Simulation Model for Wind Energy with Variable Load Conversion using T-type Three-phase Inverter

[1]Ravi Kant Bharti, [2]Prof. Sarvesh Pratap Singh

M. Tech. Scholar, Department of Electrical Engineering, SORT, People's University, Bhopal, India[1]
Assistant Professor, Department of Electrical Engineering, SORT, People's University, Bhopal, India[2]

Abstract: - In modern years, among various renewable energy sources, the Wind Energy Conversion System (WECS) has been considered as one of the most rapid growing energy sources and has gained enormous admiration. There are several techniques by which we can extract power efficiently from wind turbines which is to be communicated to the grid. 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.

Keywords: - Wind Energy Conversion Systems (WECS), MPPT, DC-DC Boost Converter, PMSG

I. INTRODUCTION

In today's world due to increase in demand of power and fast depleting resources, there is need of alternative power sources which not only meet existing power demand but also are environment friendly. There are numerous renewable sources available for example Solar, Wind, Geothermal, Tidal etc. Out of all these sources Wind Energy is emerging as an established technology which provides a bright, stable & limitless cause of energy for maintaining the endlessly rising power necessities of human race. Wind Energy Conversion System is also a power technology that has made vast progression from the last two decades with the development in wind power technologies and its control and modulation techniques. The Wind Energy Conversion System (WECS) is considered as one of the fastgrowing energy sources among various renewable energy sources available in India. In recent times majority of wind turbines are being erected in large wind farms which are located in the areas which are not connected to grid and have large storage system through batteries. Also, there is WECS that is linked to grid and power is fed to the grid. There are various techniques by which we can extract power efficiently from wind turbines which is to be transmitted to the grid.

In year 2023 the overall capacity of wind reached 539291 MW, internationally. Many of the countries have achieved soaring intensity of wind manufacture by the end of 2013 such as China produces 18839235 MW of wind energy which is 35% of total worldwide production followed by USA and Germany which produces 89077 MW and 56132 MW which is 17% and 10% of total worldwide production respectively. India is ranked fourth with 32848MW which is 6% of total worldwide production and is expected to add additional 2.5-3 GW in financial year 2019.Figure 1 shows current wind energy production scenario in India with Tamil Nadu having 44.23% of the total wind produced share in India followed by Maharashtra and Gujarat with 20.10% and 14.42% respectively. Now a days onshore production of wind is there as there is plenty of wind blowing in the middle of the sea as compared to offshore wind installations where wind speed is less and is not so strong as compared to On shore wind.
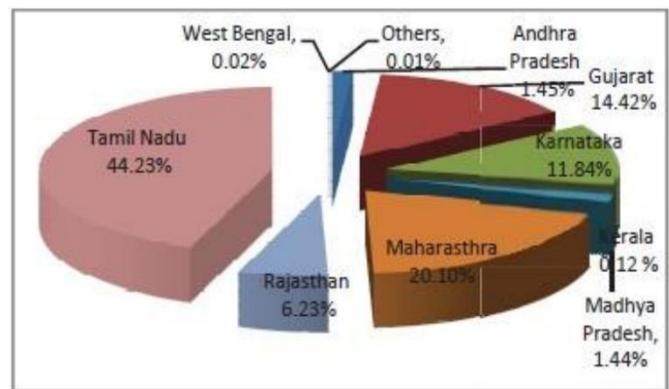

Fig. 1: Present day scenario of wind energy in India

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,

$$P_w = \frac{1}{2}\rho A V_w{}^3 \qquad (1)$$

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

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

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

$$\lambda = \frac{wR}{Vw} \qquad (3)$$

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

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

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

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

The aerodynamic torque is determined by

$$T_t = \frac{P_t}{w} \qquad (6)$$

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

The fundamental dynamic equation is described with the following equation

$$J\frac{dw}{dt} = T_t - T_{em} - f_w \qquad (8)$$

Where,
T_{em} = Electromagnetic torque
f = Turbine rotor friction
Then, the wind turbine generator drive that represents the mechanical block can be given by:

