Adoption of an Effective Control Scheme for Wind Energy Conversion Systems using Maximum Power Point Tracking

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Abstract - *Wind energy is the fastest-growing renewable energy source due to its free availability and environmental benefits. A power conditioning topology is required to boost the voltage from the WECS.MPPT algorithm enables WTS to maximize its efficiency by extracting maximum possible energy for a wide range of wind speed values. In this work, the Incremental Conductance method of maximum power point tracking is adopted for the efficient tracking of the operating point. The duty ratio generated from the controller is utilized to provide gating pulses for the boost converter. A three-phase inverter is used to convert the dc output of boost converter to ac. The synchronous reference frame theory of PWM pulse generation is used to provide gating pulses for the three-phase inverter. The specifications of the turbine include a nominal mechanical output power of 8KW and a base wind speed of 12 m/s. The wind turbine characteristics for the wind turbine model is obtained in SIMULINK. From the wind turbine characteristics, the maximum power extracted from the WECS is 5KW at a base speed of 12m/s. The simulation results depict that the output voltage and current obtained from the wind turbine are 74V and 72A respectively. Further, the voltage from the wind turbine is boosted to 300V with the help of a boost converter simulation circuit. The performance of the controller is observed with simulation analysis. Stable operation of the system for a large step change in the DC voltage validates the sturdiness of the controller.*

Key Words: Wind energy conversion systems, MPPT, Parks transformation, boost converter, wind turbine

1. INTRODUCTION

Nowadays, the scope for conventional sources like wind energy in electric power systems has drastically raised. The wind power share to the worldwide electricity production is around 4.1% at the end of 2018. With the advanced technology, it is targeted to install wind power capacity of more than 1500GW by 2020. The total installed Wind Power (WP) Capacity worldwide between 2001 and 2016 is as shown in Fig 1.1. It is observed that wind power growth in these years is tremendous, with the installed capacity increasing at an average annual growth rate of more than 25%. The effective utilization of wind energy for electrical power generation remains a major research and development interest in both developing and developed countries [1].

Grid integration of WECS is a combination of a set of power electronic devices that enables wind power transformed into usable form. The features like constant voltage, constant frequency, and high-power factor are required for power at the load side. DC to DC converter, rectifier and inverter are power electronic components that are combined for various purposes to achieve the load requirements [2].

1.1 State of the art developments

The transition of wind kinetic energy into electrical energy began in 1887 with an automatic wind turbine fitted with a generator of 12 kW dc. To produce more effectively and safely electricity from wind turbines and to succeed against conventional energy sources, several changes have been made in the configuration of the constituents of wind turbines. The huge turbines obtain higher wind power in economic means in contrast to the smaller turbines. Despite of this, the output of commercial wind turbines has risen dramatically over the last 30 years. Wind turbine system (WTS) is particularly attractive for its capacity to work at a constant power point (MPP) at differing wind speeds. MPPT Algorithm allows WTS to significantly increase its efficiency by harvesting as much energy as possible from a wide range of wind speed values. Multiple MPPT theories have been established with critical consideration so as to achieve optimum wind production (power) at all times [8]

1.2 Applications

The electrical energy obtained from the wind energy system is provided to the utility grid. There are two categories of on-grid applications. They are isolated grid electricity generation and central grid electricity generation. The isolated type of generation is popularly found in isolated areas. The power production is unaffordable due to the increased cost in the supply of diesel fuel to the remote sites. The production capacity is estimated to be between 200KW to 2MW in central grid electricity generation [7].

2. System Architecture

The system architecture of the proposed wind energy system is as shown in Fig 1.2.

