Analysis of Current and Voltage Behavior during a Fault in Wind Energy Conversion System

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***Abstract-* Wind energy production has been growing at an increasingly rapid rate, and will continue to do so in the future. In fact, it has become an integral part in supplying future energy needs, making further advancements in the field exceedingly critical. This WECS consists of a 6 kW permanent magnet synchronous generator connected to the transmission grid through a power conversion scheme. The topology of this converter system consists of an active AC/DC rectifier as well as a DC/AC IGBT inverter, used to interface the DC link with the grid. 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. And the system behavior during fault is observed.**

***Keywords-* WECS, Permanent Magnet Synchronous Generator(PMSG), Wind Turbine, Fault.**

I. INTRODUCTION

Wind energy is one of the most promising renewable energy resources for generating electricity due to its cost competitiveness compared to other conventional types of energy resources. Only some specific locations with adequate wind energy resources can be described as being suitable for wind energy electricity generation. Wind energy is not harmful to the environment and it is naturally an abundant resource. Hence, wind power could be utilized by mechanically converting it to electrical power using wind turbine (WT). Various WT concepts have been developed into wind power technologies and led to significant growth of wind power capacity during the last two decade[2]. In terms of the generators for wind-power application, there are different concepts in use today. The major distinction among them is made between fixed speed and variable speed wind turbine generator concepts. In the early stage of wind power development, fixed-speed wind turbines and induction generators were often used in wind farms. But the limitations of such generators, e.g. low efficiency and poor power quality, adversely influence their further application. With large-scale exploration and integration of wind sources, variable speed wind turbine generators, such as doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs) are emerging as the preferred technology[3]. In contrast to their fixed-speed counterparts, the variable speed generators allow operating wind turbines at the optimum tip-speed ratio and hence at the optimum power efficient for a wide wind speed range. However, the variable-speed directly-driven multi-pole permanent magnet synchronous generator (PMSG) wind architecture is chosen for this purpose and it is going to be modeled: it offers better performance due to higher efficiency and less maintenance because it does not have rotor current. What is more, PMSG can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs. Optimum wind energy extraction is achieved by running the Wind Turbine Generator (WTG) invariable speed because of the higher energy gain and the reduced stresses. Using the Permanent Magnet Synchronous Generator (PMSG) the design can be even more simplified. However, the recent advancements in power electronics and control strategies have made it possible to regulate the voltage of the PMSG in many different ways[4]. The PMSG wind architecture is chosen here. A complete detailed modeling and a control scheme of a three-phase grid connected WECS is presented. The WECS model includes a wind turbine, a PMSG, active rectifier in generator-side, and inverter in grid-side. PMSG is coupled to wind turbine without gearbox. Validation of models and control schemes is fulfilled out through simulations by using the MATLAB/ Simulink environment.

II. SYSTEM DESCRIPTION

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.

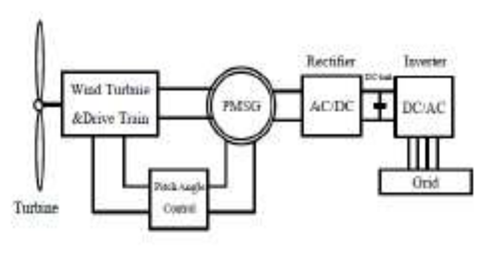

Fig 1 A typical WECS

A. WIND TURBINE

A wind turbine is used to convert the linear kinetic wind energy into rotational kinetic energy.The mechanical power generated in a wind turbine is given as

$$P_M = 0.5\rho A V_w^3 C_p \qquad (1)$$

Where Cp is the power coefficient of the blade and it is given as

$$C_p(\lambda,\beta) = 0.22((\frac{116}{\tau}) - 0.4\beta)\exp^{\frac{-12.5}{\tau}} \qquad (2)$$

$$\left.\begin{aligned} &\text{where } \tau = \frac{1}{(1/\lambda + 0.08\beta) - (0.035/\beta^3 + 1)} \\ &\lambda = \frac{\omega_W R}{V_W} \end{aligned}\right\} \qquad (3)$$

where ρ is the air density ,C_p is the power coefficient,A is the swept area of turbine blades in m^2 and V_w is the wind turbine rotating speed in red/sec, R radiusof the turbine blade in m. In direct drive system, due to the absence of a gear box, the mechanical torque (T_M) and the shaft speed of the wind turbine are directly transferred to theshaft of the PMSG. The mechanical torque developed by thewind turbine is obtained as

$$T_M = \frac{P_M}{\omega_M} \qquad (4)$$

ω_M is the shaft speed of the PMSG in rad/sec.

