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MPPT for a PMSG Based Wind Turbine in a Grid Connected DC Micro Grid System

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Abstract: ***This paper presents the optimal power control of the wind turbine by the maximum power tracking (MPPT) algorithm and it is connected to the grid which is DC micro grid. The maximum power point algorithm is obtained by varying the duty cycle of the boost converter. When we vary the duty cycle than accordingly there is a change in the DC power and DC voltage by which we get the maximum power output at all wind speed. The proposed MPPT algorithm was tested using simulation. The wind turbine is modeled in Simulink. The modeled system consist of wind turbine connected to permanent* magnet *synchronous generator (PMSG),* rectifier and *boost converter. All the things are explained in detail and the simulation of the system under various condition are presented.***

Keywords: PMSG, MPPT, DC Micro Grid, Boost Converter.

1. Introduction

Wind turbine are the device which utilize the power of the wind energy to generate electricity. Wind energy is the indirect form of the solar energy. The unequal heating of the earth surface causes the pressure difference due to which air move from one place to another which creates wind. Wind turbine are the device used to capture wind to use in the other form.[1] Wind turbine are of two types small wind turbine and large wind turbine. Small wind turbine are of capacity 50KW.Small wind are used where the wind speed is high and radiation is less. The place where radiation is high but wind speed is zero at that place we can't install wind turbine..The country like India where the coastal region is very vast where generally wind speed is very high we can easily install the wind turbine.[2]The second and the most useful region to use the wind turbine it is renewable form of energy and it does not have any pollution. The petroleum products going to last but the renewable source of energy never extinct. Wind energy are divided into two part fixed speed wind turbine and variable speed turbine, In fixed speed turbine generator is directly connected to the load while in the variable speed wind turbine its speed is controlled by power electronic device [3].In the present paper we used the variable speed small wind turbine connected to the dc micro grid, the main aim of micro grid control is to maintain a constant voltage and constant frequency under all condition. In a grid connected mode the micro grid is connected through the coupling point to the electrical grid. While in islanded mode the micro grid is operated in an autonomous way and it is disconnected.[4]DC micro grid have a number of advantage as compared to AC as it has a lesser losses and it is also independent of from voltage sag, dips and other power quality issues occurring on the AC grid side[5]. The small wind turbine used is a grid connected mode. The power capacity of the small wind turbine is of 5KW which has a high pole pair permanent magnet synchronous generator (PMSG) which is connected to three phase rectifier and further connected to a boost converter, this is connected to a DC micro grid therefore we neglect AC inverter and by neglecting it the cost of the system decreases by half and as we are using the DC micro grid the efficiency of the system increases.[6] When the system is connected via boost converter. The main function of the boost converter is to regulate the voltage amplitude at the PMSG side to extract the maximum power.[7]The maximum power point (MPPT) is generally inbuilt in SWT but it is normally not correct. Therefore it is advisable to have the independent of the wind turbine.[8]. There are many method to measure MPPT like Power curve characteristic control, optimal speed ratio control and Perturbation and observation method [9].

Among the describe method the first two method have the better dynamic response but the last one is simple to implement and can be applied to the wide range. An incremental MPPT covered in was based on the direct variation of the duty cycle of the boost converter. In this paper we use perturbation and observation control method in which we vary the duty cycle of the boost converter accordingly there is change in DC link power and DC link voltage.[10] We use the incremental MPPT control for a 5KW wind turbine which is connected to the DC micro grid. Paper is organize such manner that section 2 gives an introduction on wind energy conversion, section 3 describes the boost converter design and MPPT algorithm and section 4 describes the simulation result.

2. Wind Energy Conversion System

The block diagram (Fig.1) describes that 5KW wind turbine is connected to the permanent magnetic synchronous generator which fed the three phase rectifier, the rectifier converts ac into dc. The output dc voltage is controlled by dc/dc converter via a boost converter. The boost converter is use to control the injected maximum power from the small wind turbine into the DC grid and it is finally connected to the micro grid DC bus grid and it is further connected to the ac inverter and if it is connected to the dc there is no need of the inverter and it cost reduces to half.