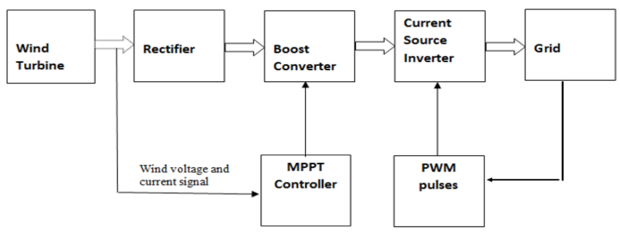

Fig 1 Overall Block Diagram of WECS

Wind turbines have two different configurations based on the rotation of the blades. Blades are rotated either in a vertical or horizontal direction [4]. The generator rotates by the mechanical power gained from the wind power by using wind turbines. The magnitude of the power absorbed by the blade is affected by turbine velocity, the diameter of the rotor, blade shape, and the pitch angle. The wind voltage and wind current are fed to the MPPT controller. The MPPT controller employs an incremental conductance method to monitor the operating point. The duty ratio obtained from the controller is compared with the fixed duty ratio. The error signal is fed to the pulse generator. Pulse generator provides gating pulses for the intermediate converter. The voltage from the wind turbine is boosted in boost converter and is fed to the grid-connected current source inverter.

The switching control technique is employed for the generation of PWM pulses for the switches of current source inverter [4]. The voltage and current parameters obtained from the grid are fed to the current source inverter controller. A current regulator, voltage regulator, and three phases to two-phase conversion blocks are the components of the controller. The six switching pulses from the converter are fed to six switches of current source inverter.

3. MPPT Controller

The voltage and current parameters are obtained from the wind turbine. They are supplied to the controller for MPPT. A duty ratio is obtained by the MPPT controller. The difference between the output of the controller and the fixed duty ratio is fed to the pulse generator. The pulse generator generates pulses for the switch of the Boost converter. The model of the MPPT controller is as shown in Fig 3.7.

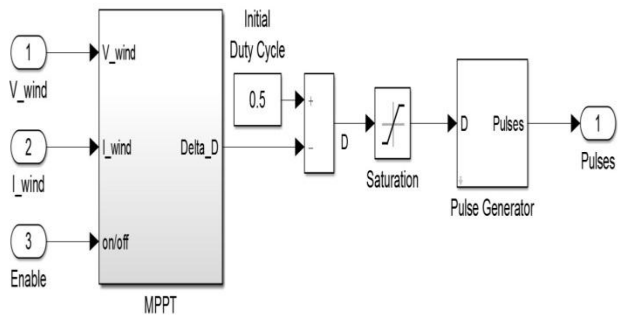

Fig 2 Overall Block Diagram for the MPPT controller

Incremental Conductance method

MPPT algorithms are essential in wind Energy applications because the MPP of a wind module changes with the wind speed. The incremental conductance algorithm is shown in Fig 3.8.

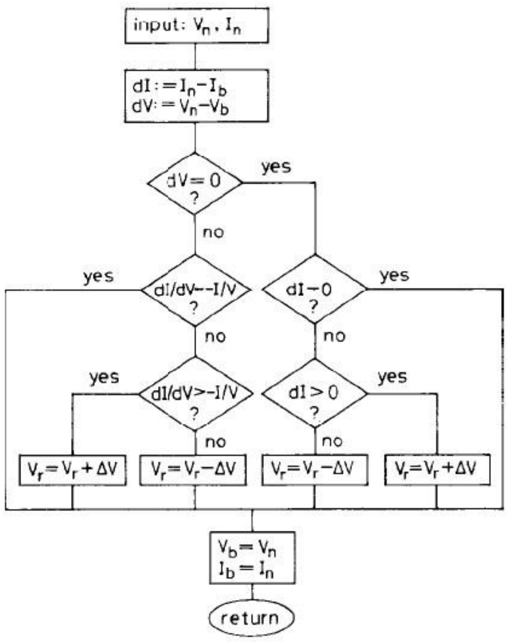

Fig 3 Incremental conductance algorithm

The IC model is discussed as follows

$P = VI$

Where,

P is wind power; V and I are wind voltage and current.