B. 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 equationsconstant and the equations are normalized.

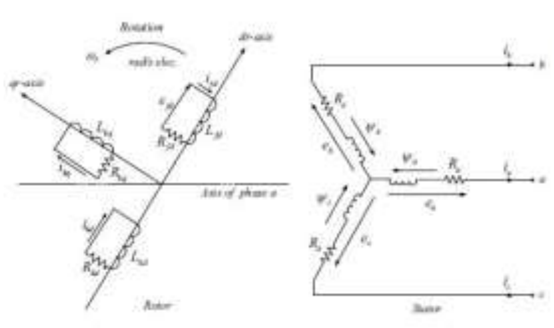

Fig-2 :Rotor and stator circuits of 3 phase synchronous generator

Stator equations in dq0 coordinates

$$\left.\begin{aligned} e_d &= p\varphi_d - \varphi_q\omega_r - R_a i_d \\ e_q &= p\varphi_q + \varphi_d\omega_r - R_a i_q \\ e_0 &= p\varphi_0 - R_a i_0 \\ \varphi_d &= -L_d i_d + L_{afd} i_{fd} + L_{akd} i_{kd} \\ \varphi_q &= -L_q i_q + L_{akq} i_{kq} \\ \varphi_0 &= -L_0 i_0 \end{aligned}\right\} \qquad (12)$$

Rotor equation in dq0 coordinates

$$\left.\begin{aligned} e_{fd} &= p\varphi_{fd} + R_{fd} i_{fd} \\ 0 &= p\varphi_{kd} + R_{kd} i_{kd} \\ 0 &= p\varphi_{kq} + R_{kq} i_{kq} \end{aligned}\right\} \qquad (13)$$

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

$$\left.\begin{aligned} \varphi_{kd} &= L_{fkd} i_{fd} + L_{kkd} i_{kd} - \frac{3}{2} L_{akd} i_d \\ \varphi_{kq} &= L_{kkq} i_{kq} - \frac{3}{2} L_{akq} i_q \end{aligned}\right\} \qquad (14)$$

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

$$P_e = \frac{2}{3}\left(e_d i_d + e_q i_q\right) \qquad (15)$$

III. METHODOLOGY

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.

