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Control of Wind Energy System Driven by Permanent Magnet Synchronous Generator by Maximum Power Point Tracking Technique

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ABSTRACT: Performance of the Wind Energy Conversion System can be greatly improved using an appropriate control strategy. Controlling the speed of wind conversion system (WECS) is done by maximum power point tracking (MPPT) technique. Optimum power tracking control strategy achieves optimum wind energy utilization. By considering the variation of wind speed, the grid-side converter injects the generated power into the AC network and regulates DC-link voltage and the Permanent Magnet Synchronous Generator side converter is used to achieve Maximum Power Point Tracking (MPPT). The proposed method, does not require the knowledge of air density, wind speed and turbine parameters.

KEYWORDS: Wind Energy System (WES), Permanent Magnet Synchronous Generator (PMSG), Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

Wind energy is the fastest growing renewable energy source next to solar energy. "Approximately 2% of the solar energy striking the Earth's surface is converted to kinetic energy in to wind. Wind turbines convert the wind's kinetic energy to electricity without emissions [1]". The idea of generating power from the wind is not new, but modern wind turbines are now efficient enough to be used by utilities [2]. Due to the increased number of wind turbines installed, the energy production by means of wind power is increasing by approximate 30% annually [3]. Wind energy has been used for hundreds of years for milling grains, pumping water, and sailing the seas. The use of windmills to generate electricity can be traced back to the late nineteenth century with the development of a 12kW dc windmill generator [4]. It is, however, only since the 1980s that the technology has become sufficiently mature to produce electricity efficiently and reliably. Over the past two decades, a variety of wind power technologies have been developed, which have improved the con-version efficiency of and reduced the costs for wind energy production. The size of wind turbines has increased from a few kilowatts to several megawatts each. In addition to on-land installations, larger wind turbines have been pushed to offshore locations to harvest more energy and reduce their impact on land use and landscape [10].

In this paper by considering the variation of wind speed, the grid-side converter injects the generated power into the AC network and regulates DC-link voltage and the Permanent Magnet Synchronous Generator side converter is used to achieve Maximum Power Point Tracking (MPPT). The proposed control strategy has been numerically tested in simulation by MATLAB/SIMULINK [5].

II. ELECTRICAL SCHEME OF WECS

A wind energy conversion system (WECS) transforms wind kinetic energy to mechanical energy by using rotor blades. "This energy is then transformed into electric energy by a generator. The system is made up of several components, participating directly in the energy conversion process. There are also other components that assist the system to achieve this task in a controlled, reliable, and efficient way"[11].

The Electrical scheme of Wind Energy Conversion System (WECS) is shown below in Figure 1. The scheme consists of a Wind Turbine coupled to a Permanent Magnet Synchronous Generator (PMSG) and it is fed to the Grid through a Power Electronic converters consisting of a Rectifier and an Inverter and a Transformer.

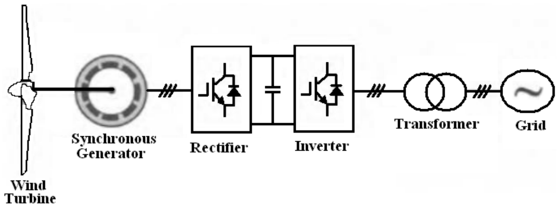

Figure 1. Electrical scheme of Wind Energy Conversion System

Since the energy source for a WECS is wind kinetic energy, wind speed plays a key role in several aspects of the conversion process, especially in relation to the maximum power output [6].

The power of an air mass flowing at speed v,, through an area A can be calculated by

$$P_w = ½ \rho A v^3_w \quad (1)$$

where ρ is the air density in kg/m^3, A is the sweep area in m^2, and v_w is the wind speed in m/s. The air density ρ is a function of air pressure and air temperature. At sea level and temperature of 15°C, air has a density of approximately 1.2 kg/m^3.

The wind power captured by the blade and converted into mechanical power can he calculated by

$$P_M = ½ \rho A v_w^3 C_p \quad (2)$$

where C_p is the power coefficient of the blade. This coefficient has a theoretical maximum value of 0.59 according to the Betz limit. For a three-blade turbine with a rotor diameter of 82 m and power coefficient of C_p = 0.36, the captured power is 2MW at a wind speed of 12 m/s and air density of ρ = 1.225 kg/m^3 [7].