Equation for incremental conductance method

$$\frac{dP}{dV} = \frac{dVI}{dV} = I + V\frac{dI}{dV} \quad (1)$$

At $\frac{dP}{dV}$=0, the maximum power point is reached.

If $\frac{dP}{dV}$=0, then $\frac{-I}{V} = \frac{dI}{dV}$

Where,

$\frac{I}{V}$ is the instantaneous conductance of the turbine generator set.

$\frac{-I}{V} = \frac{dI}{dV}$ is the incremental change in conductance.

From equation (1), an error signal is produced and it is supplied to the integral regulator. The output of the integral controller is the duty cycle. This duty ratio is fed to the pulse generator for generating pulses to the switch of the boost converter.

4. Switching Control Technique

The main objective of a switching control technique is to estimate the reference currents and voltages using feedback signals. These reference currents and voltages along with corresponding sensed currents and voltages are used in PWM current controllers to extract PWM gating signals for switching devices of the CSI.

Controller for Current Source Inverter consists of voltage (V_{dc}) regulator, PLL and measurement block, Parks transformation block and current regulator. The controller for generating gating pulses to the switches of CSI is as shown in Fig 3.9.

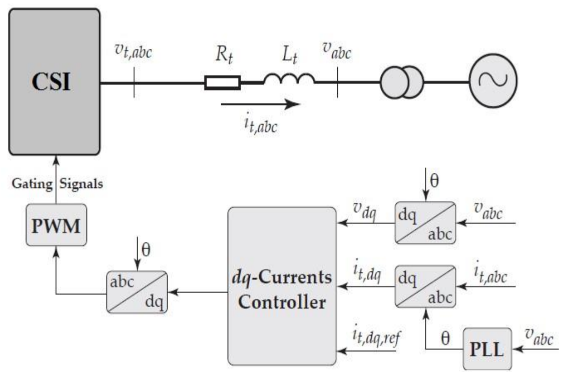

Fig 4 Controller for Current Source Inverter

For the closed-loop operation of WECS, a suitable controller for the current source inverter is used for increasing system efficiency. The Simulink model of the controller for the current source inverter is as shown in Fig 3.10. A constant reference voltage of 300V is considered up to 0.5 sec. After 0.5 seconds the reference voltage is 250V. This change in voltage is achieved through the clock and switch.

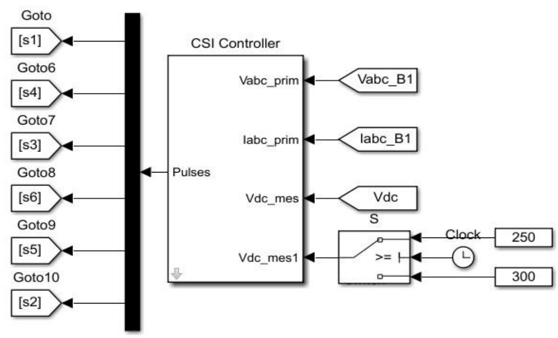

Fig 5 Simulink model of the CSI controller

Vdc (Vdc_mes) is fed as input to the voltage regulator. A reference voltage is generated using a clock and switch. These voltages are compared and are fed as input to the PI controller. Reference current I_d^* is the output of the PI controller. The block diagram of the voltage regulator is as shown in Fig 3.11.

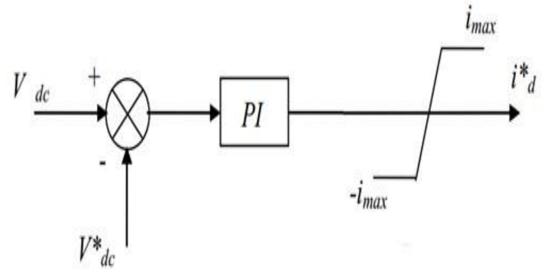

Fig 6 Voltage Regulator

The output load parameters of the current source inverter are converted to the dq- components with the help of Parks transformation.

