Wind Energy with MPPT to Variable Load Conversion System using T-type Three-phase Converter

Rupesh Dhage[1], Prof. Ashish Bhargav[2]
[1]*M. Tech. Scholar, Department of Electrical Engineering, Bhabha Engineering Research Institute, Bhopal*
[2]*Assistant Professor, Department of Electrical Engineering, Bhabha Engineering Research Institute, Bhopal*

Abstract **- Recently, Maximum Power Point Tracking (MPPT) algorithms plays an important factor in optimizing the output power obtained from WECS. Because of that, the implementation of a robust and effective MPPT algorithm in the power converter becomes necessary to keep the output power at its maximum value irrespective of any sudden change in either wind speed or load. This paper presents a novel MPPT algorithm based on optimization of converter duty cycle values. The main idea is to build a mathematical model which relates the optimal duty cycle according to wind speeds. This model has been built based on simulations of a standalone low-cost WECS consisting of wind turbine, permanent magnet synchronous generator (PMSG), uncontrolled rectifier, DC/DC boost converter and constant load. The WECS have been simulated based on variable wind speed. The duty cycle values have been selected while monitoring and recording the output power. Then, the model has been built based on the optimal duty cycle which ensures the successful achievement of the MPP operation at specific wind speed. The results obtained have shown improved and acceptable performance of low-cost WECS in terms of MPP operation achievement and tracking time.**

Index Terms **- Wind Energy Conversion Systems (WECS), MPPT, DC-DC Boost Converter, PMSG.**

I.INTRODUCTION

Wind energy conversion technologies evolves rapidly in the last decades, so it becomes obvious to pay attention in implementation and optimization of these technologies. MPPT algorithms had become a promising area of research since it enhances the efficiency of WECS in simple way at low cost. It is very crucial for these techniques to be able to satisfy the requirements of any standalone wind energy system. Recently, many new MPPT techniques have been proposed and some have been modified to satisfy and meet the requirements of wind generation industry. In addition, many of these techniques have been validated to be adopted in any WECS. However, these techniques differ in many aspects such as complexity, tracking speed, implementation difficulty and variety of hardware and software components involved [1, 2].

Wind turbines can either operate at fixed speed or variable speed. For a fixed speed wind turbine, the generator is directly connected to the electrical grid. Fixed-speed wind turbine operate at a near constant rotor speed at all times. The rotor blades are rigidly fixed to the hub, however, they are designed to become aerodynamically stalled at high wind speed, and typically above 25 m /s. Variable speed wind turbine on the other hand have the generator output controlled by power electronics equipment. Thus, it is advantageous as energy harvested increases due to extraction of power at different wind speeds [3]. Several reasons, such as the reduction of the mechanical structure stresses, the acoustic noise and the possibility to control active and reactive power have driven the choice for variable speed operation of wind turbines.

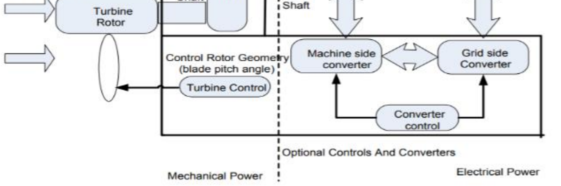

Fig. 1: A typical schematic diagram of a grid connected WECS

Mainly a WECS is an electromechanical system which consists of wind as the source, the turbine, a generator and sink (grid/local load). Wind speed distribution is generally high in hilly areas or near the shore. For such remote locations it may be far off the grid. Economic viability and convenience has given rise to two basic topologies of WECS. These are as follows. Grid connected WEC systems have large installed capacity for its capacity utilization rather than the storage. A schematic diagram of a grid-connected wind energy conversion system is shown in Fig. 1. Isolated systems have small capacity to supply local load in association.

