_e \varphi_q \quad (8)$$

$$V_q = R_s i_q + \frac{d\varphi_q}{dt} - \omega_e \varphi_d \quad (9)$$

Flux linkage equations are taken as given in below eq. (10) and (11).

$$\varphi_d = L_d i_d + \varphi_m \quad (10)$$

$$\varphi_q = L_q i_q \quad (11)$$

Where L_s=L_d=L_{sdq}= axis inductance and
Ψ_m= permanent magnet flux linkage
With the help of flux linkage equations, equations of stator voltage in d q reference frame can be written in the following form:

$$V_d = R_s i_d + L_s(\frac{di_d}{dt} - \omega_e L_q i_q) \quad (12)$$

$$V_q = R_s i_q + L_s(\frac{di_q}{dt} - \omega_e(L_d i_d + \varphi_m)) \quad (13)$$

5. SIMULATIONS AND RESULTS

In Fig. 2 simulation of PMSG based WECS is simulated using MATLAB. Wind turbine transforms kinetic energy of wind into mechanical energy and further it is transformed into electrical energy by PMSG generator. Generator is further connected to power converter which is the combination of uncontrolled diode based rectifier followed by capacitor and controlled IGBT based inverter which converts AC to DC to AC. Gate pulse for inverter is given using PWM technique. LC Filter is connected to the output of inverter and then it is given to load. Closed loop scheme is used to control inverter. Fig. 3 is the park transformation of voltage and current used for control loop.

