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Enhanced Performance of Doubly Fed Induction Generator based Grid Connected Wind Energy Conversion System

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***Abstract*—With the increased emphasis on the clean energy the wind energy has become one of most hunted solution among the different available renewable energy resources. Application of power electronic based controllers allows the wind energy conversion system (WECS) to generate power at constant frequency voltage irrespective of the variations in wind velocity. The continuous flow of quality power from WECS to grid is insured for wider range of wind speed. DFIG used in WECS having power electronic converter which requires very small friction of power in comparison to the total capacity of generation. This paper brings out the analysis of WECS using DFIG for most suited maximum power point tracking (MPPT) techniques in terms of active power, reactive power and electromagnetic torque when operating with varying wind velocity conditions. Most suitable technique among preferred techniques of maximum power point tracking (MPPT) has also been implemented to harness maximum available power for a given wind velocity. MATLAB simulation results are used to support the claim.**

Keywords*— *Wind Energy Conversion System (WECS), Double feed induction generator (DFIG), Matrix converter (MC), Back to back converter, Maximum power point tracking (MPPT), Wind turbines(WT), Wind generators(WG).

I. INTRODUCTION

In recent years with growing concerns over green house gas emissions and uncertainties in fossil fuel supplies, there is an increasing interest and attention towards clean and renewable electrical energy sources like wind energy, solar energy and fuel cell etc. Many techniques, through which mechanical to electrical energy conversion can be realized, have been proposed and developed with commercial success [1,3]. Wind energy is the most promising renewable energy resource among the all alternatives available with the installations targeted to meet 15% energy demand by the year 2020. During 2001, 24,322 MW of wind turbine capacity was totally installed in the world. In 2010 it increased to 2,03,500 MW. The energy demand in India is ever increasing and expected to grow at an annual rate of 6% over the next 10 years. In India, the total installed capacity of wind power generation was 8754 MW in the year 2008[2]. By the end of 2016, the total installed capacity will be reaching 26 GW according to the Ministry of new and renewable energy in India. The installation of wind turbines in power system has proliferated rapidly in last 20 years and the national and international growth rates and policies indicate that this development will continue [4].

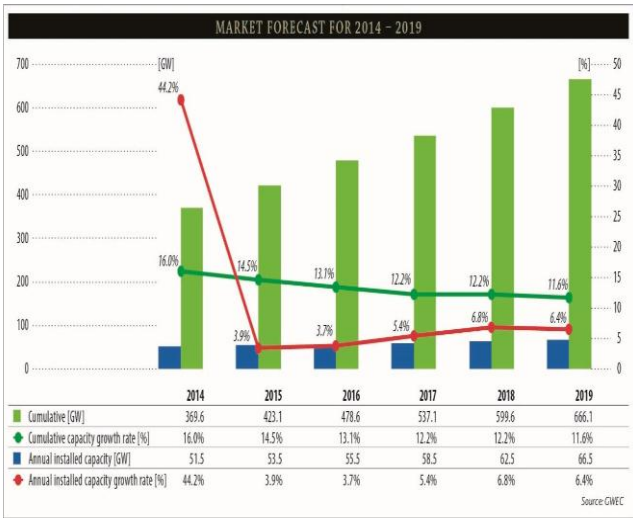

Fig. 1. Market forecast of global wind power development .
[Source- Global Wind Energy Council, Belgium (www.gwec.net)]

The effect of wind power generation on system stability has gained more importance with increasing penetration of wind power generation in power system. Global market forecast regarding wind power development gives the encouraging sign. Growth forecast advocates the significant contribution of WECS for global net power demand. Wind power generation can affect the power system stability in two ways: First it is because of the uncertainty of wind energy nature. The next issue is wind turbines instability due to a disturbance on power grids that leads to power system instability.

To harness maximum amount of wind energy under varying wind velocity conditions, Doubly Fed Induction Generator (DFIG) seems to be one of the promising options, although various other generators such as Squirrel Cage Induction Generators (SCIG) and Permanent Magnet Synchronous Generators (PMSG) are also emerging as tough competitors to DFIG. Based on electrical topology, wind turbine generators are broadly grouped in to four categories [3] namely (i) Fixed speed SCIG (ii) Variable slip (wound rotor) induction generator with variable rotor resistance (iii) Variable speed DFIG with partially rated converter interface (iv) Variable speed generators (either SCIG or PMSG) with full converter interface

II. DYNAMICS AND OPTIMAL OPERATION OF WECS

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

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

Where, Cp= power coefficient
ρ=air density in kg/m^3
R= radius of wind turbine blades
V= velocity of wind

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 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[3,7]. 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. 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.

