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Original Article

Performance Analysis of OTC and Improved PSO MPPT Techniques for DFIG-Based Wind Energy Conversion Systems

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***Abstract** - With the increase in energy power requirement and reduction in the availability of conventional fuel resources, the practice of generating electrical energy using renewable energy resources has gained importance. Wind is considered a significant resource commercially used for electricity generation. Wind velocity varies continuously, and hence, the output of the wind generator varies. As a result, the electrical power a wind turbine develops is not at the corresponding maximum value. Hence, a Maximum Power Point Tracking (MPPT) controller is designed for a wind turbine, enabling it to derive the maximum possible power at all wind speeds. In this paper, a comparative analysis of Optimal Torque (OT) and improved Particle Swarm Optimization (PSO) MPPT techniques for a Doubly-Fed Induction Generator (DFIG) is obtained. The Simulink model for DFIG is first obtained, and the system's output power without MPPT is examined. Conventional OT is then implemented. Secondly, an improved PSO MPPT technique is proposed, extracting a better quality of output power that exhibits better dynamics and gives more output power. The results of both methods are then compared and tabulated.*

***Keywords** - DFIG, MPPT, OTC, PSO, Wind energy.*

1. Introduction

The primary source for electrical power generation is from conventional fuels, namely coal, nuclear energy and gas. However, as conventional fuels are depleted, the focus on renewable energy has increased. Wind is India's second major contributor to electric power generation among various non-conventional sources. Wind turbines have generators that are either fixed or variable speed. Squirrel cage or slip ring induction generators are employed for wind turbines operated with variable speed, and permanent magnet-based alternators are employed for fixed-speed wind generators. DFIG can be considered a widely used wind generator commercially due to merits such as low cost, low weight and its power converters process around 30 percent power only, whereas others process rated power. As the wind speed is variable, to extract maximum electrical power from a wind turbine at different wind speeds, different MPPT techniques are employed.

2. Literature Review

MPPT techniques can be grouped into two categories. MPPT, which gives maximum mechanical wind power, is called an Indirect Power Controller (IPC); MPPT, which gives maximum electrical power, is called a Direct Power Controller (DPC). Different MPPT techniques are proposed under both schemes. Controlling the Tip Speed Ratio (TSR) [1], controlling based on the feedback signal of power [2], and OT control [3-6] are widely used techniques under IPC.

In OT control, generator torque is regulated such that torque will equal the reference value of optimum torque for maximum electric power of wind generator at various wind speeds. OT control is simple, economical, has good convergence speed and does not require any memory management. However, the technique's efficacy for varying wind profiles was not discussed.

A hybrid MPPT technique was proposed in [7] to track MPPT under constant and variable wind speeds. In cases where wind velocity is varying, TSR control is employed, and when the wind velocity is almost constant, MPPT is tracked using the Hill Climbing (HCS) algorithm. In [8], another modified HCS algorithm with variable steps is presented. The significant step size is initially considered until the maximum power point is approached, then the size is decreased. Authors compare two indirect MPPT controllers, TSR and OTC, in [9]. It was concluded that TSR has an initial overshoot, and power output is not as smooth as OTC. However, TSR has a fast response when compared with OTC.

A fuzzy logic control was proposed in [10] to augment wind power output. However, the technique replaced the PI controller with a fuzzy controller, and neither the parameters used in IPC nor the parameters used in DPC are controlled by fuzzy logic. A sensorless fuzzy control was proposed in [11], where the model is based on the value of variation in power is zero at MPPT. The ratio of power change to speed change is taken as an error. The error is compared with zero and is called a change in error. The two parameters, namely error and change in error, are given as inputs to the Fuzzy control system to compute q–axis rotor reference current. The control is fast. However, it is found to be less efficient at high wind speeds.

[13-23] explained various MPPT techniques for various wind generators. The MPPT techniques were mainly classified into IPC and DPC techniques. In IPC, the controller function extracts maximum mechanical power, whereas in DPC, the objective is to maximize generator output power. The merits, demerits and comparision of various methods are also presented.

Various optimization techniques were also implemented to achieve MPPT in DFIG-based systems. [24] introduced the Cuckoo search optimization algorithm to reach MPP in the output of DFIG-based generators. The output of DFIG is first converted to DC using a diode bridge rectifier. Then, the output DC power is controlled using aDC–DC converter whose pulses are controlled using the Cuckoo search optimization technique.

