Performance Comparison of Grid Integrated Micro Wind System with Diode Rectifier and Active Rectifier

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Abstract – *Renewable energy systems have gained popularity in the past decades due to the increasing energy crisis of which PV and Wind energy systems are the common ones. Microwinds are wind energy systems having rated power less than 5 kW. In micro wind turbine applications, permanent magnet synchronous generator (PMSG) is widely used. A novel algorithm for the estimation of rotor angle of the PMSG, based on flux estimators was implemented. The comparison involves the investigation of active and reactive power given to the grid through an ordinary diode rectifier and an active rectifier. The study demonstrates that active rectifier control shows superior performance in various aspects. Using active rectifier maximum power from the wind turbine can be extracted. Excessive power loss and braking torque can be avoided by the smooth start up operation of the PMSG.*

Key Words: **Permanent Magnet Synchronous Generator (PMSG), Wind Turbine, Active rectifier, Torque control, Reactive power, WECS.**

1. INTRODUCTION

The production of electricity from renewable energy sources has increased due to environmental problems and shortage of traditional energy sources in near future. Wind energy is one of the best technologies available today to provide a sustainable supply because of its abundant, inexhaustible potential and environmental advantage. Hence many countries are integrating wind energy to grid and many more are expected to follow.

The wind turbine which is installed on the top of a tall tower collects wind energy and converts it into electricity. The turbine output is then made electrically compatible with the utility requirements and the output is fed into the household wiring or the grid. The kinetic energy in the wind is converted into mechanical energy by the turbine and gearbox arrangement because of their different operating speed ranges. This mechanical energy is converted into electrical energy by means of a generator. The wind power extracted by a wind turbine is not constant as wind is an intermittent renewable source. For this reason, the fluctuation of wind power results in fluctuated power output from generator. Due to the fluctuation of generator output, it is not appropriate for the generator to be directly connected to the power grid.

The major distinction among the wind turbines is made between fixed and variable speed wind turbine generator concepts. In earlier days fixed speed wind turbines and induction generators were often used in wind farms. Compared to fixed speed wind turbines, variable speed turbines have many advantages like wide spread operation at maximum power point and high efficiency. Variable speed wind generators like doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs) are emerging as a promising technology with the wide spread exploration and integration of wind sources.

In microwind turbine applications, permanent magnet synchronous generator (PMSG) is widely used. Two power conversion stages are present: the ac/dc and dc/ac stage. In grid-connected systems, two major topologies for the first ac/dc power conversions are used: diode-bridge passive rectifier followed by a boost converter or a three-phase full-bridge active rectifier (back-to-back converter). For very low-power microwind systems (with rated power less than 5 kW), the most usual topology for the ac/dc stage is the diode-bridge followed by a boost converter [1]. The dc/ac power conversion stage is often a full-bridge topology, which injects the electric power into the grid.

In wind power applications, a careful choice of the generator parameters and the topology of the first AC-DC conversion stage are of paramount importance to maximize electromechanical energy conversion. The two major topologies of the first AC-DC power conversion stage are taken into account in this work: passive and active rectifier[6].

A wind energy conversion system using PMSG is modeled. The paper presents a performance comparison of the system using a diode and active rectifier. Considerable reduction is seen in reactive power when an active rectifier is used. All the components of the wind turbine and grid side converter are developed and implemented in MATLAB/Simulink

2. SYSTEM DESCRIPTION AND DYNAMIC MODELING

The wind energy conversion system considered in this paper consist of a variable speed wind turbine, driving a permanent magnet synchronous generator connected to a single phase grid through a power conditioning system. The system structure is shown in fig.1.