II.MODELING OF WIND TURBINE

The wind energy captured by the blades was transformed by the wind turbine into mechanic energy. The aerodynamic energy of the wind can be represented as,

$$P_w = \frac{1}{2}\rho A V_w{}^3 \tag{1}$$

Where,
A = Circular Area
V_w = Wind speed
$\boldsymbol{\rho}$ = Air density

Using the wind aerodynamic energy, aerodynamic power can be produced by the turbine. It can be expressed as

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

Where,
C_p = Power coefficient
B = Pitch angle
ʎ = Speed ratio

$$\lambda = \frac{wR}{Vw} \tag{3}$$

Where,
w = Turbine rotor speed
R = Turbine Radius
C_p can be expressed by

$$C_p(\lambda, \beta) = C1\left(\frac{C2}{\lambda_i} - C3\beta - C4\right)e^{-\frac{C5}{\lambda_i}} + C6\lambda \tag{4}$$

Where,
C1 to C6 = Constant on the wind turbine rotor and blade design

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{5}$$

The aerodynamic torque is determined by

$$T_t = \frac{P_t}{w} \tag{6}$$

$$T_t = \frac{0.5\rho\pi R^3 V^2 C_p}{\lambda} \tag{7}$$

The fundamental dynamic equation is described with the following equation

$$J\frac{dw}{dt} = T_t - T_{em} - f_w \tag{8}$$

Where,
T_{em} = Electromagnetic torque
f = Turbine rotor friction

Then, the wind turbine generator drive that represents the mechanical block can be given by:

$$T_t - T_{em} = J\frac{dw}{dt} + f_w \tag{9}$$

III.PROPSOED METHODOLOGY

Wind is one of the most abundant renewable sources of energy in nature. The economic and environmental advantages offered by wind energy are the most important reasons why electrical systems based on wind energy are receiving widespread global attention. Wind energy can be outfit by a breeze energy transformation framework, made out of wind turbine cutting edges, an electric generator, a power electronic converter and the relating control framework. Fig. 4.1 shows the square graph of essential parts of WECS. There are different WECS setups in light of utilizing coordinated or offbeat machines, and slow down managed or pitch directed frameworks. Be that as it may, the practical goal of these frameworks is something similar: changing over the breeze motor energy into electric power and infusing this electric power into a utility lattice.

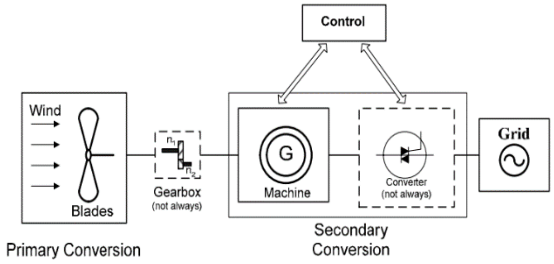

Fig. 2: Block diagram of a WECS

Here the basic WECS is considered to be the grid connected one with back-to-back inverter configuration; hence, all of its components relevant for the electrical domain will be considered. The complete systems will contain:

- Wind turbine model with gearbox and pitch control
- MPPT control
- Multiphase machine model
- Indirect rotor field-oriented control (IRFOC) for machine-side converter control
- 3-level T-type inverters in back-to-back configuration
- PLL for grid-side inverter synchronisation
- Voltage oriented control (VOC) for grid-side inverter control

Wind Turbine with Gearbox and Pitch Control

Regardless of the load requirements and the topology of the WECS detailed in the previous section, majority of the wind turbines used today are horizontal-axis wind turbines; hence, they are considered in this chapter. Usually, modelling of the wind turbine is associated with the amount of wind energy generated by air mass of density ρ flowing at the speed v_w through an area A. If C_p is wind turbine efficiency, equation for captured wind power by the turbine is:

$$P_t = (1/2)\rho.v_w^2C_p \quad (10)$$

Turbine efficiency C_p is highly dependable on the approaching angle of the wind and blade pitch. Systems controlling these parameters are yaw and pitch control.

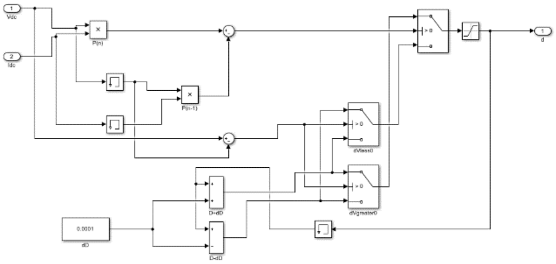

Fig. 3: Wind Turbine with Gearbox and Pitch Control

Yaw mechanism directs the turbine blades to perpendicular position to the wind direction, while pitch limits captured wind power when wind speed is above nominal. Yaw control is omitted from the turbine model since it does not have any impact on the electrical subsystem, i.e. it is assumed that turbine blades are always perpendicular to the wind. Controlling simulation shown in figure 2.