The system requires additional hardware and conversion stages, making the system more costly and causing more conversion losses. [25-26] introduced particle swarm optimization techniques controlling the output power of DFIG. However, the optimization technique is used to obtain optimum values for gains of the PI controller and, therefore, is not employed to control output power directly.

[27-28] implemented two optimization techniques, namely, Particle swam and Gery wolf optimization techniques, where the task of the optimization technique is to retrieve the highest possible output power from the wind turbine. Both techniques were highly efficient and had fewer oscillations in output power. [29] applied a hybrid MPPT technique where the optimum power coefficient is initially determined by using swarm intelligence, and then based on the optimum value of the power coefficient, maximum power is extracted using a power curve. The advantage of these population-based techniques is that they oscillate around the MPP. However, the disadvantage is that if the population size is more, it is slow to track MPP; if the population size is less, MPP may not be tracked accurately.

In this paper, instead of randomly initialling particles based on the MPP to be achieved, particles are initialized in a finite range based on the required rotor speed. As a result, MPP is tracked efficiently even with low population size and convergence is achieved quickly. In tracking MPP, most of the literature has used the change in power and speed as control variables to generate a reference for torque.

In contrast, the proposed technique uses torque and speed as control variables to generate a reference for the torque of the wind generator. This paper proposes improved PSO control, and the results are compared with traditional OT control. Both techniques are compared under dynamic wind profiles such as step change.

The structure of the submitted paper is sectioned as follows. Section “DFIG operation” explains the components of DFIG and its operation. Section “Grid-Side Converter (GSC) operation” discusses the modelling of GSC. Section “Rotor Side Converter (RSC) operation” discusses the modelling of RSC. Section “MPPT using OT control” discusses the concept of OTC. Section “OT control based MPPT”, discusses the implementation of OTC for achieving maximum power in DFIG. Section “Improved PSO-based MPPT” describes the implementation of MPPT using the modified PSO”. Finally, a comparative analysis of both techniques under different wind patterns and conclusions are drawn.

3. DFIG Operation

DFIG is a slip ring or wound rotor induction machine with power flow in both stator and rotor windings. A slip-ring induction machine may be made to operate as a generator by regulating the flow of electrical power in both stator and rotor windings. The machine can work as a generator above and below the synchronous speed. DFIG has two converters, namely RSC and GSC. Rotor-Side Converter (RSC) regulates power flow, while GSC regulates the DC link voltage and supplies reactive power if the grid needs it. Figure 1 describes a diagram of DFIG connected to the grid.

4. GSC Operation

Figure 2 shows the block diagram of GSC. GSC is modelled in the d – q axis reference frame. The voltage at the DC link must be kept constant to balance RSC and GSC. At times of need, GSC can also be used to give reactive power support to the grid. As the goal of GSC is to control DC link voltage and control reactive power, the voltage at the DC link and required reactive power are taken as references. The actual DC-link voltage and the reference voltage are compared, and the error is then given to the PI controller to derive the reference value for the d-axis current.

The reference value for q-axis current is derived depending on the required magnitude of reactive power. The 3 phase currents at (Point of Common Coupling) PCC are measured and are converted into d and q-axis components. Reference currents and d-q components are compared to generate pulses for GSC.