The gearbox conversion ratio (r_{gb}), also known as the gear ratio, is designed to match the high-speed generator with the low-speed turbine blades.

For a given rated speed of the generator and turbine, the gearbox ratio can be determined by

$$r_{gb} = n_m / n_M = [(1 - s)*60*f_s]/[P*n_M] \quad (3)$$

where n_m and n_M are the generator and turbine rated speeds in rpm, s is the rated slip, f_s is the rated stator frequency in Hz, and P is the number of pole pairs of the generator. The gear ratio versus the rated turbine speed for different number of poles and different frequencies is shown in Figure 2.

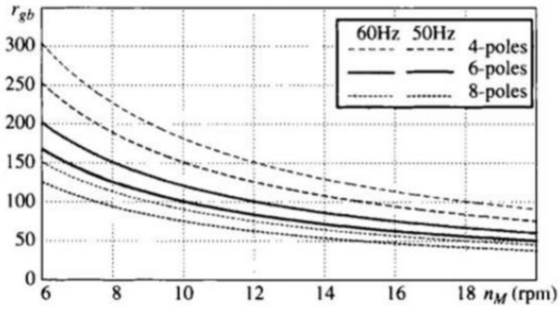

Figure.2. Gear ratio versus rated turbine speed

III. MAXIMUM POWER POINT TRACKING (MPPT) CONTROL

The control of a variable-speed wind turbine below the rated wind speed is achieved by controlling the generator [9]. The main goal is to maximize the wind power capture at different wind speeds, which can achieved by adjusting the turbine speed in such a way that the optimal tip speed ratio $\lambda_{T,opt}$ is maintained. Figure.3 shows the typical characteristics of a wind turbine operating at different wind speeds, where P_M and ω_M are the mechanical power and mechanical speed of the turbine, respectively.

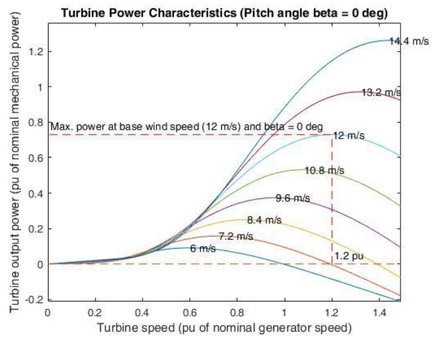

Figure.3. Typical characteristics of a wind turbine operating at different wind speeds

The trajectory of MPPs represents a power curve, which can be described by

$P_M \propto \omega^3_M$ (4)

The mechanical power captured by the turbine can also be expressed in terms of the torque:

$P_M = T_M \omega_M$ (5)

where T_M is the turbine mechanical torque. Substituting (5) into (4) yields

$T_M \propto \omega^2_M$ (6)

The proposed flow diagram of Maximum Power Point Tracking controller [8] used in this project is shown in Figure 4.

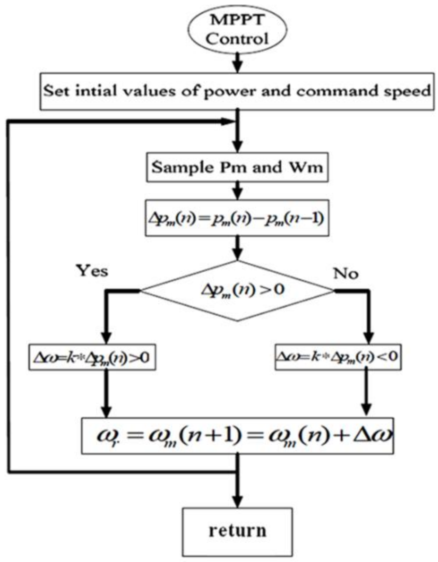

Figure.4. Flow chart of MPPT Controller

A simplified control block diagram with this method is illustrated in Figure.5 below.

