Performance Enhancement of Power Grid Connected Wind Energy Conversion System

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Abstract

Power generation systems based on wind energy conversion system are increasing continuously worldwide. Therefore the intense interest of researchers and scientists is being oriented towards its development and performance improvement as well as efficiency and output enhancement. Application of power electronic converters with wind turbine generator system are playing significant role in its development and practical realization. This has not only improved the performance of wind energy conversion system (WECS) but also ensured the seamless integration with grid to enhance the penetration of wind power in global power generation. Modified matrix converter topology and the corresponding suitable maximum power point tracking (MPPT) techniques are proposed in this paper. Power electronic converters (PEC) are used to interface the doubly fed induction generator (DFIG) with the grid to maximize the power captured. Wind energy conversion system based on the matrix converter topology and suitable maximum power point tracking (MPPT) techniques is proposed in this paper. A suitable maximum power point tracking technique with the matrix converter will ensure the control of terminal voltage and frequency of the wind generator. Hence the WECS is operating at its maximum power point for all wind velocities.

Keywords: Wind energy conversion system (WECS), Power electronic converters (PEC), doubly fed induction generator (DFIG), Back to back converter, Maximum power point tracking (MPPT), Wind turbines(WT), Wind generators(WG).

I. INTRODUCTION

Electricity generation from wind turbines has become the focus of considerable attention. There is a significant development in wind power technologies as well as the growth of wind power capacity installation worldwide. As a result various wind turbine concepts have been developed and modified so far [1]. Wind power has many benefits that make it an attractive source of power for small and distributed power generation applications. The beneficial part of wind power includes the inexhaustible fuel, local economic development, modular and scalable technology, energy price stability and reduced dependency on imported fuels like petroleum products [2-3].

The current estimation of total wind energy potential is about 10 times the amount of electricity consumption by the entire world. Since WECS are considered as energy replacement rather than the capacity replacement resource. As wind resources are intermittent and hence not available all the times to ensure the power generation continuously. In a wind energy conversion system, the kinetic energy of the wind is converted into rotational energy in a rotor of the wind turbine. The wind rotational energy is then transferred to a generator, either directly or through a gearbox for stepping up the rotor speed [4]. The mechanical energy is converted to variable-frequency, variable-voltage electrical energy by the generator. The generated electrical energy from WECS is transmitted to a utility grid either directly or through an electrical energy conversion stage using power electronic converters (PEC) which ensures the production of constant-frequency, constant-amplitude voltage suitable for interface to the grid [5-8].

Wind energy conversion system (WECS) is interfaced with the utility system through power electronic converters which plays an important role in the integration of wind power into the electric grid. The grid-connected converter control schemes can be divided into two parts: generator-side control and grid side control**.** The generator side control objective is to capture maximum power from source. Recently, few control algorithms used in grid connected inverter with power quality solution have been suggested. Control of grid side inverter is needed to achieve the grid synchronization, power quality improvement by harmonics compensation at PCC, control of dc-link voltage, control of active power delivered to grid and control of reactive power [9-12].

II. WIND TURBINE CONCEPT AND GENERATOR TYPES

Analyzing on the basis of rotation speed the wind turbine can be classified into the category like fixed speed turbines, limited variable speed turbine and variable speed turbines. The variable speed wind turbines depending on the power converter rating and generator capacity are further classified into wind generator systems with a partial scale and full-scale power electronic converters. In this section the wind turbine concepts and the basic configurations of wind generator systems are described [13].

The fixed speed wind generator systems use multiple-stage gearbox and a SCIG directly connected to the grid through a transformer. As the SCIG operates in a narrow speed range close to the synchronous speed, therefore this generator system is called the fixed-speed wind generator system.

The variable speed wind turbine with DFIG corresponds to a partial-scale power electronic converter. The stator is directly connected to the power grid and the rotor is connected through a power electronic converter. The power converter controls the rotor frequency and thus the rotor speed. This concept supports a wide speed range operation, depending on the size of the frequency converter. The permissible variable speed is in the range of 30% of the synchronous speed. The rating of the power electronic converter is approximately 25–30% of the generator capacity. Therefore this concept is popular and economic. The rotor energy, instead of being dissipated is fed into the grid by the power electronic converter. Power converter system performs reactive power compensation and smooth grid connection [14].