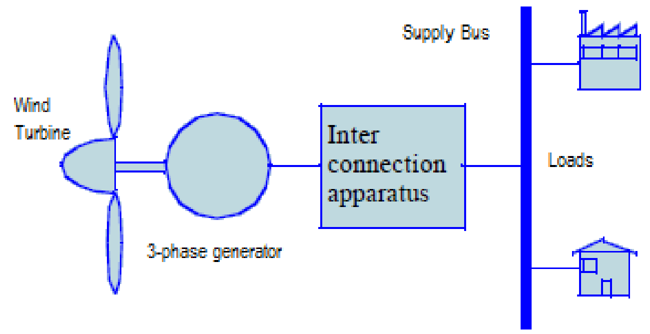

Fig-1: Structure of a typical wind energy system.

2.1 Wind Turbine

A wind turbine is used to convert the linear kinetic wind energy into rotational kinetic energy. The amount of mechanical power captured by a wind turbine from wind is a function of area (A) swept by its blades, air density (ρ), the incoming wind velocity (ν) and its conversion efficiency C_p. The conversion efficiency or the power coefficient of a turbine C_p is a function of tip speed ratio λ and pitch angle β. The power coefficient C_p denotes the power extraction efficiency.

$$P_m = \frac{1}{2}\rho A \nu^3 C_p(\lambda,\beta) \tag{1}$$

where λ is the ratio of tip speed of the turbine blades to wind speed.

Mathematically

$$\lambda = \frac{\omega_m R}{\nu} \tag{2}$$

where ω_m is the turbine rotational speed in mechanical radians per second, R is the radius of the turbine in meters and ν is the incoming wind velocity. The wind power coefficient is defined as the ratio of power transmitted to the turbine shaft to the power given by the wind. The wind power coefficient can be obtained using the equation

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{21}{\lambda_i}} + 0.0068\lambda \tag{3}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{4}$$

While extracting maximum power from the turbine, the value of pitch angle β is kept around constant (around 0^0), to ensure maximum possible turbine output. The Betz limit, $C_{p\max}$ =16/27 is the maximum theoretically possible turbine power coefficient. Practically it is 40% -45%. The rotor efficiency curve Cp (λ) is a non linear function of TSR, which is determined by the blade design and pitch angle. Because of the relationship between C_p and λ, for each wind velocity there is a turbine speed that gives maximum output power.

Fig.2 shows the relationship between wind power coefficient and tip speed ratio at zero blade pitch angle. A two mass drive train model is considered here. The dynamic equations of the drive train written on generator side are:

$$T'_{wtr} = J'_{wtr}\frac{d\Omega'_{wtr}}{dt} + D'_e(\Omega'_{wtr} - \Omega_{gen}) + k'_{se}(\theta'_{wtr} - \theta_{gen}) \tag{4}$$

$$\frac{d\theta'_{wtr}}{dt} = \Omega'_{wtr} \tag{5}$$

$$-T_{gen} = J_{gen}\frac{d\Omega_{gen}}{dt} + D'_e(\Omega_{gen} - \Omega'_{wtr}) + k'_{se}(\theta_{gen} - \theta'_v \tag{6}$$

$$\frac{d\theta_{gen}}{dt} = \Omega_{gen} \tag{7}$$

where the equivalent stiffness is given by:

$$\frac{1}{k'_{se}} = \frac{1}{\frac{k_{wtr}}{k_{gear}^2}} + \frac{1}{k_{gen}} \tag{8}$$

and the equivalent moment of inertia of the rotor is

$$J'_{wtr} = \frac{1}{k_{gear}^2} . J_{wtr} \tag{9}$$

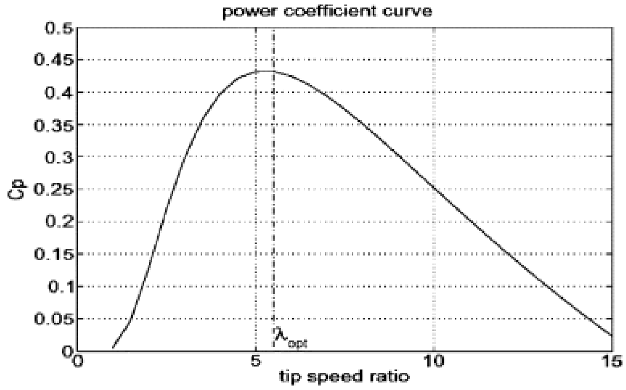

Fig-2: Typical C_p-λ curve for wind turbine

2.2 Generator

In this section the generator model and its control are presented. The electric generator model main equations are obtained from the rotor and stator circuits in fig.3.The rotor circuit helps to understand the field winding and two damper winding. Park's transformation is used to make the coefficients of these equations constant and the equations are normalized.