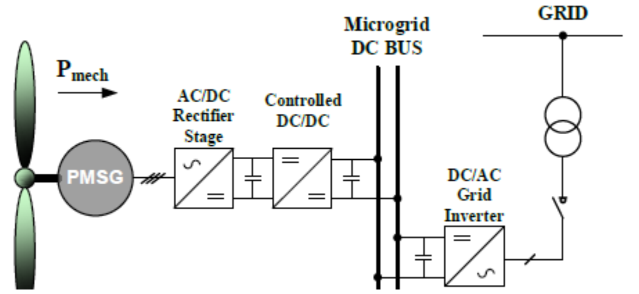

Figure 1: Wind Turbine Connected to a DC Micro grid

3. Mathematical Modeling of System

3.1 Mathematical Modeling of Wind Turbine

The wind speed model and aerodynamic model of wind turbine are included in a wind turbine model. Its gives equivalent wind speed for wind turbine. The mechanical power output of the wind turbine is given as

$$P_{wind} = \frac{1}{2}C_p(\lambda,\beta)\pi r^2\rho_{air}V_W^3 \quad (1)$$

Where, ρ is the air density (kg/m^3), rotor radius of blades (m) is r, and V_W is the uncertain wind speed (m/s) C_p is the performance coefficient of the wind turbine, where λ is the tip speed ratio, the performance coefficient C_p is calculated by [2].

$$Cp = C_1\left(C_2\frac{1}{\alpha} - C_3\beta - C_4\beta^x - C_5\right)e^{-C_6\frac{1}{\alpha}} \quad (2)$$

β is function of pitch angle of rotor blades (in degree), when β is equal to zero, the blade is fully imported by velocity of wind and wind turbine capture the maximum power in the wind. The other coefficient, x and $c_1 - c_6$ can be define in different ways based on turbine rotor.[7] The coefficients defined in [2] are used for wind turbine model where:

$c_1 = 0.5$, $c_2 = 116$, $c_3 = 0.4$, $C_4 = 0$, $c_5 = 21$, $x = 0$

$$\frac{1}{\alpha} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{1+\beta^3} \quad (3)$$

The tip speed ratio is defined as:

$$\lambda = \frac{\omega_a r}{V_W} \quad (4)$$

Where, w_a is the rotor angular velocity (rad/sec) of the wind turbine generator, The output of wind turbine mechanical torque is define as

$$T_{mech} = \frac{0.5C_p\pi r^2\rho_{air}V_W^3}{\omega_a} \quad (5)$$

3.2 Mathematical Modeling of PMSG

The dynamic model of PMSG is developed in d-q rotating reference frame [6]. The direct axis and quadrature axis voltage equation of generator is define as

$$V_d = -R_s i_d - L_d\frac{di_d}{dt} + \omega_e L_q i_q \quad (6)$$

$$V_q = -R_s i_q - L_q\frac{di_q}{dt} - \omega_e L_d i_d + \omega_e\mu_g \quad (7)$$

Where μ_g is the permanent flux of generator, ω_e is the electrical speed rotor in rad/s of the generator, describe by

$$\omega_e = \omega_a P$$

Where P is the number of pole pairs of generator.

The electromagnetic torque of generator is define as

$$T_{elect} = \frac{3}{4}P[\mu_g + (L_d - L_q)i_d]i_q \quad (8)$$

Then, the rotational angular speed is define as

$$\frac{d}{dt}\omega_a = \frac{1}{j}(T_{mech} - T_{elect} - B_x\omega_a) \quad (9)$$

Where B_x is damping coefficient (Nm/s)

4. Control for Wind Turbine

4.1 MPPT control for Wind Turbine

The main advantage of the incremental MPPT technique that it is independent of turbine parameters. This can be achieved from the DC link current and voltage without requiring any speed or wind measurements. Maximum power operation a wind turbine occurs when

$$\frac{dp}{dw} = 0 \quad (10)$$

And the back emf of the PMSG is is directly proportional to the rotational speed

$$\frac{dP}{dv_{dc}} = 0 \quad (11)$$

Where v_{dc} is the DC link voltage which is proportional to the amplitude of the PMSG's proportional to the rotational speed. This is also called perturbation and observation method since it observes perturbation in power and according to that it provide the correction in particular parameters like Duty cycle of the DC-DC converter to control the dc voltage or to regulate the current in order to adjust the rotor speed and adjust MPPT. This method is based on perturbing control variable in arbitrary small steps and the next perturbation is decided on observing the change in the power curve due to the preceding perturbation.

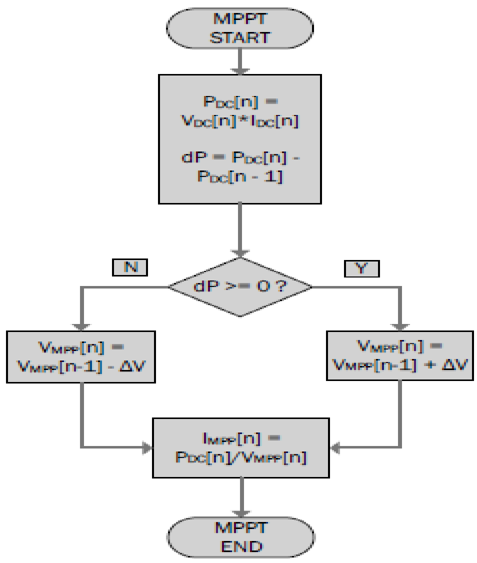

Figure 2: Flowchart of MPPT Algorithm

4.2 Boost Converter

The main function of the boost converter is to step up DC voltage. The boost converter is shown in Fig 3 and it is the switching circuit that produces a higher average output voltage than the input dc link voltage. It means it act as the step –up transformer.