A variable speed wind turbine with a direct-drive generator connected to the grid through a full-scale power converter is also used to feed power. The most important difference between geared drive wind turbines and direct-drive types is the rotor speed of the generator. The direct-drive generators rotate at a low speed, because the generator rotor is directly connected. To deliver a certain power, the lower speed makes it necessary to produce a higher torque. The high torque means a larger size of the generator. Therefore for direct-drive generators, the low speed and high torque operation require multi-poles. Therefore it requires a larger diameter for placing the large number of poles. Compared with the variable speed concept with a partial-scale power converter, the full-scale power converter can perform smooth grid connection over the entire speed range. The cost of the system is high and the power loss in the power electronics also increases as all the generated power has to pass through the power electronic converter [15-18].

The Electrically Excited Synchronous Generator (EESG) is usually built with a rotor carrying the field system provided with a DC excitation. The stator has three-phase winding which is similar to that of the induction machine. The rotor can have salient poles or cylindrical poles. Salient poles structure in low-speed machines is the most useful version for application to direct-drive wind turbines. The amplitude and frequency of the voltage can be fully controlled by the power electronic at the generator side, so that the generator speed is fully controllable over a wide range also to very low speeds. In addition, the EESG has the opportunities of controlling the flux for a minimized loss in different power ranges, because the excitation current can be controlled by means of the power converter in the rotor side.

III. DFIG BASED WIND ENERGY CONVERSION SYSTEM

DFIG may operate as a generator or motor in both sub-synchronously and super-synchronously.

Wind power $P = 0.5C_p \rho \pi R^2 V^3$ (1)

Where, Cp= power cofficient

ρ=air density in kg/m^3

R= radius of wind turbine blades

V= velocity of wind

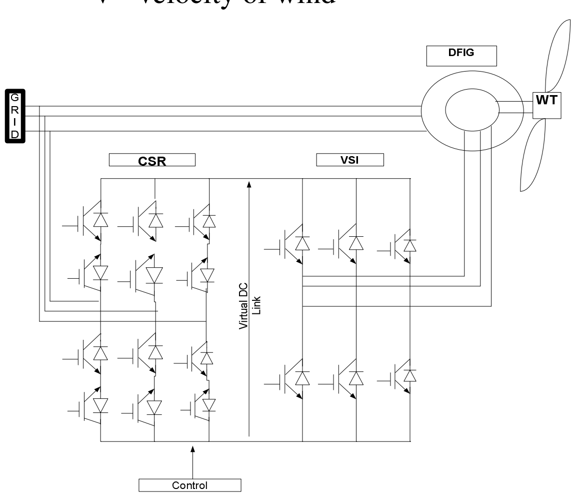

Fig 1- Proposed WECS with Matrix Converter representation

Wind turbine is a non-linear system whose output depends on various parameters such as wind velocity, dimensions of the wind turbine and tip speed ratio. The power extracted (P_{wt}) by a wind turbine is

$$P_{wt} = 0.5Cp(\lambda.\beta)\rho AV^3 \quad (2)$$

where V is the wind speed, ρ is the air density, A is the area of swept by the blades and Cp is the wind power coefficient (denotes power extraction efficiency which is a function of β and λ, β being the pitch angle and λ being the tip speed ratio – TSR given by R Ω / v where R is turbine radius, Ω is turbine shaft speed). Thus, power captured by the wind turbine is heavily dependent upon tip speed ratio (TSR) when β is unchanged. The power conversion efficiency has a well determined maximum Cp,max for a specific tip speed ratio λ. The optimal control of active power in a variable-speed fixed-pitch WECS can therefore be easily achieved, if λ is controlled for attaining the Cp,max corresponding to a given wind velocity [5,14]. From equation (2) and expression for λ, it follows that

$$P_{wt} = 0.5Cp(\lambda.\beta)\rho\pi R^2 V^3 \quad (3)$$

$$P_{wt} = 0.5\{C_p(\lambda)/\lambda^3\}\rho\pi R^5\Omega^3 \quad (4)$$

Thus the torque produced by the turbine is computed as

$$T_{wt} = P_{wt}/\Omega \quad (5)$$

Hence the torque produced by the turbine is proportional to Ω^2 and power is proportional to Ω^3 . So, by the above equations it can be seen that for a particular TSR, the power extracted by the turbine is maximum for a given wind velocity.