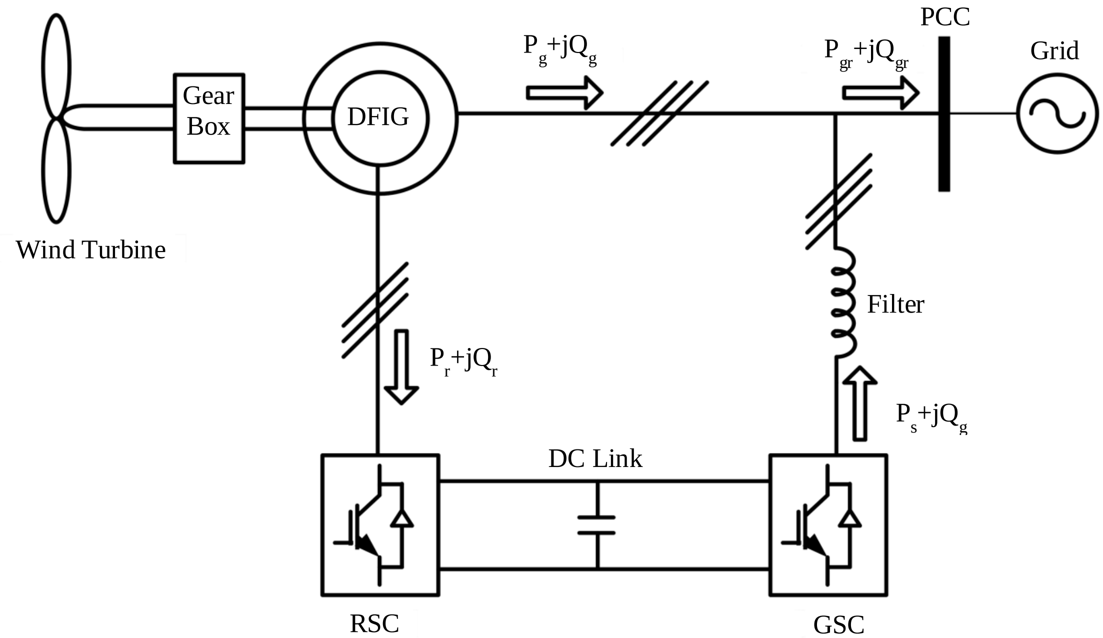

Fig. 1 Block diagram of DFIG

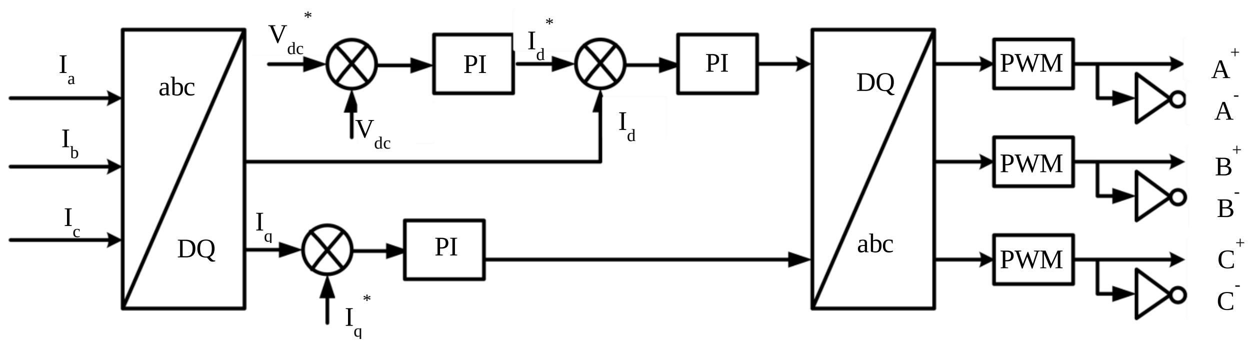

Fig. 2 Block diagram of GSC

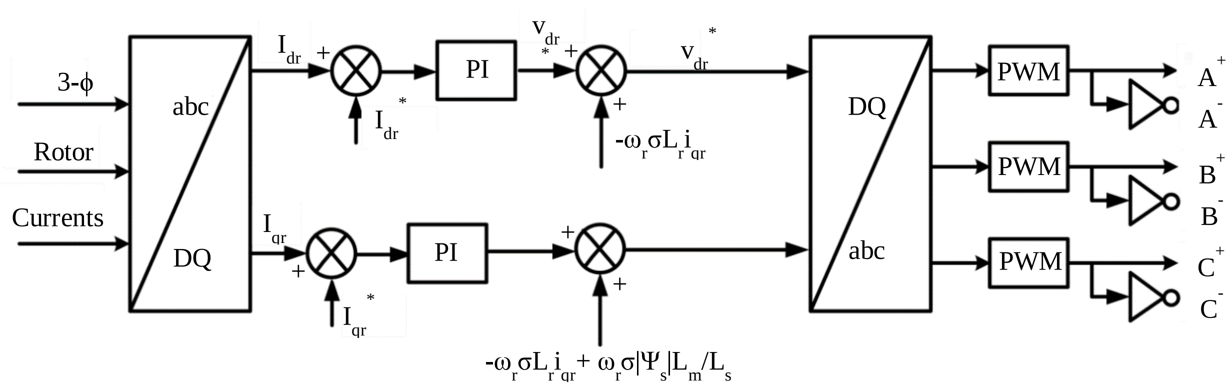

Fig. 3 Block diagram of RSC

5. RSC Operation

RSC regulates the flow of electrical power between DFIG and the grid. Figure 3 describes the block diagram of RSC without MPPT. The required active power and speed are taken as references for d and q-axis currents. These are compared with actual currents measured from the rotor side. The error is processed by the PI controller and is used to generate pulses to RSC.