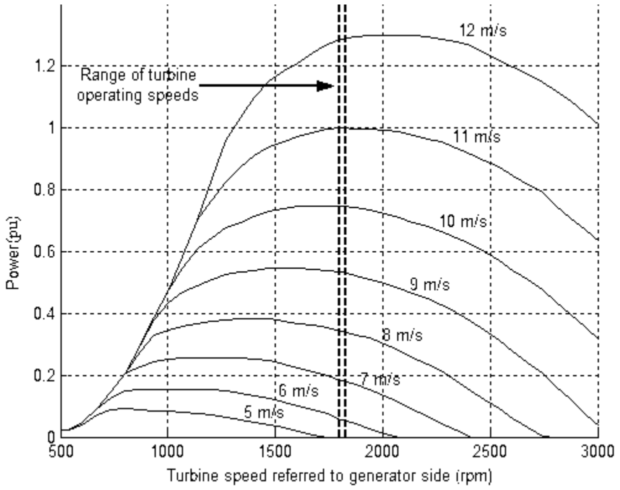

Fig. 2. Wind Turbine Characteristics

This is equivalent to maintaining the tip speed ratio at its optimal value λ_{opt} and can be achieved by operating the turbine at a variable speed, corresponding to the wind speed.

III. CAPTURED ENERGY

Maximum power point tracking (MPPT) is used to compensate for unknown or time-varying parameters, which are sometimes the cause of poor efficiency [25]. 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.

P & O, adjustment of gear ratio, sliding mode control, optimal torque control methods of MPPT are suitable for the small capacity WECS. The response is slow and sluggish.

MPPT techniques like HCS, AHCS, TSR, anemometer method, MPPT algorithms by changing the speed reference in the desired direction and mapping power technique in which maps/curves are used to find out the optimum point work well in smooth wind conditions only. They are complex and less reliable

Method using matrix converter with DFIG, MPPT based on adaptive control strategy and MPPT by directly adjusting the DC/DC converter duty cycle uses power electronics circuitry for controllers. They use pulse width modulation, space vector modulation and duty cycle control techniques. This includes the extra cost, complexity and application of filters to handle harmonics issues.

PSS in DFIG, FMAC, PSF control and neural network techniques of MPPT requires the knowledge of wind turbine's maximum power curve. It becomes difficult to follow the maximum electric power point when wind speed is irregularly changing which is the natural phenomenon of variable wind velocity regions.

P&O, TSR, PSF, HCS and PSS MPPT techniques are used in widely used wind generators. As P & O does not require prior knowledge of maximum wind turbine power at different wind velocity and electric machine parameters. In TSR method the instantaneous tip speed ratio value is calculated on-line. PSF improves the dynamic stability control of WECS. HCS technique is most preferred in small capacity WECS for smooth wind speed. PSS technique improves the damping of oscillations in the network.

P&O is suitable for low inertia wind turbines while PSF method realize on the measurement of the shaft speed. TSR, HCS, PSF and PSS are mostly applicable in DFIG which contributes to majority of the wind generators. Simulation results of DFIG using TSR, HCS, PSF and PSS techniques for MPPT are compared.

IV. WECS CONTROL

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 [16,23,26].