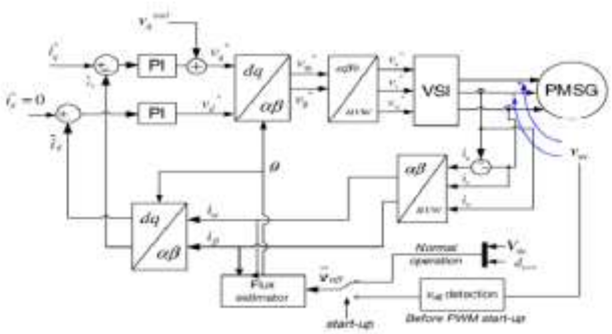

Fig-3 :Block schematic of PMSG torque control

The control strategy of an active rectifier suitable for modular systems is described, with smooth transitions between dc-link voltage control and MPPT. In this way, different kinds of converters can be connected to the dc link, such as a grid-tied converter or a dc/dc converter for energy storage systems, without the need of a dedicated communication between the power stages. This goal was achieved by developing a dedicated state machine for the control of the modular power system.When active rectifier is implemented, the PMSG is controlled by means of a classic Field-Oriented Control (FOC). In order to avoid the use of a position sensor in the generator, a sensorless algorithm for the rotor angle estimation was implemented. Accurate rotor angle estimation is of paramount importance, as it deeply affects the performance of the drive. The active rectifier behaves like a full-featured PM motor drive performing an FOC. A flux estimator based on the integration of the terminal voltage is employed. The control strategy does not present excessive computational load and can be implemented even on low-cost processors.Moreover with the use of an auxiliary voltage sensor we can obtain a precise and smooth start-upoperation for the PMSG. This is a very important feature for wind systems as it limits any excessive braking torque for the wind generator which could determine an undesired deceleration and stop of the wind turbine. Especially in the case of vertical axis wind turbines (VAWTs), the starting torque at cut in is very low and a sudden load from the generator can cause a stall or a deceleration until complete shutdown of the converter, then the start-up sequence repeats again, without reaching the steady-state operation.

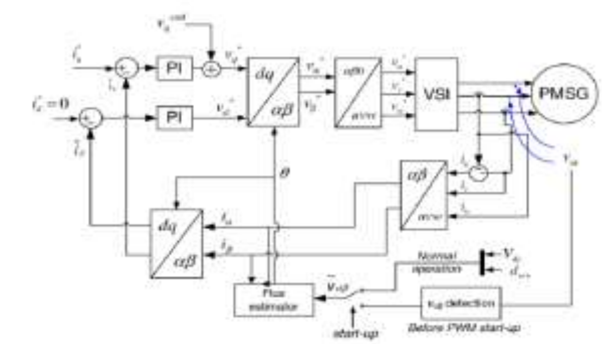

Fig 4 Block schematic of the PMSG torque control.

In order to fully realize the potential that wind energy holds, it must be integrated into the transmission grid. This is especially difficult since the grid should be an extremely stable supply of power, and as discussed earlier, the wind is hardly an ideal supply source. As the wind speeds change, the turbine blades will spin respectively faster or slower, causing the output electrical voltage and frequency to also fluctuate.

The power converter is the interface between the load/generator and the grid. The power may flow in both directions, of course, dependent on topology and applications. Three important issues are of concern using such a system. The first one is reliability; the second is efficiency and the third one is cost.

IV. SIMULATION AND RESULTS

A grid connected wind energy conversion system using a PMSG is simulated in MATLAB/ Simulink and the simulation diagram is shown in Fig 5. A wind speed of 6 m/s is used to carry out simulations.

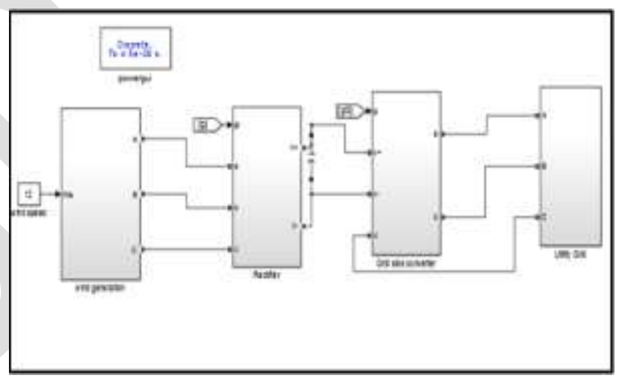

Fig 5 Simulation of overall system in MATLAB

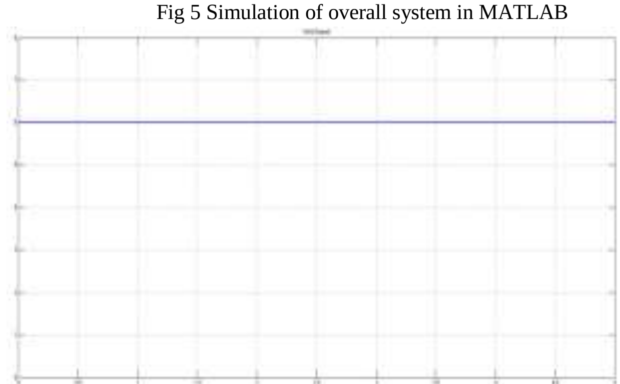

Fig 6 Wind speed of 6 m/s

Scale: X axis-Time(0.5s/div) Y axis- Speed(1 m/s per div)

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.