6. MPPT using OT Control

In this MPPT technique, the torque of DFIG is adjusted to make it equal to the reference torque required for maximum power of the wind generator for any speed. Equation (1) gives mechanical power developed by the generator.

$$P = 0.5\rho\pi R^5\left(\frac{C_p}{\lambda^3}\right)\omega_m^2 \tag{1}$$

Where,

P = Air density(kg/m^3),
R = Turbine radius(m),
C_p = Coefficient of developed power,
Λ = TSR and
ω_m = Rotor angular velocity (rad/s)

When the rotor of DFIG runs at optimal TSR (λ_{opt}), then equation (1) can be rewritten as,

$$P_{m-opt} = 0.5\rho\pi R^5\left(\frac{C_{p\max}}{\lambda_{opt}^3}\right)\omega_m^2 \tag{2}$$

The resulting reference optimum torque equation can be rewritten as

$$T_{m-opt} = K_{opt}\omega_m^2 \tag{3}$$

Figure 4 shows the block diagram of OTC.

7. OT Control-Based MPPT

The rotor controlling circuit is modified by adding an MPPT controller into the RSC of the generator. Figure 5 describes the modified RSC.

This technique takes the optimum TSR for the wind turbine, and the optimum rotor speed for that particular wind velocity can be computed. Based on the optimum speed, the optimum torque value is obtained. This optimum torque is a reference for generating the q-axis component of the rotor current.

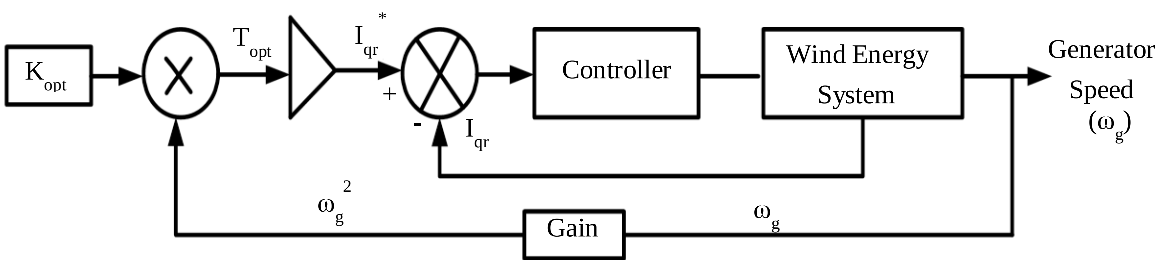

Fig. 4 Block diagram of OTC

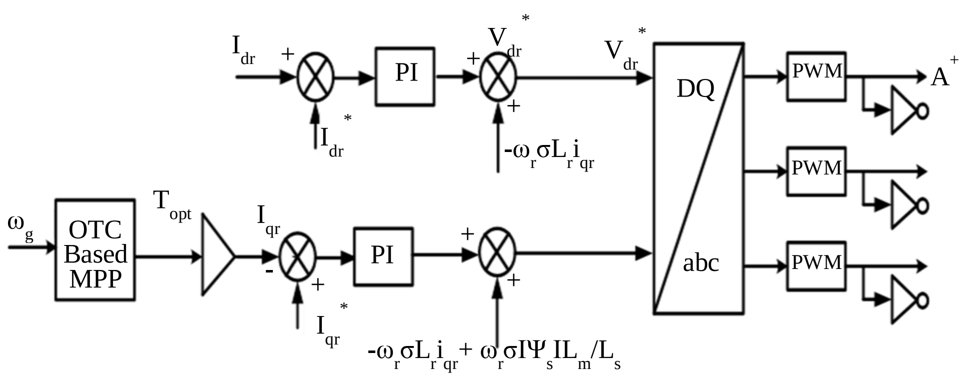

Fig. 5 Block diagram of RSC with OTC

8. Improved PSO-Based MPPT

In the improved PSO technique, the value of TSR is calculated for every wind speed, and the particles are placed in the power–wind curve using equation (4).