IV. ENERGY CAPTURE

Maximum power point tracking (MPPT) is used to compensate for unknown or time-varying parameters, which are sometimes the cause of poor efficiency [20]. MPPT controller goal is to maximize output power and generator efficiency without the need for a low speed or high-speed shaft encoder, eliminating concern about sensor reliability. Intelligent control strategies for energy optimization include the data-mining methods, which also consider the power demand from the utility grid, as well as various MPPT techniques. Possible MPPT techniques used in WECS employing various generators with small, medium and large capacity are listed as [20-22].

- Perturbation and observation (P&O) method.
- Power system stabilizers (PSS) in DFIG.
- Flux magnitude angle control (FMAC).
- Hill climbing search (HCS).
- Tip speed ratio (TSR) control.
- Power Signal Feedback (PSF) control.
- Optimal Torque (OT) control.
- Mapping power technique in which maps/curves are used to find out the optimum point.
- Anemometer method which uses the predetermined look up table.
- MPPT by maximum efficiency control and a maximum torque control.
- Advance hill climb search (AHCS) technique.

- MPPT algorithm by directly adjusting the DC/DC converter duty cycle.
- MPPT algorithms by changing the speed reference in the desired direction.
- Using matrix converter in DFIG.
- Using MPPT algorithms with current feedback.
- Sliding mode control using fuzzy for variable speed wind turbine.
- Maximum Power Point Tracking based on adaptive control strategy.
- Adjustment of gear ratio with the change of wind speed to achieve the maximum power from the system.
- Neural network techniques

The purpose of the MPPT is to maintain the tip speed ratio of the wind turbine as close as possible to optimal tip speed ratio. To ensure; fast time response, simple control and better stability is essential [20]. Hence due to various operation condition requirement all the methods of MPPT identified above are not suitable for all kind of wind generators.

V. PROPOSED CONTROL TECHNIQUE

In the proposed topology of WECS the MC is controlled using the SVM scheme. In the convention method used for the analysis, two rotating axes are required. Towards the input side, a synchronous frame rotating at the grid electrical frequency is used. This frame is orientated along the input voltage vector. For the output side, a conventional vector control system, for DFIGs, is used [14]. In this case, the reference rotating frame is orientated along the stator flux. It is assumed that the MC is controlled to operate with close-to-unity power factor at the input.
Current and voltage at the output side are controlled by controlling the duty cycle of the switches. The relations between voltage and current are justified by following equations.

$$V_{ABC} = S.V_{abc} \qquad (6)$$

$$I_{abc} = S^T.I_{ABC} \qquad (7)$$

Where V_{ABC} = Out put voltage
V_{abc} = Input voltage
I_{ABC} =Output current
I_{abc} =Input current

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \qquad (8)$$

$S_{11} - S_{33}$ is duty cycle of corresponding switches of matrix converter

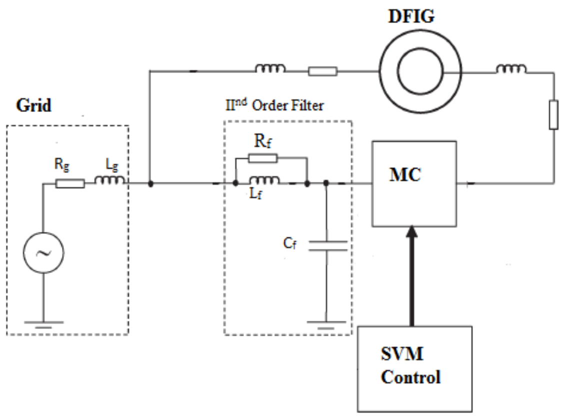

Fig. 2. Proposed Control Technique

DFIG model of WECS using MC control topology used in this paper is shown in Fig.2. A second-order L–C filter is used at the input to filter out the supply side harmonics and ensures the sinusoidal input current hence improve the quality of the current. The grid is represented by a voltage source and a series impedance.