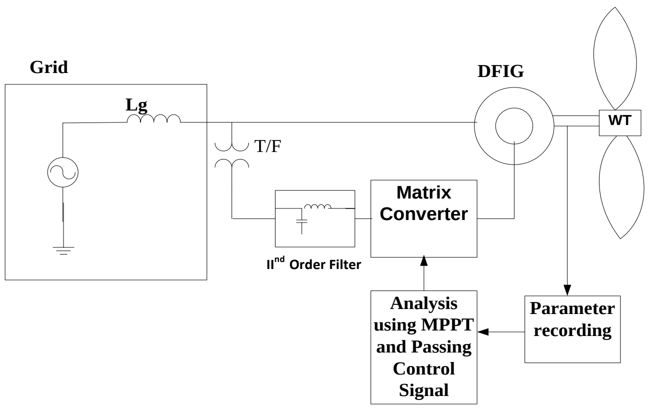

Fig. 3. Proposed Control System of WECS

TABLE 1. MPPT techniques for Wind Energy Conversion Systems *using* DFIG

Generator (Power Range)	Converter Options	Device Count (Semiconductor Cost)	MPPT Techniques
DFIG (kW-MW)	Diode Bridge/SCR Inverter	DC-Link Capacitor 6 Controllable Switches (Low)	P&O
	SCR Rectifier/SCR Inverter	DC-Link Capacitor 12 Controllable Switches (Moderate)	P&O, OT
	Back-to-Back Hard-Switching Inverters	DC-Link Capacitor 12 Controllable Switches (Moderate)	TSR, HCS and PSS
	Matrix Converter	18 Controllable Switches (High)	TSR,PSF

Table1 gives the summary of wind energy conversion system using DFIG for various MPPT. 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.

V. 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.

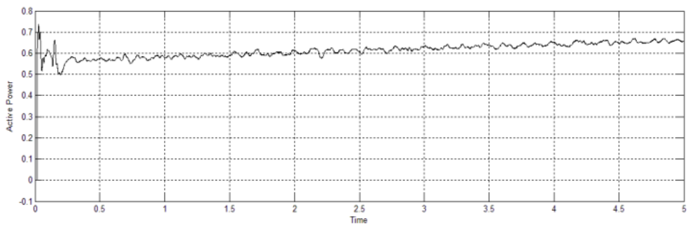

Fig. 4. Active power of WECS using PSF MPPT.

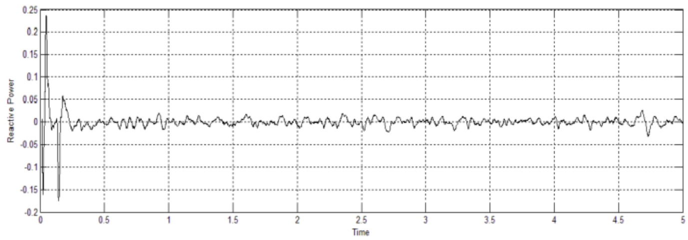

Fig. 5. Reactive power of WECS using PSF MPPT.

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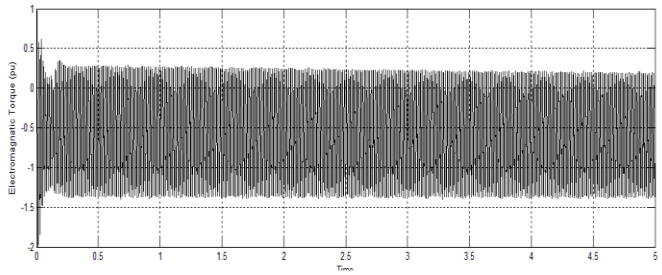