$$\begin{bmatrix} U_d \\ U_q \\ U_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(wt) & \cos\left(wt-\frac{2\pi}{3}\right) & \cos\left(wt+\frac{2\pi}{3}\right) \\ -\sin(wt) & -\sin\left(wt-\frac{2\pi}{3}\right) & \sin\left(wt+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

The three-phase load currents and voltages are considered as measured values. These voltages and currents are fed to the current controller. Id and Iq measured currents are compared with the reference current Id* (Iq* = 0) obtained from the voltage regulator. The error is fed to the PI controller. The outputs of the PI controllers are the reference voltages Vd* and Vq* as shown in Fig 3.12.

The reference voltages Vd* and Vq* are obtained from the current controller. These voltages and currents are again converted from dq frame to three-phase abc parameters using inverse Park's transformation. The reference three-phase voltages and currents are fed to the PWM generator. PWM generator generates switching pulses for the switches of current source inverter.

5. Simulation using MATLAB tool

MATLAB Simulink is a data flow virtual language development tool for the design, simulation and study of complex structures. Power electronic components are obtained from the sim power system toolbox.

5.1 Simulation Circuit

The simulation model of the proposed WECS is shown in Fig 3.14. The proposed system for the WECS is implemented using MATLAB/SIMULINK. The proposed model for the simulation includes wind turbine, MPPT Controller, Boost converter, CSI and controller for the CSI.

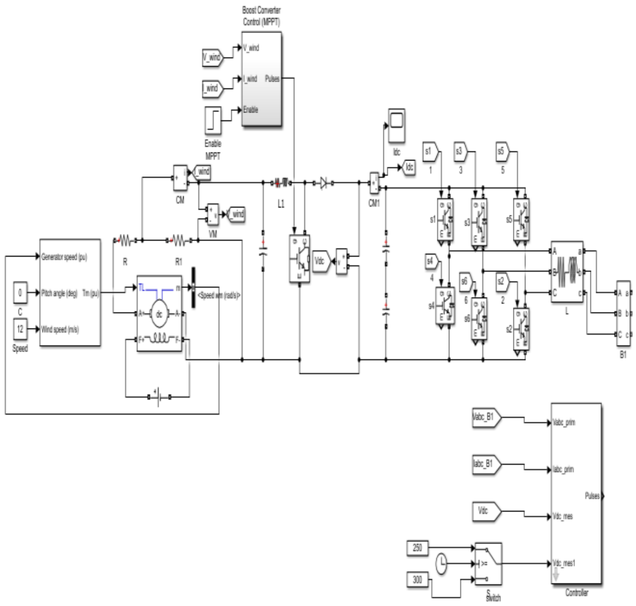

Fig 7 Simulation Circuit of WECS

5.2 Simulation Results

The output voltage, output current, and output power waveforms are obtained from the wind turbine. A small disturbance is introduced at 0.5 sec to check the performance of the MPPT controller. The magnitude of wind voltage obtained from the turbine is 74V as shown in Fig 3.15.

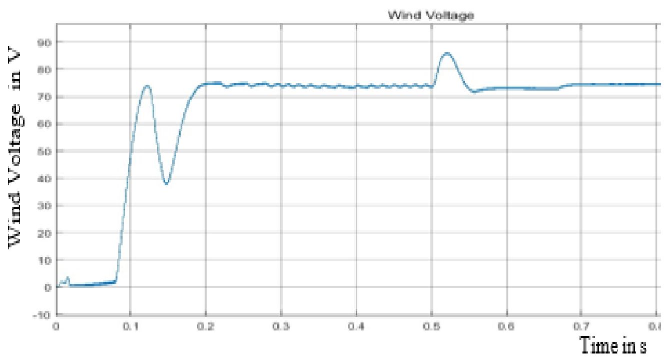

Fig 8 Wind Voltage

The output current from the turbine is as shown in Fig 3.16.