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

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. 2 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.
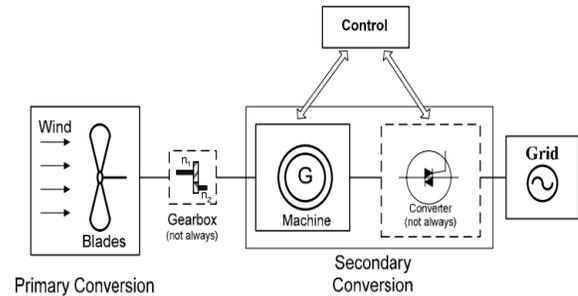

Fig. 2: Block diagram of a WECS

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
Voltage-controlled inverters typically lead to a variable switching rate, as each sampling point has the prediction control methods for generating switches based on the optimal

voltage level selected. The output of the source voltage filters is difficult to model with different frequencies. This paper proposes a predictive algorithm to control the inverter load current for single phase voltage source with constant switching frequency. This method defines a zero voltage and a potential optimum pressure condition based on the reference current pitch used for the corresponding sampling time at each sampling point. 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:

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

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.
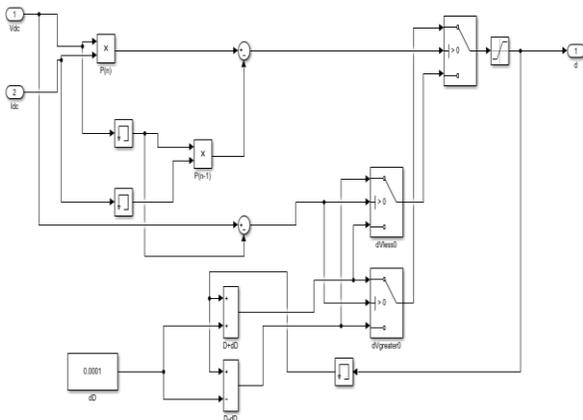

Fig. 3: Wind Turbine with Gearbox and Pitch Control

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.
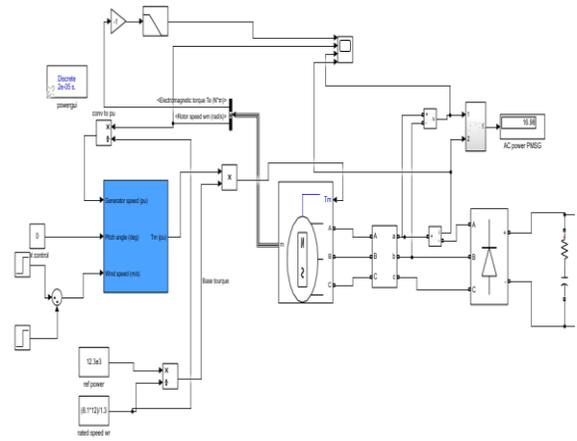

Fig. 4: WECS with diode bridge rectifier

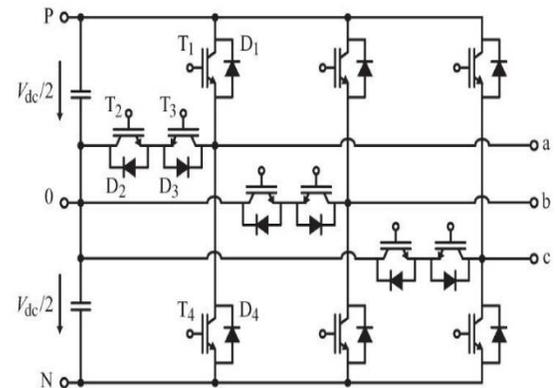### Design of Three Phase T-Type Inverter