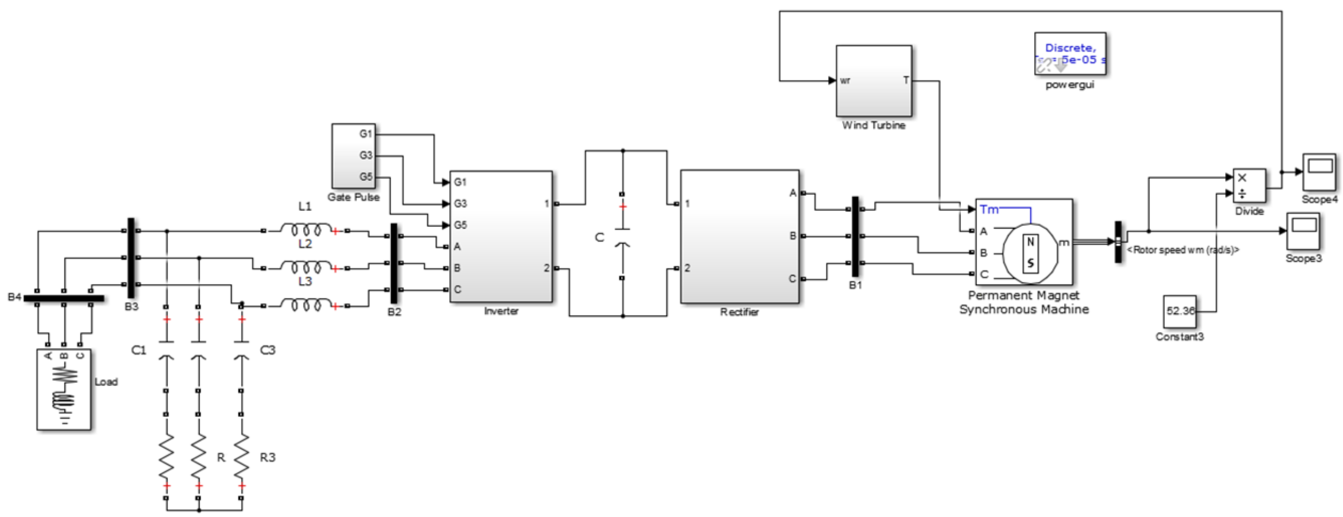

Fig. 2 Wind Energy Conversion in standalone mode

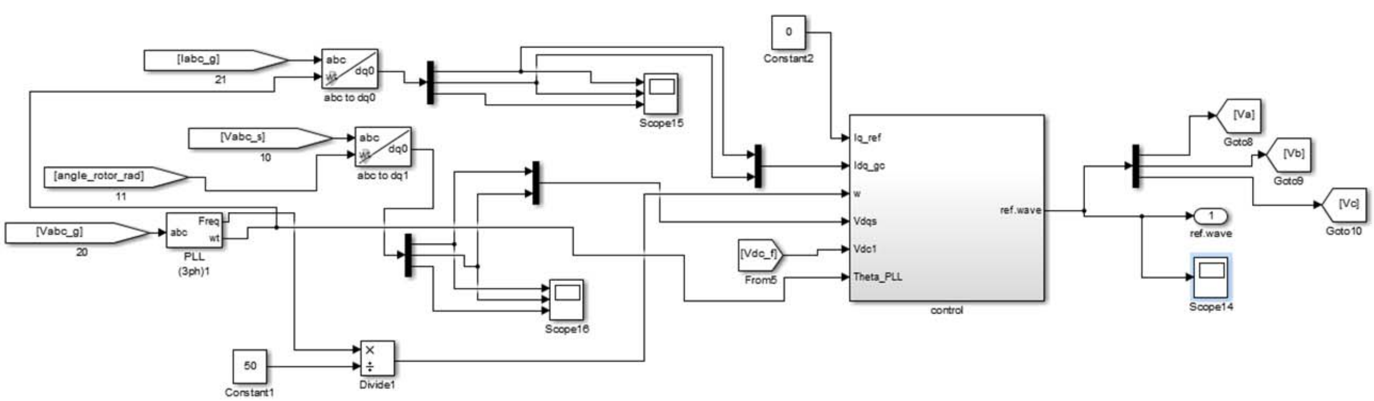

Fig. 3 Control Scheme

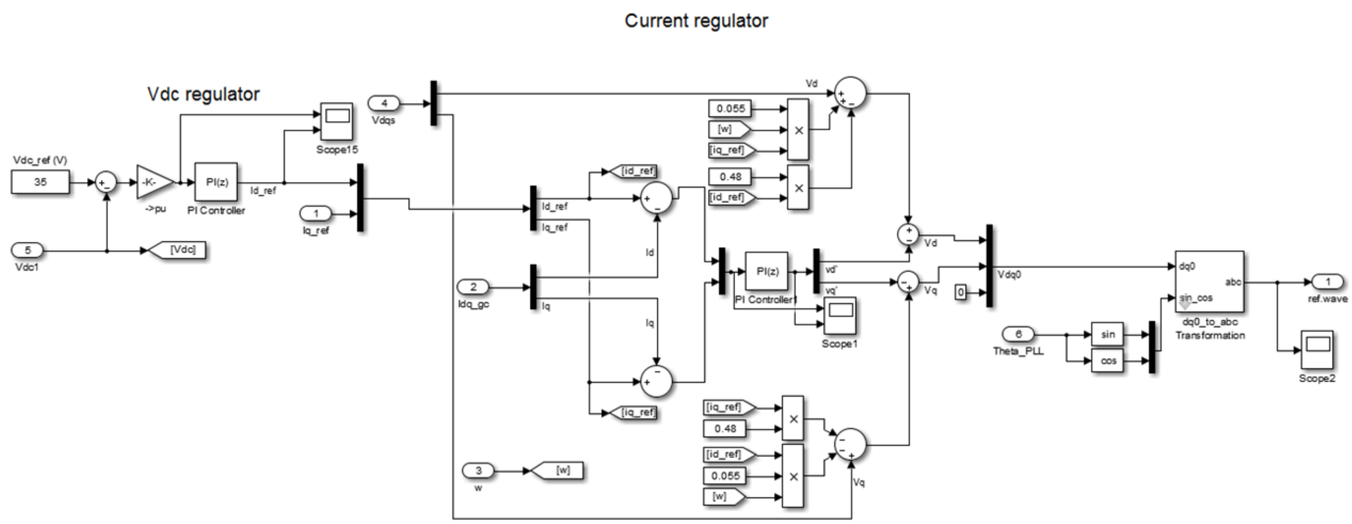

Fig. 4: Close loop control scheme

In Fig. 4 both inner and outer loops are controlled by PI controller. Inner loop is current loop and the out-put voltage loop used for calculating the error between Vdc(ref) and Vdc which gives Id(ref) and Iq is set to zero for decoupling control of the active power and reactive power .

Specifications

Generator type	PMSG
Generator Rating	200W
Rated RPM	500
Turbine	300W
Wind speed	9.2m/sec
Load	300W

6. RESULTS

In this simulation close loop is used for controlling the system. Wind turbine of 300W is moving at a rated wind speed 9.2m/sec as shown in Fig. 5. Fig. 6 shows the torque generated by the turbine which is given as an input to generator of 200W.Fig. 7 is the rotor speed at which generator is running. Fig. 8 and 9 is the generator output voltage and current respectively. Rectifier converts it into DC voltage which is shown in Fig. 10 which is further converted into AC by inverter which is controlled by close loop and gate pulse is given using SPWM technique. AC output is filtered using LC filter and fed to load as shown in Fig. 11 and Fig. 12 is the active and reactive power of 300W load.