$$\omega_j^k = \frac{(\omega_{max}-\omega_{min})}{N_p-1}(j-1) + \omega_{min} \tag{4}$$

Where, ω_{max} = Maximum Speed
ω_{min} = Minimum Speed
Np = Number of Particles

Once particles are initialized, the power of each Particle is calculated by equation (5).

$$P_j^k = T_j^k * \omega_j^k \quad (5)$$

The position of each Particle is updated by using equations (6) and (7) until all the particles move and reach MPP.

$$v_j^{k+1} = Wv_j^k + c_1 r_1 \{\omega_{jpbest}^k - \omega_j^k\} + c_2 r_2 \{\omega_{jGbest}^k - \omega_j^k\} \quad (6)$$

Where c_1 and c_2 are acceleration coefficients, r_1 and r_2 are random variable, and W denotes inertia weight.

$$\omega_j^{k+1} = \omega_j^k + v_j^{k+1} \quad (7)$$

The flowchart for the improved PSO is shown below:

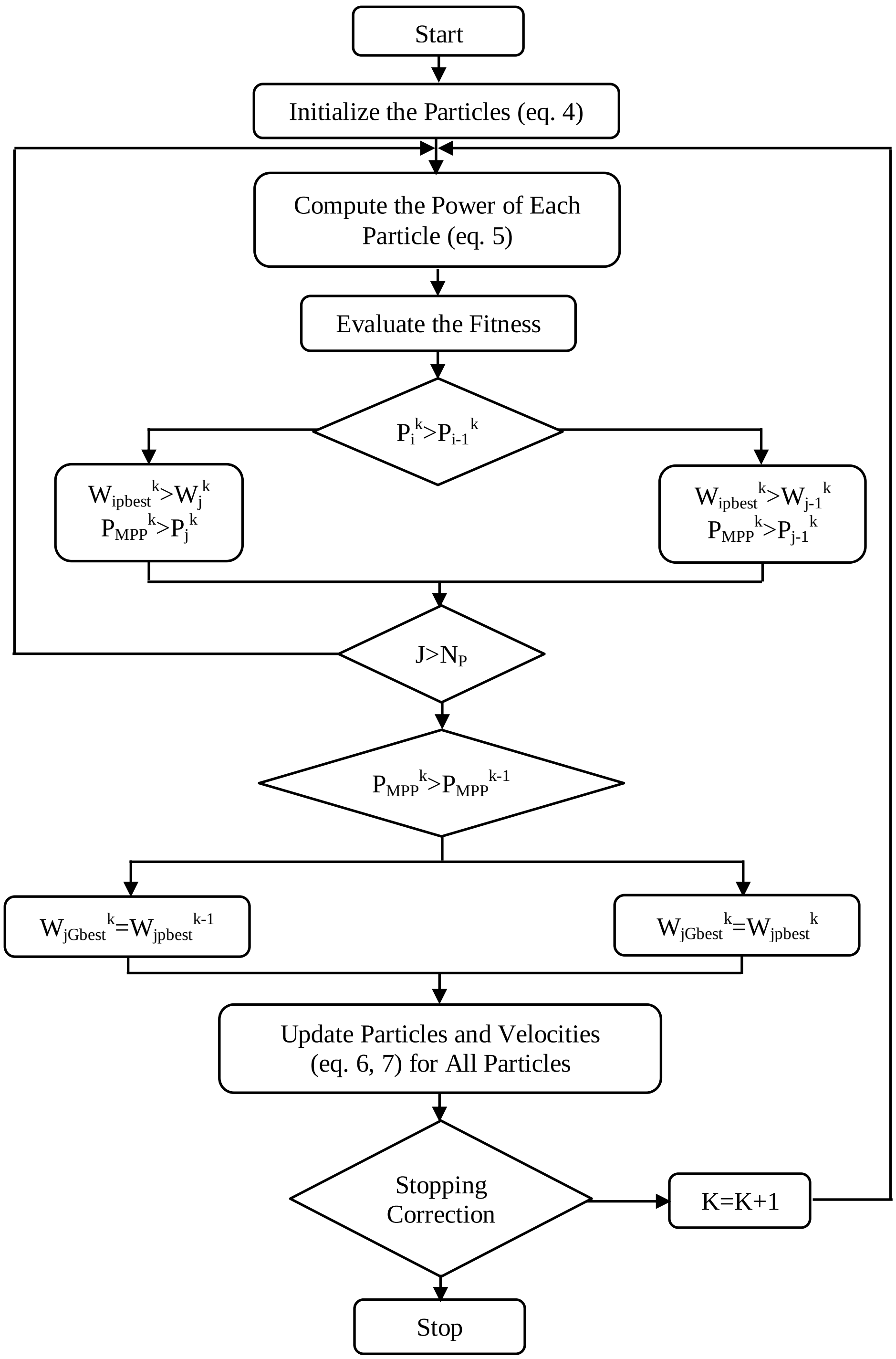

Fig. 6 Flow chart of improved PSO

9. Simulation Results

Figure 7 shows the complete Simulink model of DFIG with MPPT. Figure 8 indicates the power (both active and reactive) transported to the grid without MPPT at 9m/s wind velocity. DFIG generated -0.85 MW power to the grid at 9 m/s, and reactive power drawn from the grid is zero. Negative power indicates the generating mode of operation of DFIG. Figure 9 indicates the power (both active and reactive) transported to the grid with improved PSO for a 9m/s wind velocity. DFIG generated 1.07MW power to the grid at 9 m/s, and reactive power drawn from the grid is zero.

The output power magnitude with OT control at 8 m/s is 0.7 MW. To evaluate the sensitivity of OT control, the wind is subjected to a step increase from 9 m/s to 10 m/s at 5 sec in Figure 10. Figure 10 indicates that OT control is not so sensitive and is attaining its steady maximum power of 1.4 MW at 9 seconds, i.e., after 3 seconds of the change in wind.