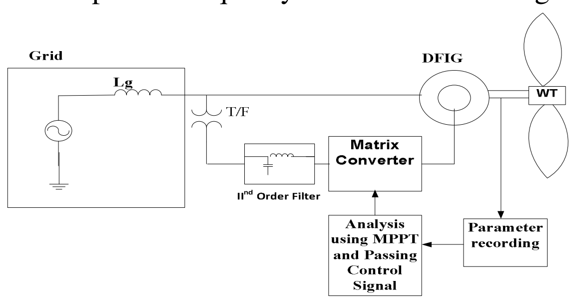

Figure 3. Proposed Control System of WECS

The proposed control system of wind energy conversion system is shown in Fig.3. The wind turbine transmits mechanical power to the DFIG through a drive train according to nominal turbine speed, number of generator pole-pairs and network frequency. Slip power flows from and to the rotor circuit through the Rotor Side Converter for the super and sub-synchronous operation modes respectively. The net performance enhancement of WECS depends on the suitable application of power electronic control and the MPPT technique. The cost of the overall system increases as the complexity of the power electronic converter and MPPT technique increases. However higher order control of MPPT and power converter designs may increase efficiency of the overall system.

VI. Simulation Study and Results

DFIG using the identified most widely used MPPT techniques simulated using MATLAB connected with wind turbines using TSR, HCS, PSF and PSS techniques for maximum power extraction. The simulation results are analyzed for active power, reactive power and the electromagnetic torque.

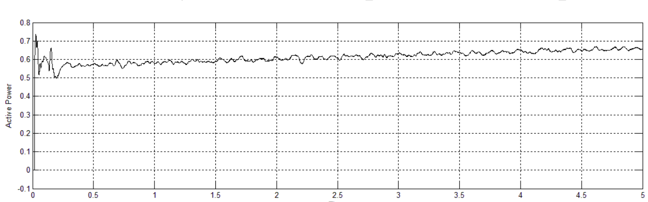

Figure 4. Active power of WECS using PSF MPPT.

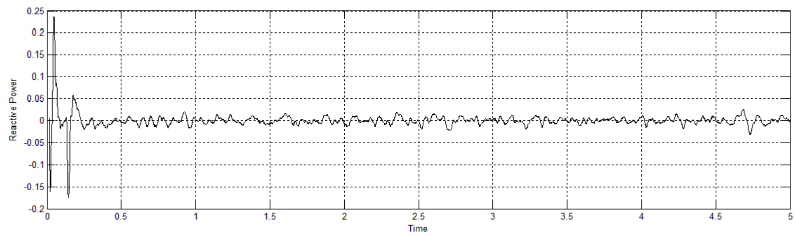

Figure 5. Reactive power of WECS using PSF MPPT.