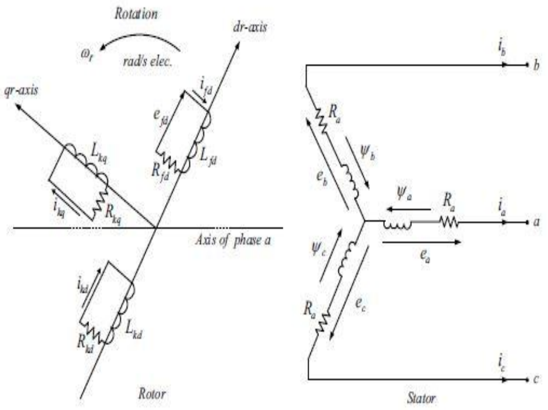

Fig-3: Rotor and stator circuits of 3 phase synchronous generator

Stator equations in dq0 coordinates

$$e_d = p\varphi_d - \varphi_q \omega_r - R_a i_d \tag{10}$$

(11)

$$e_q = p\varphi_q + \varphi_d \omega_r - R_a i_q$$

$$e_0 = p\varphi_0 - R_a i_0 \tag{12}$$

$$\varphi_d = -L_d i_d + L_{afd} i_{fd} + L_{akd} i_{kd}$$

$$\varphi_q = -L_q i_q + L_{akq} i_{kq} \tag{13}$$

$$\varphi_0 = -L_0 i_0 \tag{14}$$

Rotor equation in dq0 coordinates

$$e_{fd} = p\varphi_{fd} + R_{fd} i_{fd} \tag{15}$$

$$0 = p\varphi_{kd} + R_{kd} i_{kd} \tag{16}$$

$$0 = p\varphi_{kq} + R_{kq} i_{kq} \tag{17}$$

$$\varphi_{fd} = L_{ffd} i_{fd} + L_{fkd} i_{kd} - \frac{3}{2} L_{afd} i_d \tag{18}$$

$$\varphi_{kd} = L_{fkd} i_{fd} + L_{kkd} i_{kd} - \frac{3}{2} L_{akd} i_d \tag{19}$$

$$\varphi_{kq} = L_{kkq} i_{kq} - \frac{3}{2} L_{akq} i_q \tag{20}$$

Since the connection of synchronous generator to the AC/DC/AC power converter is balanced, electric power output (P_e) is

$$P_e = \frac{2}{3}\left(e_d i_d + e_q i_q\right) \tag{21}$$

In the present work, a surface PMSG is considered, therefore the rotor flux is estimated instead of back emf, for rotor angle detection immune from electric noise problems and digital numerical dynamic variations. Here, a flux estimator employing an adaptive LPF instead of a pure integrator is chosen.