Fig. 6. Electromagnetic torque of WECS using PSF MPPT

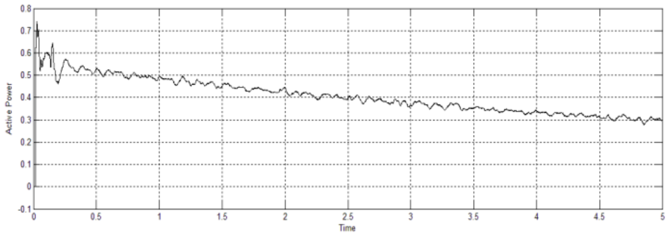

Fig. 7. Active power of WECS using PSS MPPT

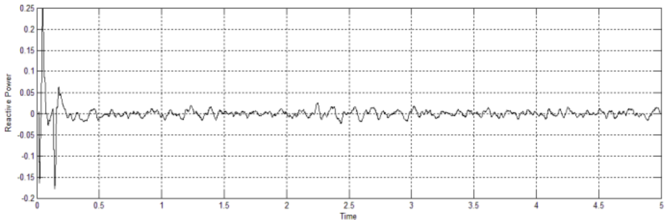

Fig. 8. Reactive power of WECS using PSS MPPT

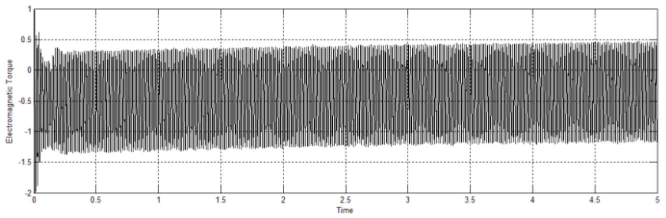

Fig. 9. Electromagnetic torque of WECS using PSS MPPT

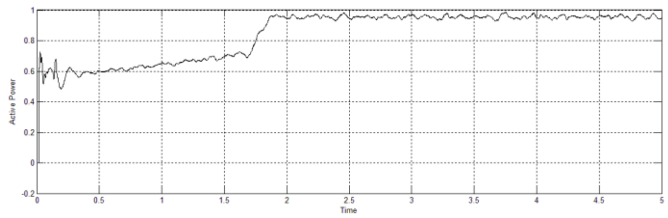

Fig.10. Active power of WECS using TSR MPPT

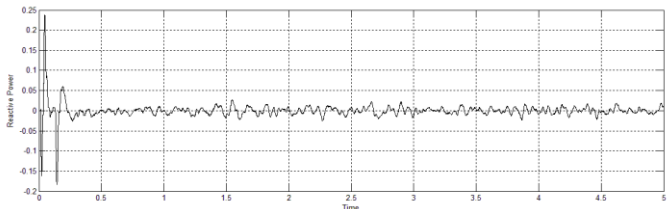

Fig. 11. Reactive power of WECS using TSR MPPT

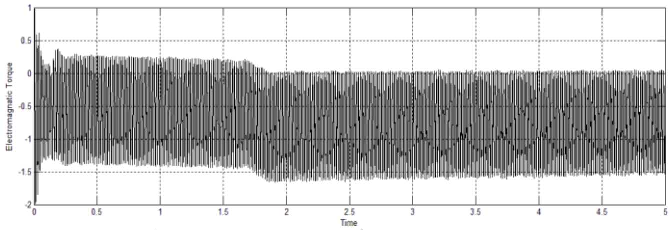

Fig. 12. Electromagnetic torque of WECS using TSR MPPT

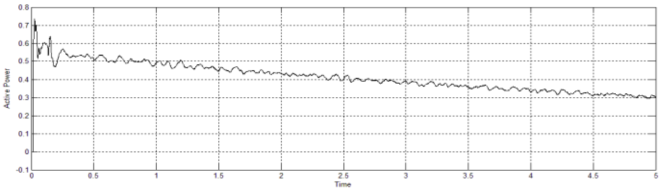

Fig. 13. Active power of WECS using HCS MPPT

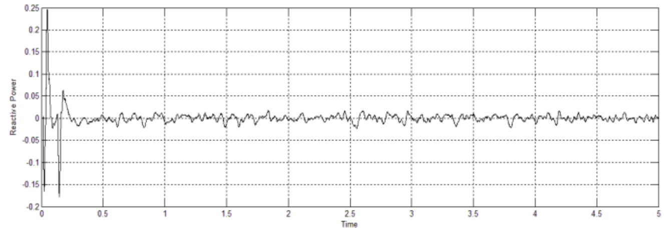

Fig. 14. Reactive power of WECS using HCS MPPT

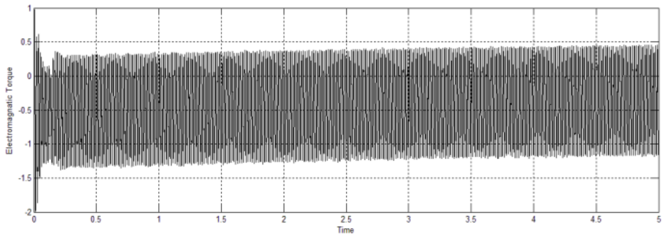

Fig. 15. Electromagnetic torque of WECS using HCS MPPT

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.

VI. CONCLUSION

WECS employing various wind generators are analyzed, studied and corresponding MPPT techniques to extract the maximum power have been identified. DFIG is found to be widely used as wind generator for various rating wind farms throughout the world. Therefore the DFIG using four most efficient MPPT techniques named PSF, PSS, TSR and HCS simulated using MATLAB to analyze the performance with variable wind profile operation.

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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