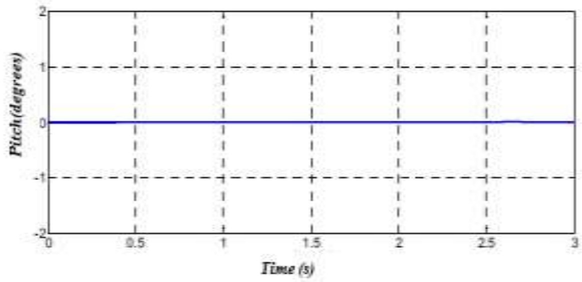

Fig 7 Pitch angle=0^{o} for wind speed 6 m/s.

Scale X axis:time (0.5s/div) Y axis: 1^{o}/div

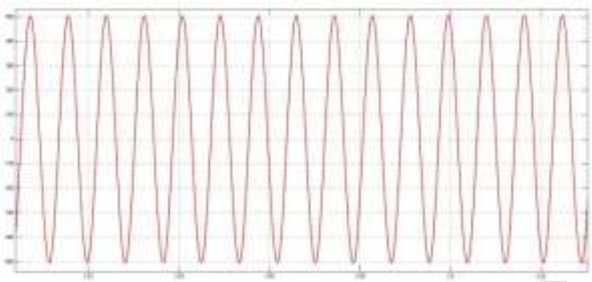

Fig 8 Generated line voltage at a wind speed of 6 m/s

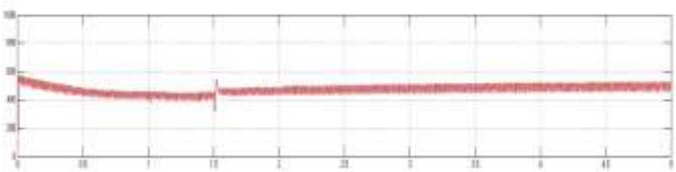

Fig .9 Active rectifier output at 6 m/s

Scale X axis: time(0.5s/div) Y axis: voltage(200 V/div)

A three phase symmetrical fault is given to the system to study the system behavior during fault. At t=1.5 s, a fault occurs in the system and at that instant the power generated is given to a braking resistor instead of giving it to the grid. Corresponding waveform are shown by figure 10-14.

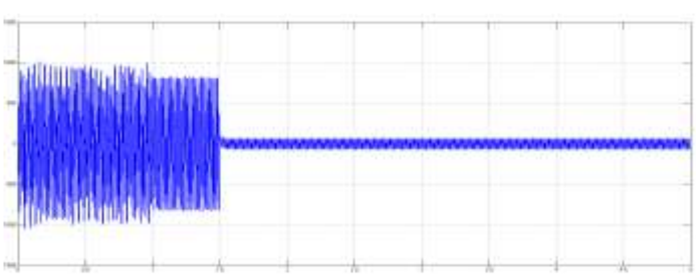

Fig 10 Voltage across braking resistor

Scale: X axis: time(0.5s/div) Y axis: voltage(500 V/div)

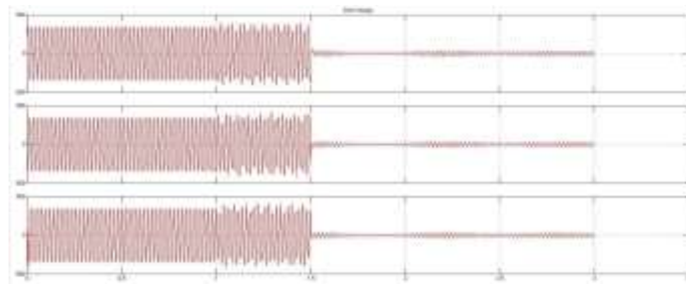

Fig 11 Grid voltage of each phase

Scale: X axis: time(0.5s/div) Y axis: voltage(500 V/div)