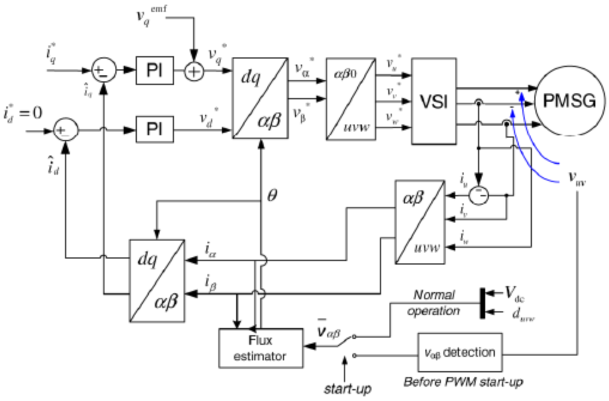

Fig-4 :Block schematic of PMSG torque control

2.3 Power conditioning system

Being the interface between wind turbine generator and the power grid, the wind power converter has to satisfy the requirements of both sides. For the generator side, the current flow in the stator should be controlled to adjust the torque and as a consequence the rotating speed. This will contribute to active power balance in normal operation when extracting maximum power from the wind turbine also and also in case of grid faults. The converter should also have the ability to handle variable fundamental frequency and voltage amplitude of the generator output to control the speed. For the grid side, the converter must comply with the grid codes regardless of wind speed, i.e. it should have the ability to control reactive power (Q) and perform a fast active power (P) response.

The generator side converter can be a passive rectifier, a hybrid rectifier or an active rectifier. The diode-bridge rectifier is the simplest generator-side converter. But phase current harmonics and unregulated dc-link voltage with high ripple content are its major drawbacks.

Three phase controlled rectifiers can be classified from the point of view of commutation process as line commutated controlled rectifiers and forced commutated PWM rectifiers. Forced commutated rectifiers are built with semiconductors switches having gate turn off capability. This allows full control of the converter as these valves can be switched ON and OFF whenever required. Active rectifiers come under the last category. So active rectifier can be defined as " A non isolated AC-DC converter that uses actively controlled switches such as MOSFETs or IGBTs instead of diodes or thyristors in order to rectify voltage or current mainly with two benefits: output voltage regulation and AC input harmonic reduction."

3. SIMULATIONS AND RESULTS

In order to compare the performance of a WECS an ordinary rectifier and active rectifier implemented wind system is simulated in MATLAB shown in fig.5. A wind speed of 12 m/s is given to the system as shown in fig 6. Fig 7 shows the response of pitch angle around 0 degrees for 12 m/s wind speed during a 3 second steady state simulation experiment.

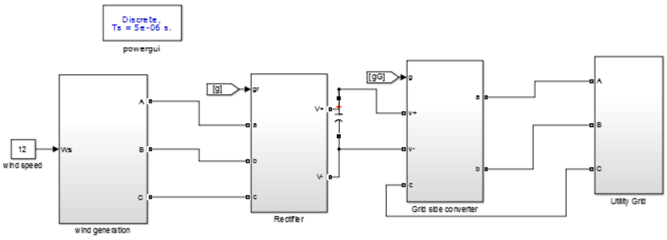

Fig-5 Simulation diagram of the system

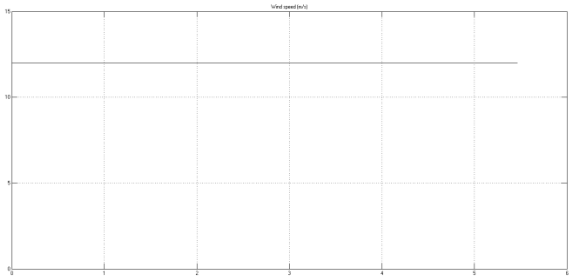

Fig-6 :Wind speed of 12 m/s(x axis 1 unit=5m/s, y axis 1 unit=1 s)

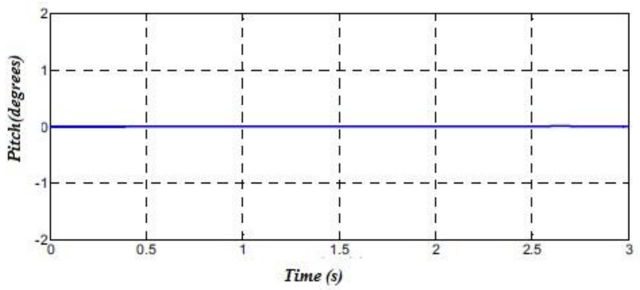

Fig-7: Steady state response of pitch angle at 12 m/s wind speed.