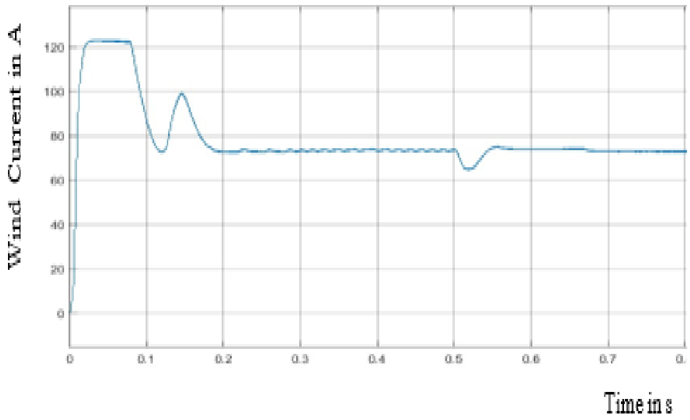

Fig 9 Wind Current

An output power of 5KW is obtained from the wind turbine as shown in Fig 3.17.

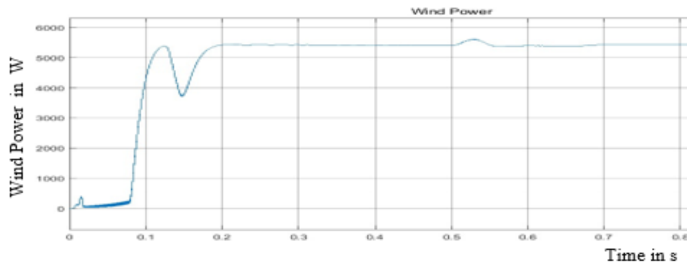

Fig 10 Wind Power

Step Response

To estimate the performance of the controller, step change in the reference value of DC voltage from 300V to 250V is introduced at 0.5sec. The output boost converter output voltage waveform is as shown in Fig 3.18.

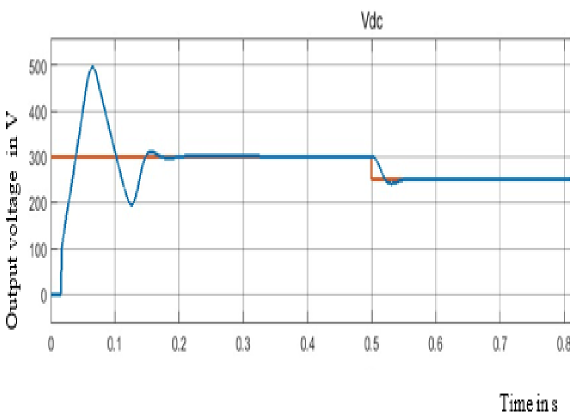

Fig 11 Boost Converter Voltage

3.4. Sustainability and Societal Concerns

Renewable energy sustainability refers to meeting current generation energy requirements without compromising upcoming generation demands [19]. Wind power is described as an emission-free technology and this is one of the main advantages that makes it such an exciting and attractive proposition solution for energy supply.

Societal Concerns

Wind turbines have an effect on the environment too. The aerodynamic blades create less noise whereas the majority of the sound is from the machines. The research has been carried out to reduce the noise of the machine. Among them, few recommendations are to reduce the blade size. With the use of wind power, people are not exposed to many hazardous wastes and emissions.

Conclusion

The WECS with MPPT controller is implemented in MATLAB and it is verified by simulation. The Incremental Conductance method is employed for monitoring the operating point. The proposed method offers advantages such as good tracking efficiency, high response and well control for the extracted power. The DC-link choke helps to limit the current variations and thus provides the short circuit protection under the fault conditions. To estimate the performance of the controller, a step-change in the reference value of DC voltage is introduced at 0.5sec. For the large change in DC voltage, stable operation of the system validates the sturdiness of controller

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