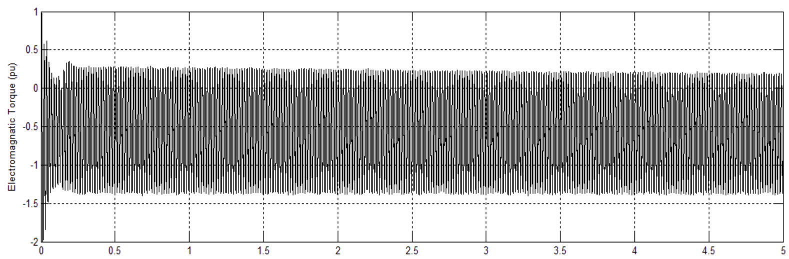

Figure 6. Electromagnetic torque of WECS using PSF MPPT

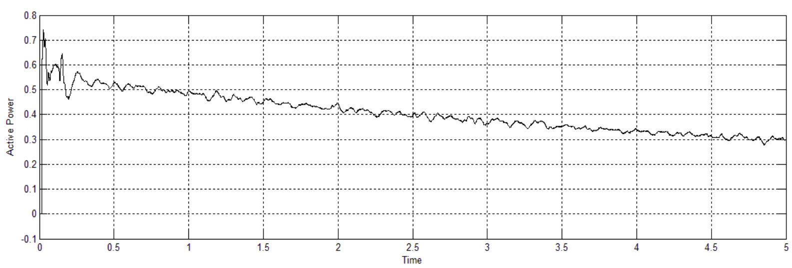

Figure 7. Active power of WECS using PSS MPPT

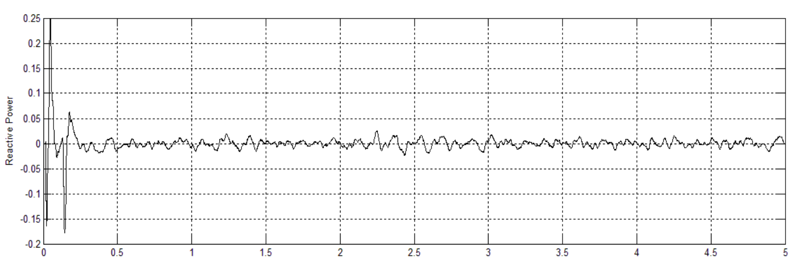

Figure 8. Reactive power of WECS using PSS MPPT

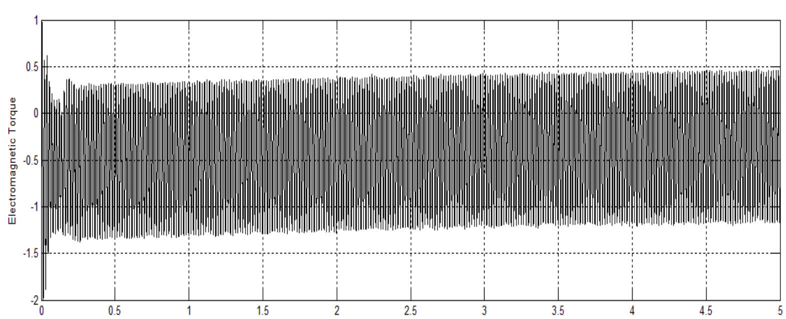

Figure 9. Electromagnetic torque of WECS using PSS MPPT

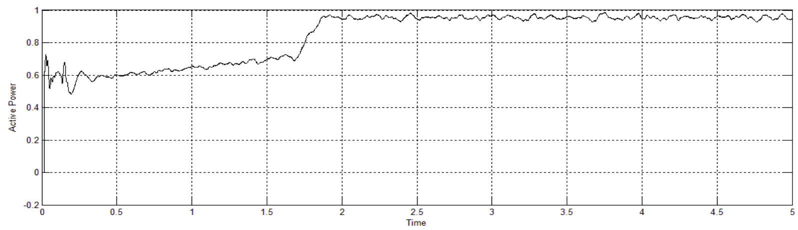

Figure 10. Active power of WECS using TSR MPPT

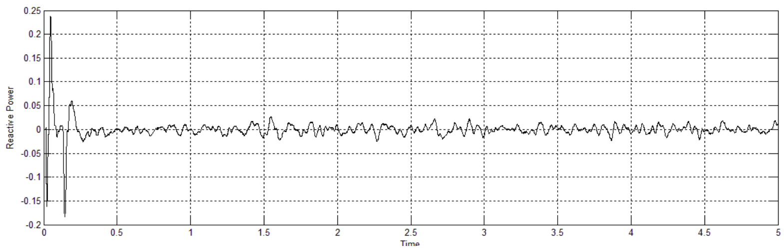

Figure 11. Reactive power of WECS using TSR MPPT

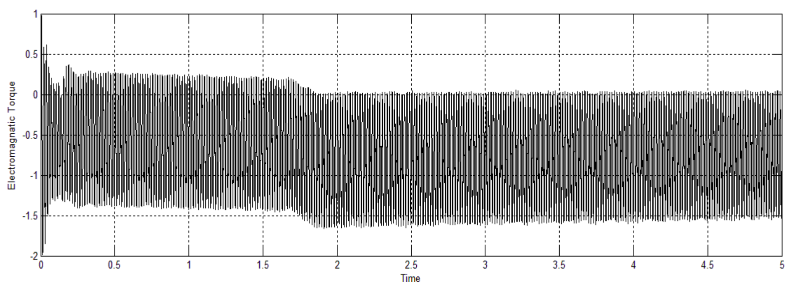

Figure 12. Electromagnetic torque of WECS using TSR MPPT

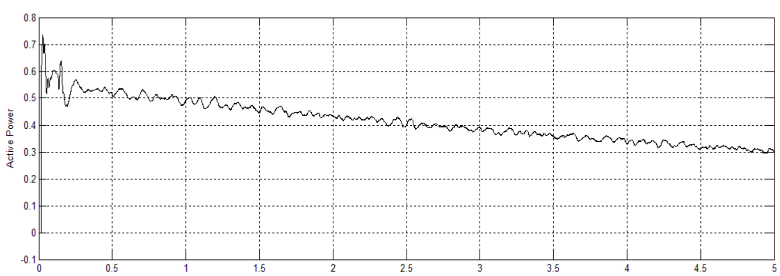

Figure 13. Active power of WECS using HCS MPPT

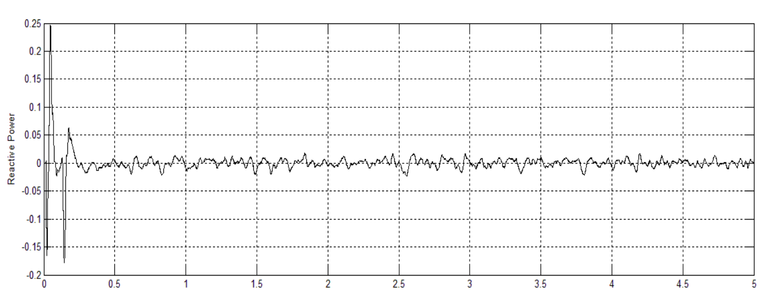

Figure14. Reactive power of WECS using HCS MPPT

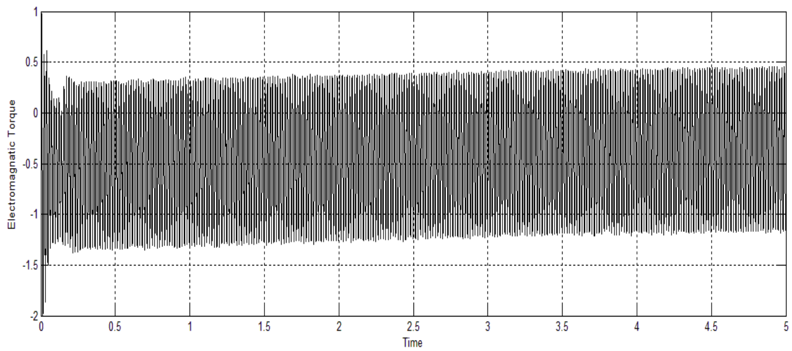

Figure 15. Electromagnetic torque of WECS using HCS MPPT

Simulation results shows that the reactive power profile of WECS for all techniques are nearly similar. Electromagnetic torque profile of WECS using PSF, PSS and HCS are mostly identical. Electromagnetic torque profile of WECS using TSR is poor in comparison to all. Active power profile of the WECS using PSF MPPT technique is the best among all four compared techniques.

VII. CONCLUSION

Wind energy conversion systems using various wind generators are studied and corresponding MPPT techniques to extract the maximum power have been identified. DFIG is widely used as wind generator for various rating wind farms throughout the world. Hence DFIG using four most efficient MPPT techniques named PSF, PSS, TSR and HCS simulated using MATLAB.

Simulation results for DFIG using all the four MPPT techniques have been compared regarding active power, reactive power and electromagnetic torque.

As per the simulation results it is concluded that DFIG using PSF MPPT technique is most efficient among all. MPPT technique using PSF is also having a better future scope with the advanced power electronic converters like matrix converter. This technique is most suited with matrix converter for control purpose.

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