Active power and reactive power generated using diode rectifier is shown in fig.8 and fig.9. and that using active rectifier is shown in fig.10 and fig.11. It can be seen that more power is drawn when an active rectifier is used. Also the reactive power is negligible in this case which improves system efficiency.

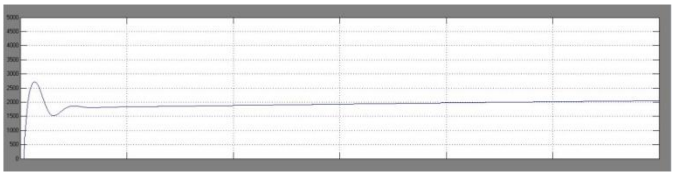

Fig-8: Active power using a diode rectifier (x axis,1 unit=0.5s, y axis 1 unit=500 kW)

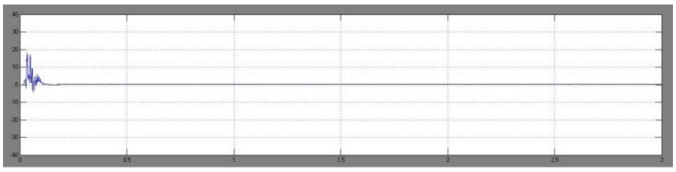

Fig-9**:** Reactive power using a diode rectifier (x axis,1 unit=0.5s, y axis 1 unit=10 VAR)

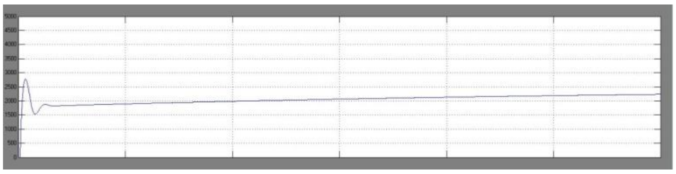

Fig-10: Active power using a active rectifier (x axis,1 unit=0.5s, y axis 1 unit=500 kW)

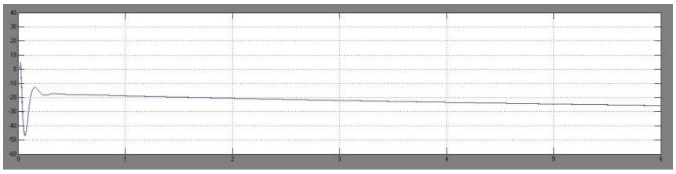

Fig-11: Reactive power using an active rectifier (x axis,1 unit=0.5s, y axis 1 unit=10 VAR)

Generator voltage and current waveforms are shown in fig 12.

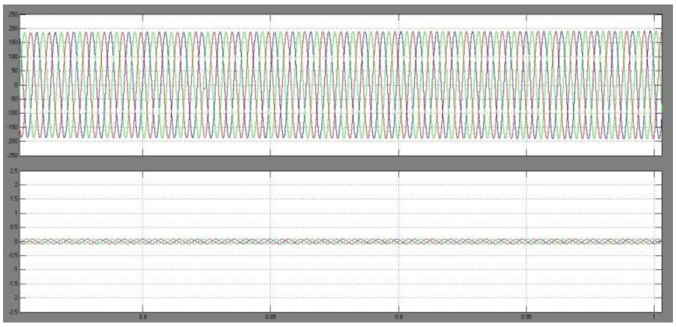

Fig-12: Output voltage and current of PMSG (x axis= 0.8 s/div, y axis= 50 V/div, 0.5 A/div)

4. CONCLUSIONS

In this paper, the development of mathematical models of the components of the wind energy conversion system (turbine, gear train, permanent magnet synchronous generator and the rectifier)is discussed. Modeling and simulation of wind turbine systems allow researchers to study the parameters which lead to enhanced power generation capabilities. The output voltage obtained from the PMSG was unstable as a result of the varying wind profile and it created a need for change in the conversion chain of the wind by the introduction of the control part and correction system in order to provide a better energy quality. The method may also be extended to grid connected WECS.

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