On the other hand, it is necessary to implement pitch control, so that a proper MPPT algorithm can be developed. Here the pitch mechanism is simplified and it keeps turbine efficiency at maximum while the captured power and consequently wind speed are below rated values. When the wind speed is above rated, captured power is limited to the nominal value by the pitch mechanism. This has been modelled by a simple limiter. Since the turbine torque value is necessary for the rest of the system, it is obtained by division of the turbine-produced power with the shaft speed. However, a problem with this approach is division by zero. To overcome this, turbine shaft speed has been limited to be larger than 10^{-6}, which has a negligible impact on system operation.

WECS with Diode Bridge Rectifier

Heating losses induced in the superconducting coil from currents and fields (AC losses) is an important factor for superconducting electrical machines design and operation. Indeed because of the efficiency of the cooling system, AC losses in the cold parts are amplified by a factor from 50 up to 1000 for temperatures in the 80 K-20 K range. That is why superconductors are mainly used in synchronous generators for the DC field winding. But even if the field winding carries nominally DC current, significant AC currents and fields are introduced during steady-state operation. This has been underlined by various authors. General level AC losses in wind turbines applications resulting from field PWM modulation and wind turbulences.

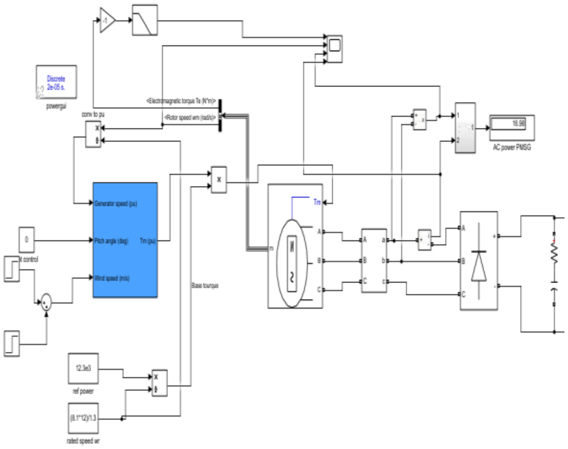

Fig. 4: WECS with diode bridge rectifier

Design of Three Phase T-Type Inverter

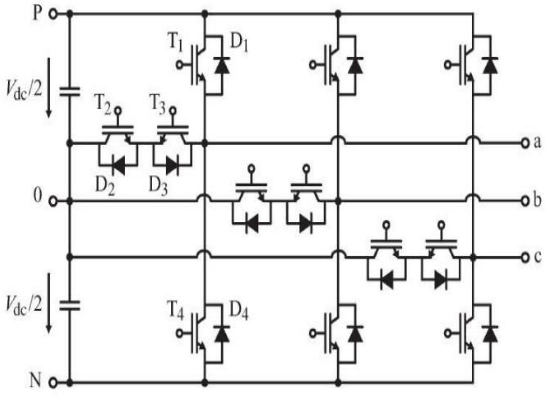

Fig. 5: Three-phase T-type inverter

To show the impact of the power converter on the field current, we reproduce the consistent state activity of a regular WECS. The system overview using simulation is shown on Figure 4. The generator is a conventional 50 Hz synchronous machine. The AC/DC/AC converter has a diode bridge rectifier in the generator side and a PWM inverter in the grid side. This illustrates the importance of choosing an appropriate converter topology and control strategy that can help to keep AC losses as low as possible in the superconductor and in the cold parts of the generator. Note that AC fields should be taken into account too, but they cannot be estimated with the considered lumped parameter model.

The T type MLI consist of conventional three leg topology with addition of other three legs clamped neutrally from each conventional leg as shown in Figure 5. The switches connected in between clamped neutral & load is bidirectional switches. The voltage rating of all switches present between the two phase of source side is selected same as the voltage rating of source side. However, the voltage rating of switches connected in between neutral point & load side is taken as half of that of source voltage. Basically, the three types of the operation which is the main part of this inverter.

IV.SIMULATION RESULT

Successful operation of a wind turbine depends on many factors such as the availability of the wind, mechanical construction of the turbine, ease of access and the electrical subsystem. Advancements in the mechanical subsystem are mainly related to the improvements of the gearbox design in order to increase its reliability. Further, it is possible to completely remove it by use of low-speed high pole number synchronous machine. As far as the electrical subsystem is concerned, many improvements have been made over the years in terms of the efficiency and robustness of the electrical systems. Figure 6 shows the variable wind speed for generate and varied a different condition for the proposed work.