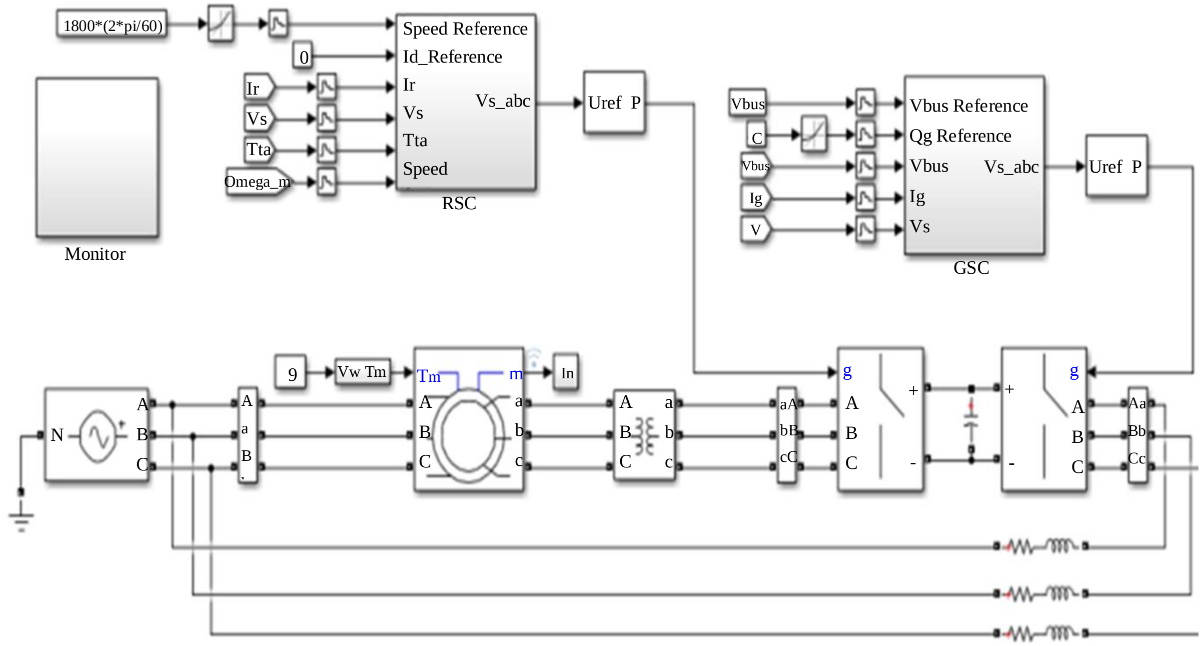

Fig. 7 Simulink model of DFIG with MPPT

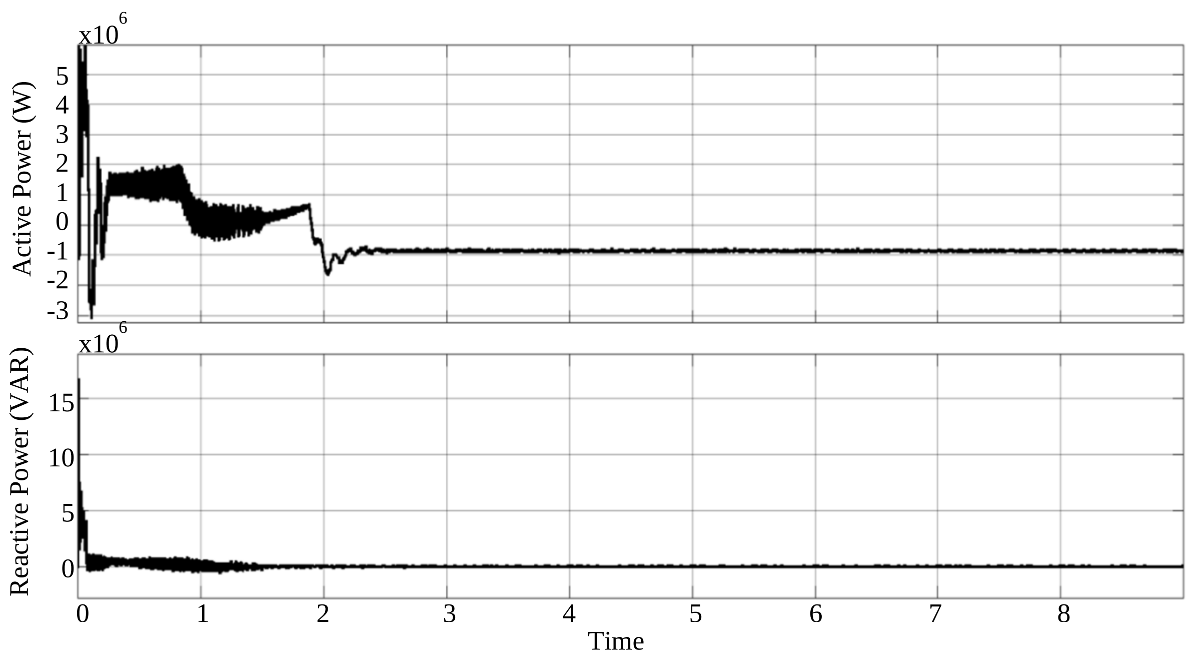

Fig. 8 Active and reactive powers at wind speed of 9 m/s without MPPT

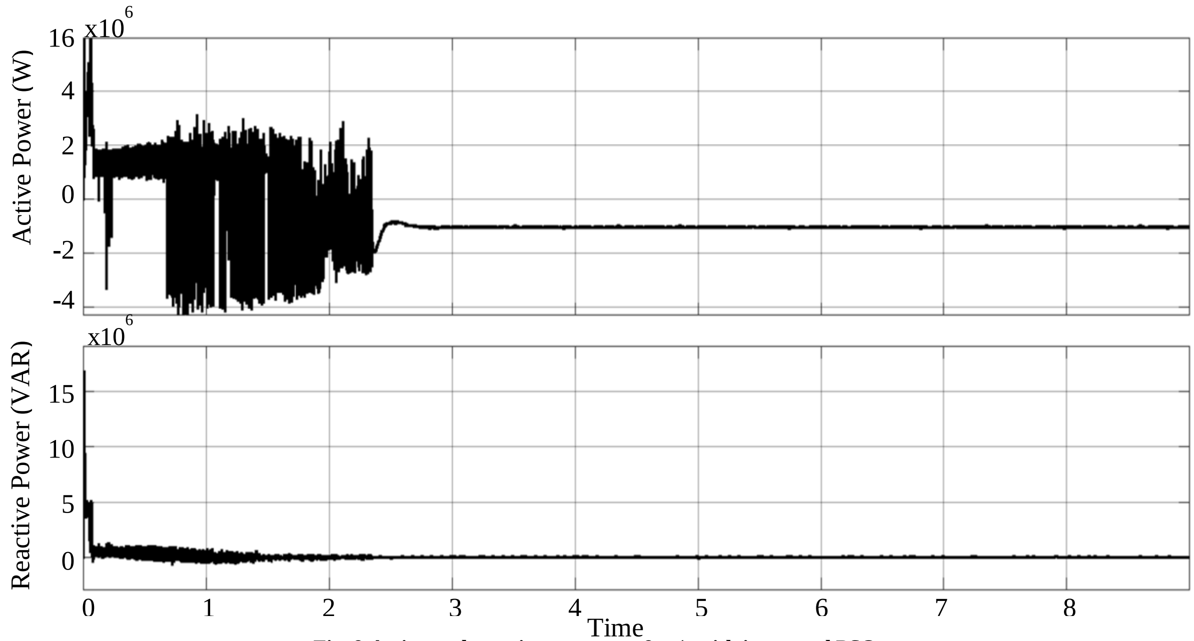