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.
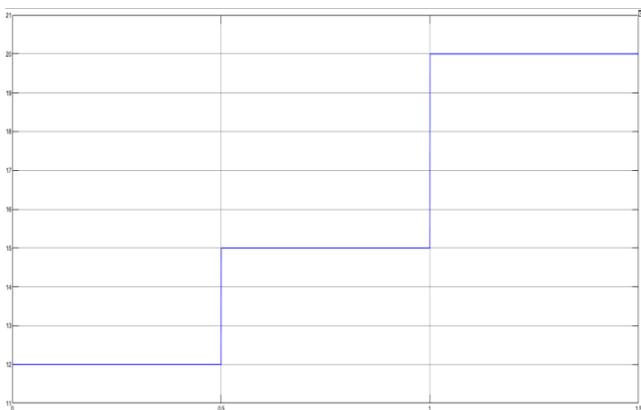

Fig. 6: Wind speed (m/s)

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.
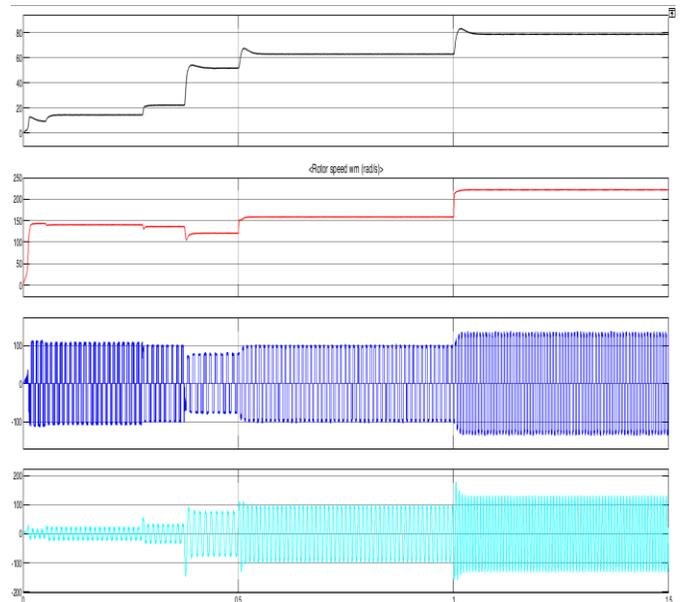

Fig. 7: Electromagnetic torque (N.m), Rotor speed (rad/sec), Wind line voltage (V), Line current (A)

Figure 8 shows a bridge rectifier DC voltage where the DC voltage changes with wind speed but voltage is low.
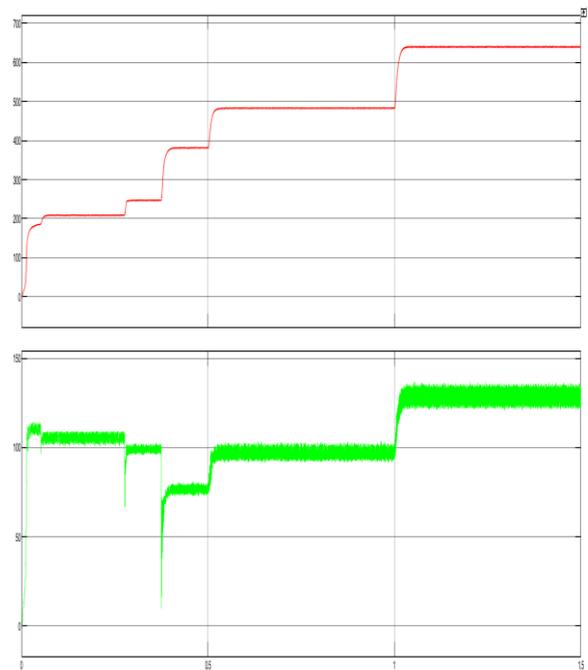

Fig. 8: DC-DC boost output voltage (V), Bridge rectifier output voltage (V)

V.   CONCLUSION

High and stable output power can be achieved by this method which has new and unique arrangements and configurations of generators & convertors. In recent times the most of the wind turbines are being erected in big wind farms which are located in the areas which are not connected to grid and have large storage system through batteries. Apart from standalone systems there are grid connected systems also by which WECS is connected to grid and power is fed to grid and trough this technique power can be extracted competently from wind turbines and then it will be transmitted to the grid. 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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