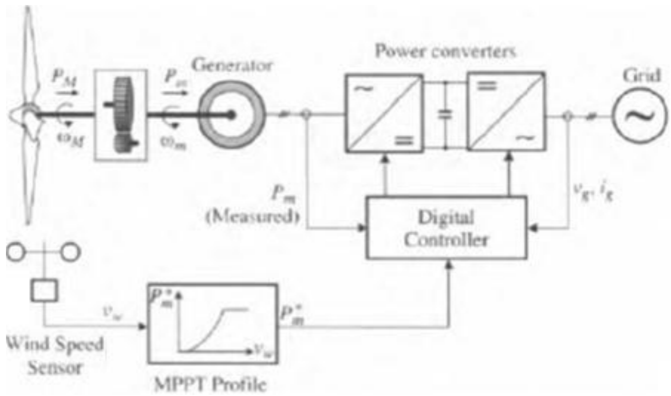

Figure.5. MPPT control with Wind turbine power profile

IV. SIMULATION MODEL AND RESULTS

The Simulink model for the proposed Wind Energy Conversion System using MATLAB Simulink software is shown in Figure 6.

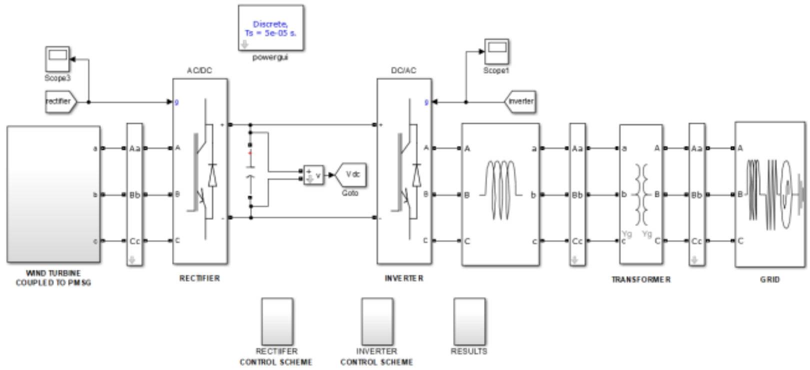

Figure 6. Simulink model for the WECS

The Simulink models for the Generator side Rectifier control and the Grid side Inverter control are shown below in Figures 7, 8 respectively.

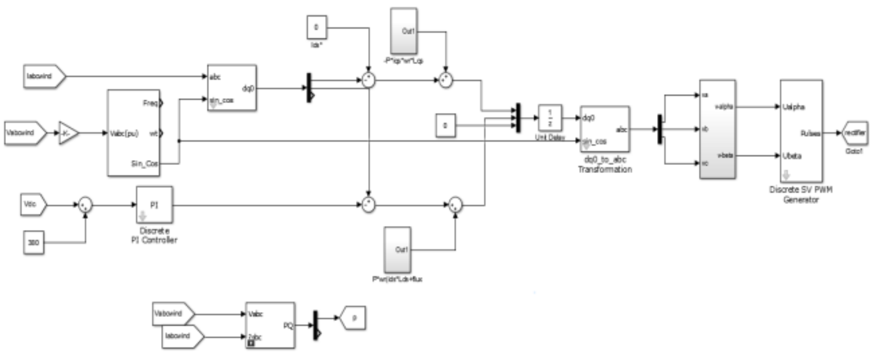

Figure 7. Simulink model for Generator side Rectifier control

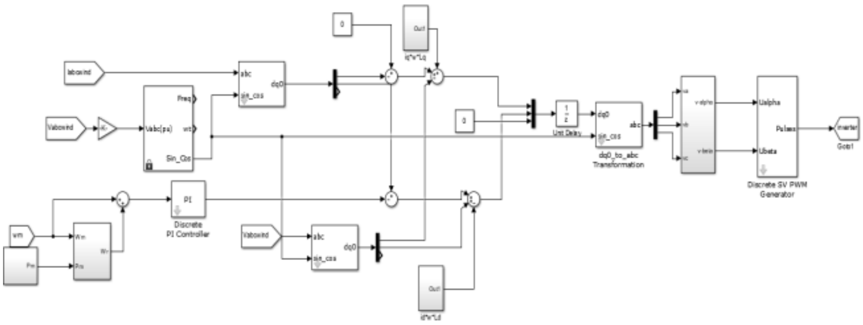

Figure 8. Simulink model for Grid side Inverter control

Figures 9, 10 and 11 show the wind speed, turbine speed and power response of the novel algorithm for the ramp wind condition respectively. It is obvious from the results of simulation that the turbine speed and the power can follow the varying of wind closely and smoothly.