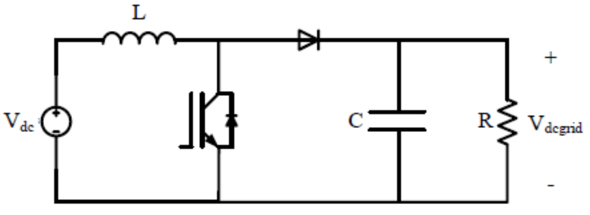

Figure 3: Boost Converter Topology

Table 1: Boost Converter Parameter

Parameter	Value
Input voltage (DC Link Voltage) V_{dc}	50-339V
Output Voltage(DC Grid voltage)V_{dcgrid}	400V
Converter Power P	5Kw
Inductor resistance R_L	0.002Ohms
Inductor L	35mh
Switching frequency f_s	10KHz

The voltage conversion ratio of the boost converter is output voltage to the input voltage

$$M(D)= V_{dcgrid}/V_{dc}$$
$$=1/1-D \quad (12)$$

The boost converter inductor, L is given as

$$L=V_{DC}D/2i_l f_s \quad (13)$$

Where i_l is the desired inductor current peak ripple

F_s is the switching frequency

The boost converter capacitor 'C' value is

$$c = V_{dcgrid} D/2V_O R f_s \quad (14)$$

Where V_o is the output voltage peak ripple

R is the load resistance

Boost converter is designed using 12, 13, 14 to find the duty cycle D, inductor L and capacitance C. Below table describes the boost converter parameters which has the predefined set parameters as well as the calculated value. The inductor resistance R_L and equivalent series resistance (ESR)of the capacitor R_C were taken from actual inductor and capacitor data.

5. Simulation Result and Discussion

Simulation of the micro grid system was carried out for a 5kW wind turbine whose parameters are given in Table 2. The wind turbine including the PMSG and the Boost converter were modelled in Simulink, and are shown in Fig. 4. The simulation considered the operation of PMSG based wind turbine with the micro grid operating at a fixed DC voltage Vdc grid of 400V under grid-connected conditions and with varying wind speed conditions.

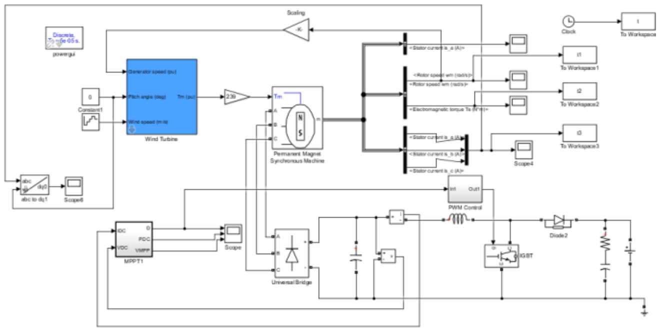

Figure 4: Simulink Model of DC grid Connected PMSG Based Wind Turbine System

Table 2: PMSG and Wind Turbine Parameter

Parameter	Value
Rated Power	5KW
Stator Resistance	1.95 ohms
Stator Inductor	1.9 mh
No of pole pairs	15
System Inertia	$1kg/m^2$
Cut in Wind Speed	2.5m/s
Rated wind Speed	12m/s
Rotor Diameter	5.5m

A typical wind speed profile from 9m/s to 12m/s was provided to the wind turbine model with steps in wind speeds, shown in Fig.5. The wind turbine extracts the wind which was at the speed of 9 m/s and it is varied till 12m/s. The Fig. 5 is showing the wind profile of wind energy. The wind energy is given to the wind turbine from which we get the mechanical torque. Fig. 6 describes the behavior of the mechanical torque. This torque act as the input torque for the rotor of the PMSG generator. The rotor speed is shown by the Fig. 7, whose maximum speed is given as 20rad/s. The behavior of the output torque of the generator which is called as the electromagnetic torque is shown in fig8. From the generator we get the three output voltage, current and power shown in Fig. 9-fig11.The voltage which we get is rectified via rectifiers. The received dc voltage is of very low value and it is called as the DC link voltage which is shown by the Fig 12and corresponding we get the DC link current Fig.13 and Dc link power shown byfig14.The given DC link voltage is boost to 400V by the use of the boost converter fig15which is the output voltage given to the grid. The MPPT algorithm varies as we change the speed of turbine and it varies accordingly.