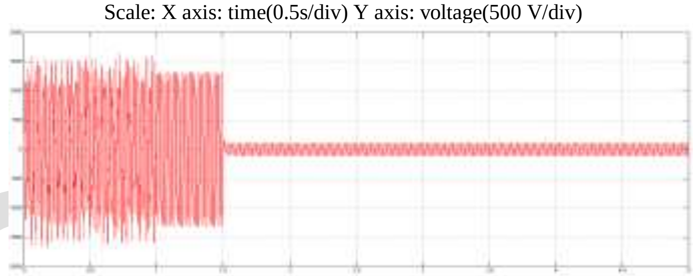

Fig 12 Current through the braking resistor

Scale: X axis: time(0.5s/div) Y axis: voltage(500 A/div)

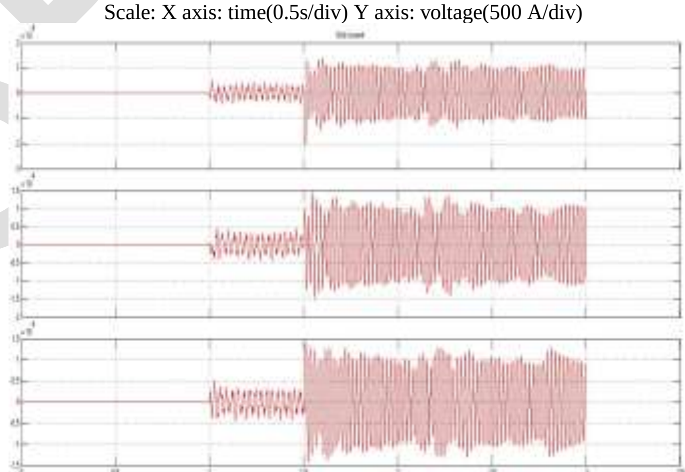

Fig 13 Grid current

Scale: X axis: time(0.5s/div) Y axis: voltage(5kA/div)

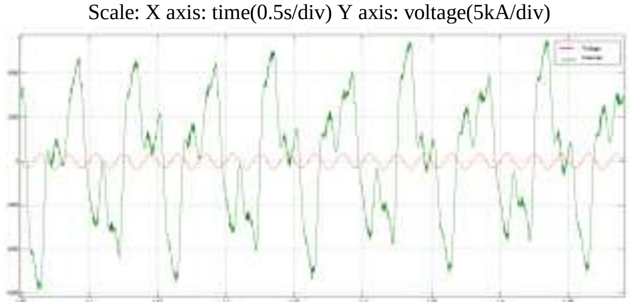

Fig 14 Grid voltage and current during healthy condition

Scale- X axis: Time(0.01s/div) Y axis: Voltage, Current(2000 V or A per div)

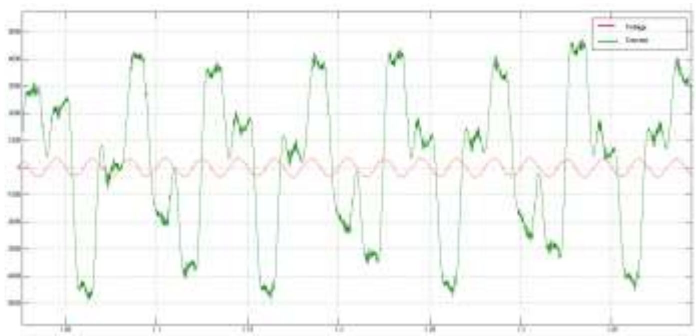

Fig 15 Grid voltage and current during fault

Scale- X axis: Time(0.01s/div) Y axis: Voltage, Current(1000 V or A per div)

V. CONCLUSION

In this paper the wind turbine driven synchronous generator is modelled using Matlab/Simulink tool and is also analyzed for various wind velocities. . By implementing an active rectifier, active power is maximized and reactive power brought within limits. Also a preliminary fault analysis was done when the system was subjected to a three phase symmetrical fault. The system behavior was also observed during the fault.

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