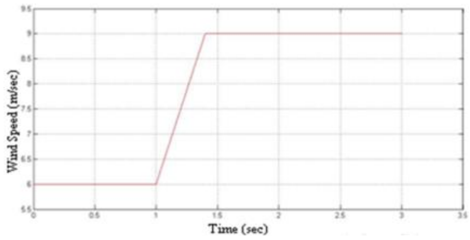

Figure 9. Wind Speed under Ramp condition

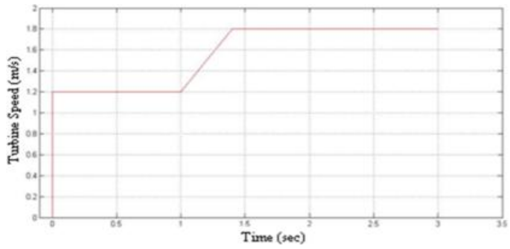

Figure 10. Turbine Speed under Ramp condition

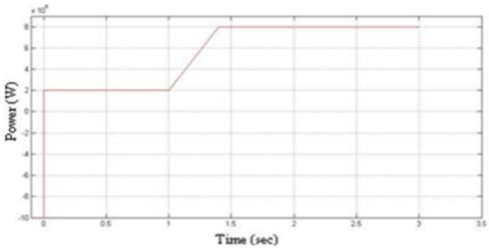

Figure 11. Power under Ramp condition

Figures 12, 13 and 14 show the wind speed, turbine speed and power response of the novel algorithm for the gust wind condition.

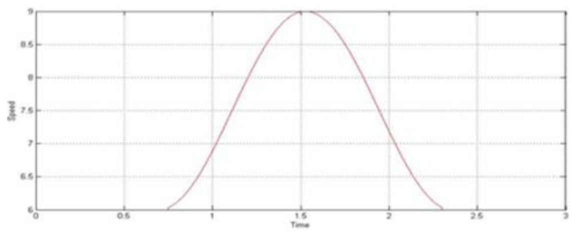

Figure 12. Wind speed under Gust condition

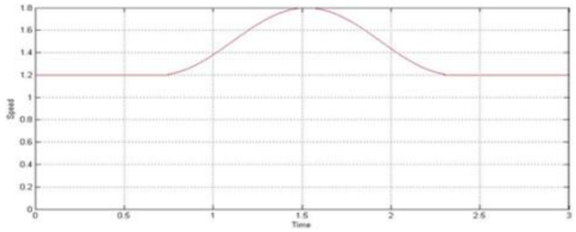

Figure 13. Turbine speed under Gust condition

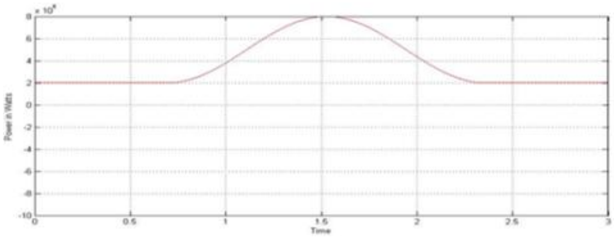

Figure 14. Power under Gust condition

V. CONCLUSION

A control strategy for a direct-drive stand-alone variable speed wind turbine with a PMSG has been presented in this paper. A simple control strategy for the generator side converter and grid side inverter to extract maximum power is discussed and implemented using Simulation software. The controller is capable of maximizing output of the variable-speed wind turbine under fluctuating wind. It is seen that the controller can maintain the load voltage and frequency quite well at constant load and under varying load condition.

The project proposes a MPPT control strategy which takes dynamic of wind turbine into account, in theory analysis. However, mechanical sensors such as speed and position sensors have some drawbacks, degrading reliability, increasing cost, and complexity of the drive system. A sensorless control for PM machine drives is essential for the WECS.