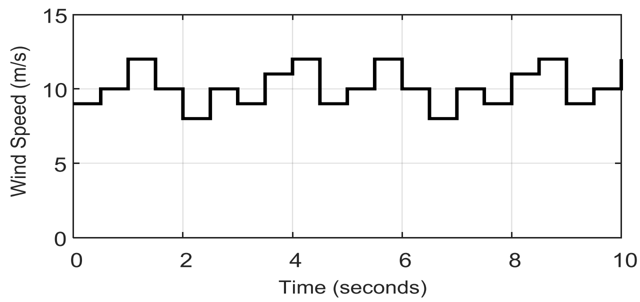

Figure 5: variation of the wind speed

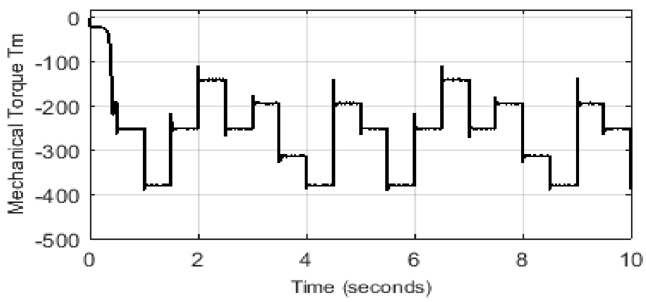

Figure 6: Mechanical Torque generated by Wind Turbine

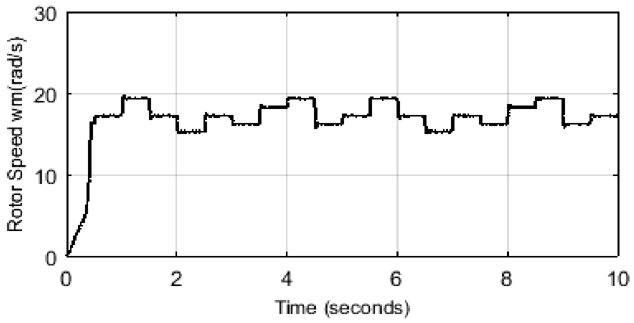

Figure 7: Rotar Angular Speed

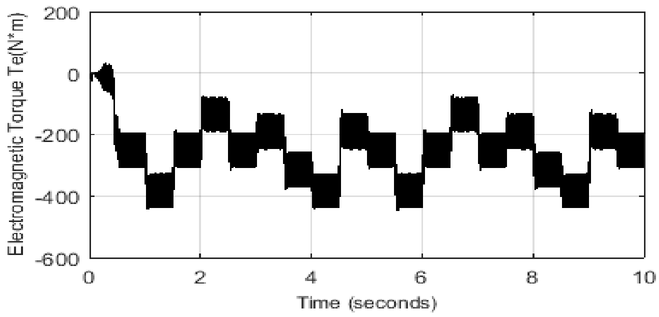

Figure 8: Electromagnetic torque of generator

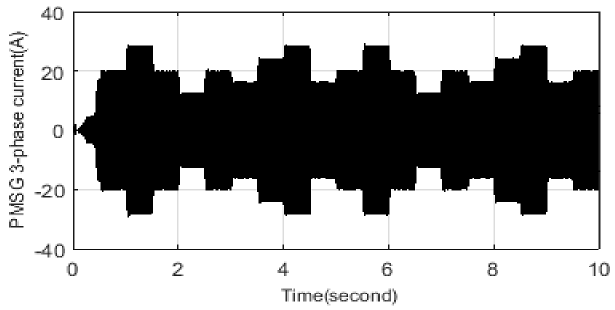

Figure 9: 3phase current of PMSG

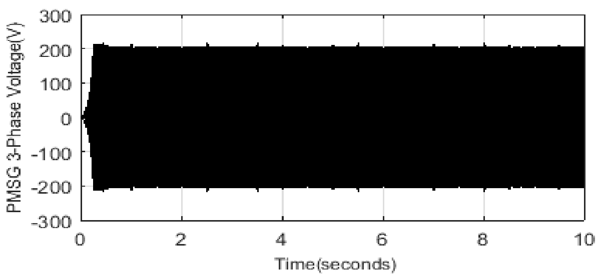

Figure 10: 3-phase Voltage of PMSG

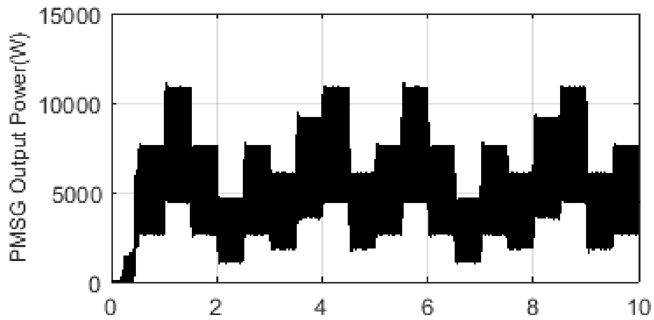

Figure 11: Output power of PMSG

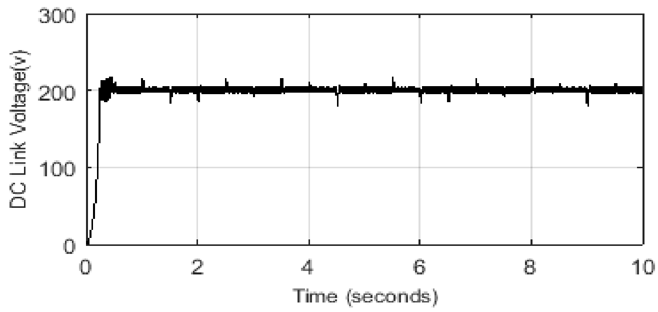

Figure 12: DC link voltage

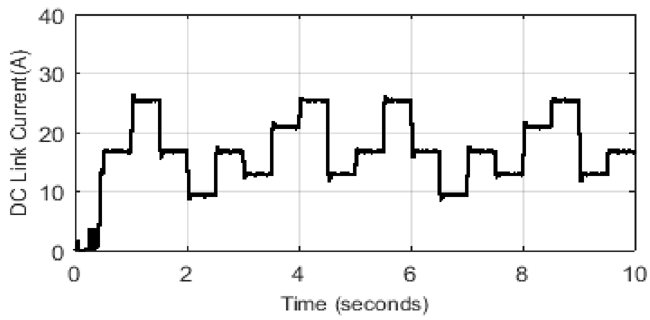

Figure 13: DC link current

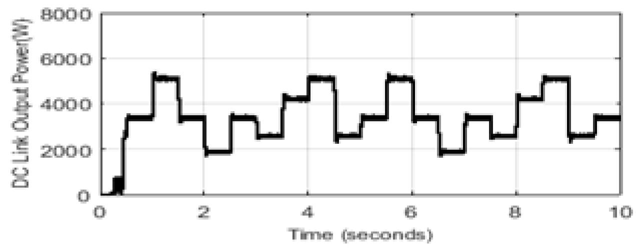

Figure 14: DC link power

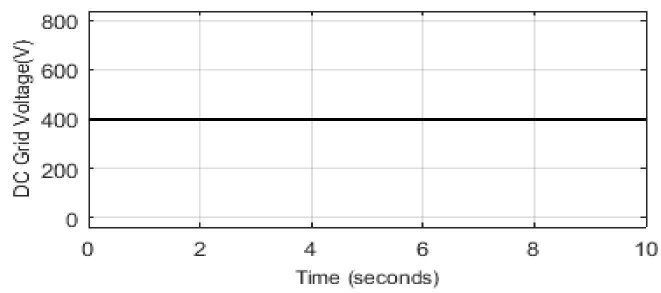

Figure 15: Output Dc grid voltage

6. Conclusion

The paper presented on MPPT algorithm to obtain a maximum power output from a wind turbine which is connected to the DC micro grid. The system consists of PMSG which is driven by the small wind turbine which is coupled to the DC micro grid via a various rectification stage and a boost converter. The proposed algorithm is based on power-speed characteristic of the wind turbine which is independent of the system parameters. It is successfully implemented on the wind turbine by the Matlab/Simulink model and the simulation result shows the optimal power point operation was achieved for all wind speed. The proposed MPPT algorithm controls the boost inductor current according to variations in the DC link power, to obtain maximum power This algorithm was successfully implemented in the simulation model, and simulations for varying wind speeds from 9m/s to 12m/s were carried out. The boost converter allowed for successful transfer of energy from a DC link voltage of around 200V to a fixed micro grid parameters output voltage of 400V, with a varying DC link current of around 10A to 25A. The simulation results showed that the optimal power operating point was achieved for all wind speeds. This tracking algorithm provided maximum power output into the DC micro grid under all conditions.

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