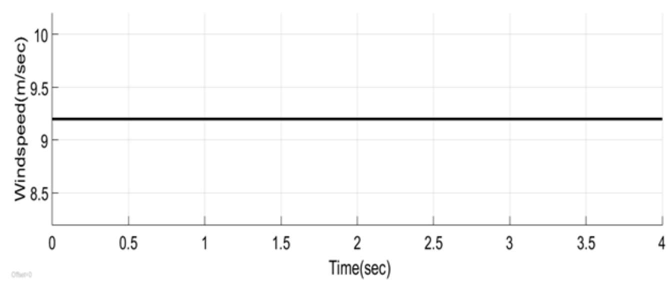

Fig. 5 Wind speed

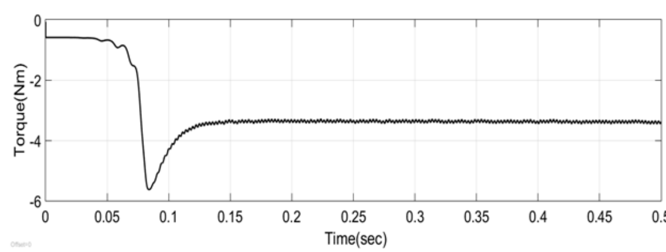

Fig. 6 Torque

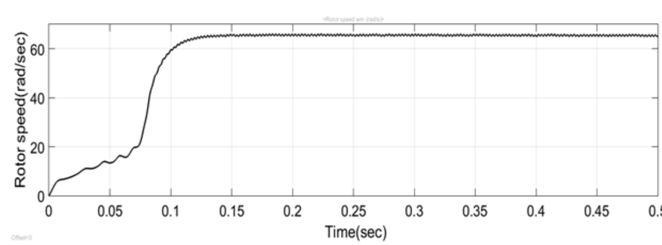

Fig. 7 Rotor speed

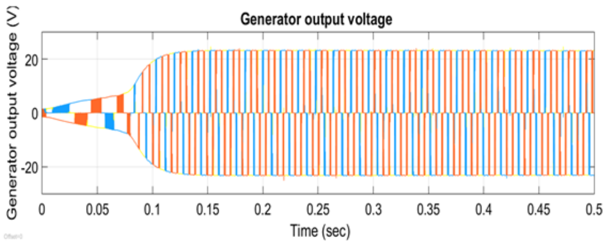

Fig. 8 Generator output voltage

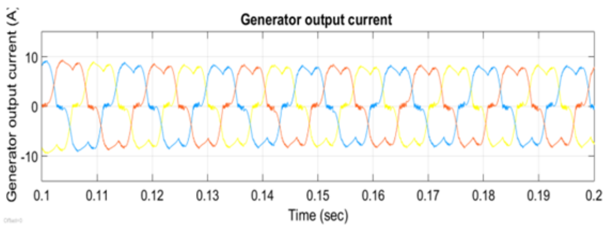

Fig. 9 Generator output current

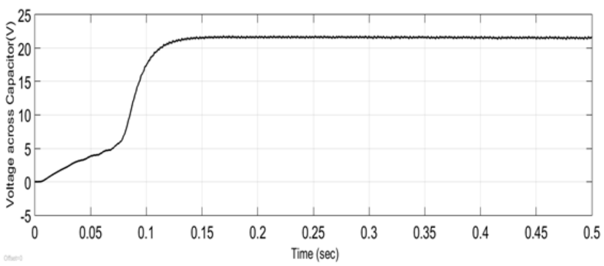

Fig. 9 Voltage across capacitor

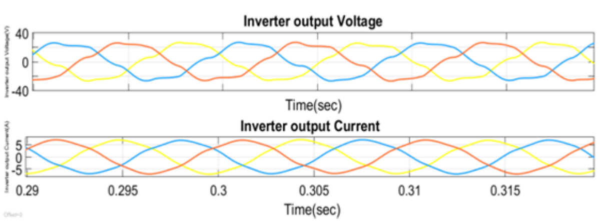

Fig. 10 Inverter output Voltage and Current

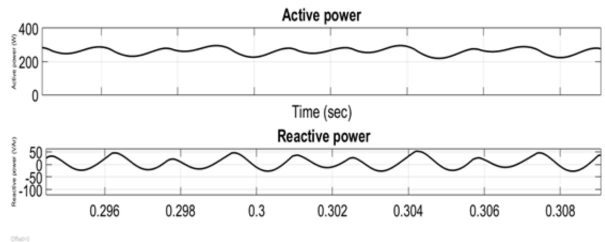

Fig. 11 Active & Reactive Powers

7. CONCLUSION

Wind Energy is the optimum solution to meet the global energy demand. To get the maximum power from the kinetic energy of wind, variable speed wind energy conversion system is the best option. By using direct drive system the efficiency of the system can be increased and PMSG with back to back converter topology is suitable for this application.

REFERENCES

[1 Global Wind Energy Council report" international energy agencies.

[2] Indian Wind energy Association.

[3] Sourav Ghosh, Prof. Pradip Kumar Saha, Prof. Gautam Kumar Panda Wind Energy Conversion System Connected With Grid Using Permanent Magnet Synchronous Generator (PMSG) International Journal of Advanced Research.

[4] Giampaolo Buticchi, Emilio Lorenzani, Fabio Immovilli, and Claudio Bianchini, Active Rectifier With Integrated System Control for Microwind Power Systems IEEE Transaction on sustainable energy, VOL. 6, NO. 1, JANUARY 2015.

[5] Chia-Nan Wang,Wen-Chang Lin, and Xuan-Khoa Le Modelling of a PMSG Wind Turbine with Autonomous Control Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2014, Article ID 856173.