VI. APPENDIX

In this paper the fallowing parameters are used to simulate the proposed system

Parameters	Value
Turbine model	3 Blade Horizontal Axis
Blade angle	$\beta = 0$
Air density	$\rho = 1.225 kg/m^3$
λ_{opt}	8.1
Generation parameter	2MW D-PMSG
Number of poles	60
Rated power factor	0.95
Rated speed	22.5rpm
Inverter	4MW Double PWM
Grid voltage	380V
L_{ds}	0.02682H
L_{qs}	0.02682H
Line inductance	0.001H

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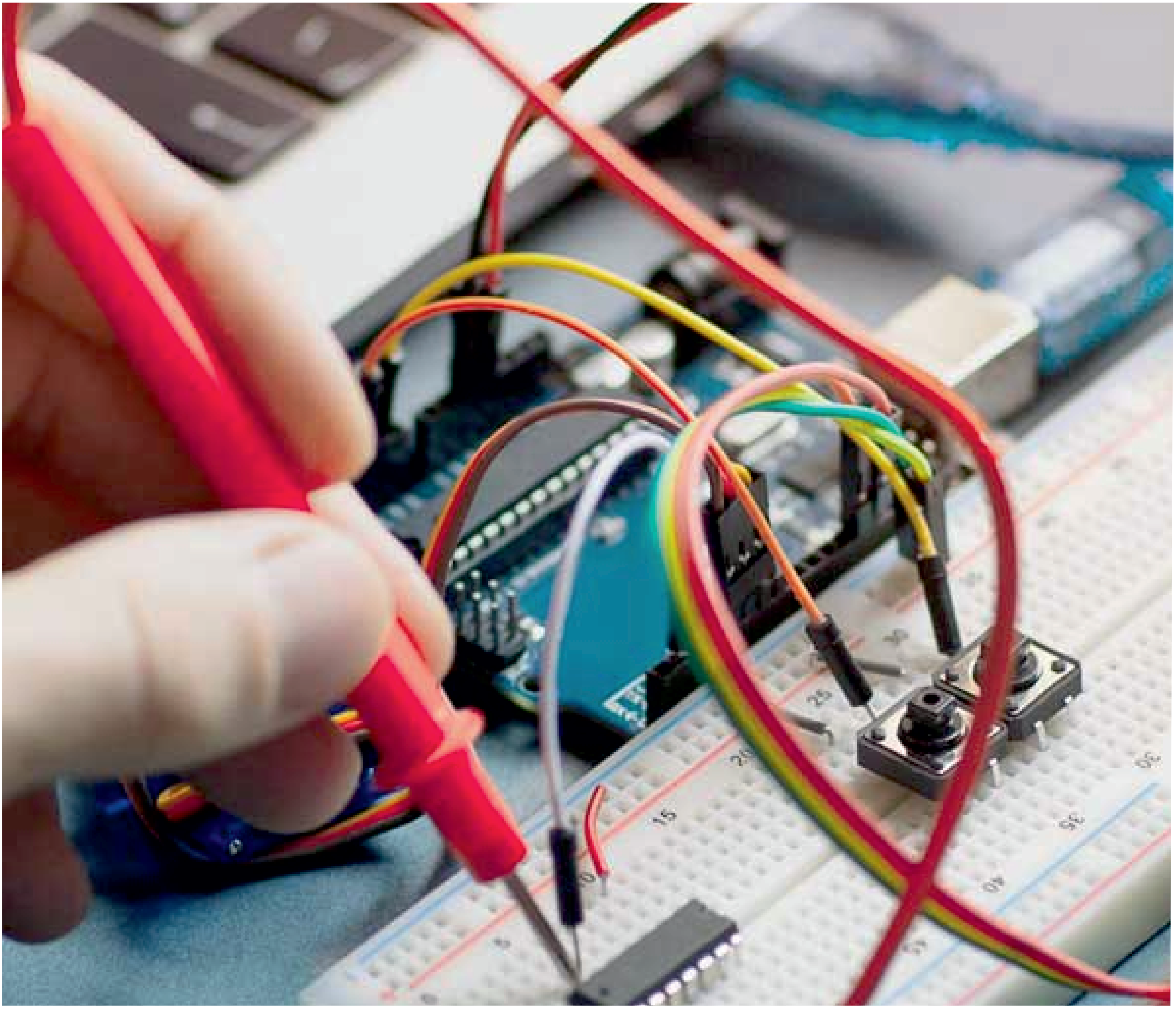

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