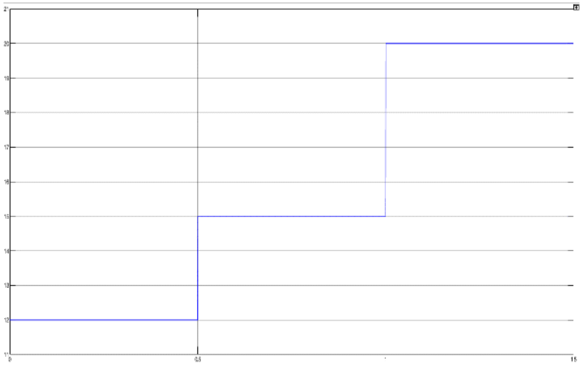

Fig. 6: Wind speed (m/s)

Figure 7 shows the electromagnetic torque (N.m), rotor speed (rad/sec), wind line voltage (V) and line current (A) where the wind speed change voltage current and torque change simultaneously. Where the line voltage has a change frequency with the wind speed and grid current frequency change simultaneously.

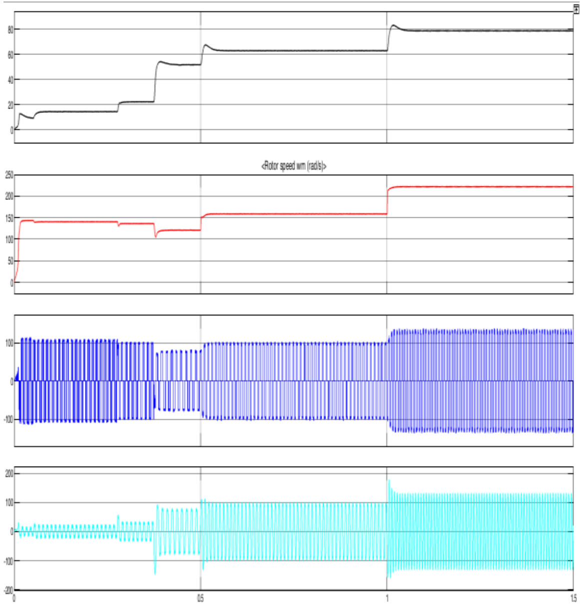

Fig. 7: Electromagnetic torque (N.m), Rotor speed (rad/sec), Wind line voltage (V), Line current (A)

Figure 8 shows a bridge rectifier DC voltage where the DC voltage changes with wind speed but voltage is low. In that case required DC-DC boost converter to boosting voltage and capable to connected with load.

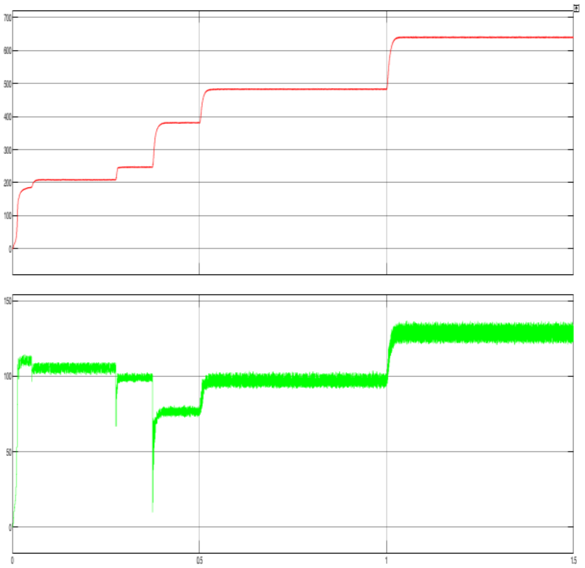

Fig. 8: DC-DC boost output voltage (V), Bridge rectifier output voltage (V)

IV.CONCLUSION

The paper presented a new proposed adaptive fractional order PI. The controller acquires the advantage of both: adaptive PI and classical fractional order PI. The MPPT is based on mathematical model relating the optimal duty cycle with input wind speed. The model is built according to simulations of the system under different wind speed and duty cycle values. The results have shown the effectiveness of the proposed MPPT algorithm to respond for any sudden change in wind speed values. This MPPT algorithm can be used to build a low cost MPPT controller which is customized for each rated wind turbine.

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