Fig. 9 Active and reactive powers at 9 m/s with improved PSO

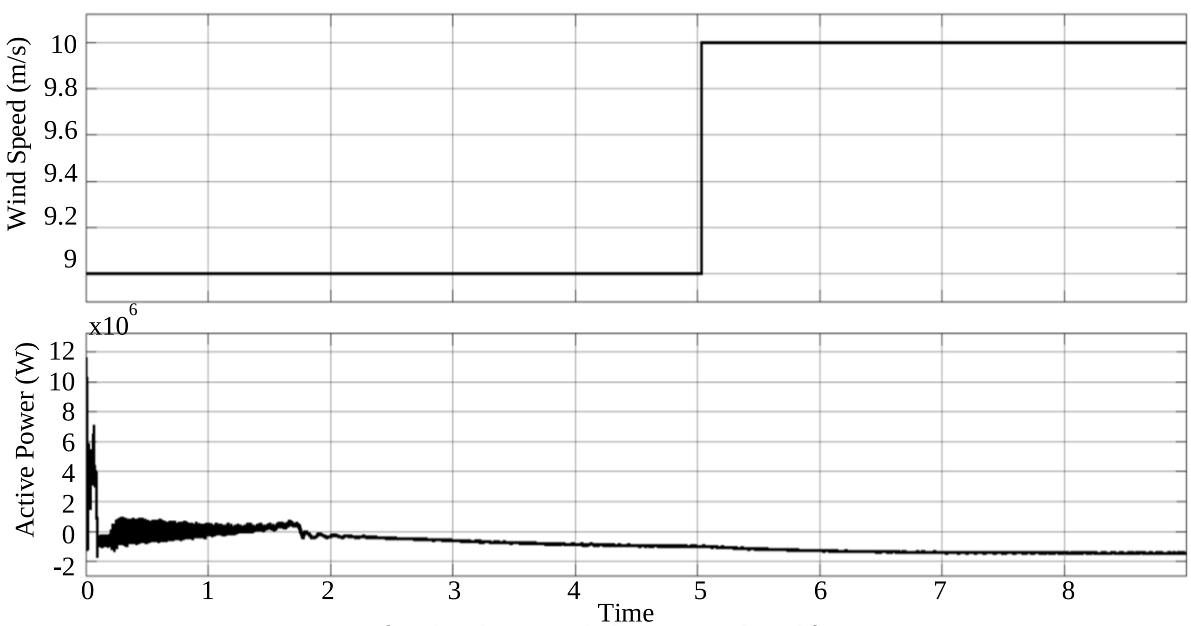

Fig. 10 Sensitivity of OT-based MPPT with changes in wind speed from 9 m/s to 10 m/s

Table 1. DFIG active power without MPPT, with OTC and improved PSO-based MPPT for different wind speeds

Wind Velocity(m/s)	Active Power without MPPT (MW)	Active Power with OTC-Based MPPT (MW)	Active Power with Improved PSO-Based MPPT (MW)
6	0.25	-0.25	0.35
7	-0.1	-0.4	0.45
8	-0.4	-0.7	-0.75
9	-0.85	-1.0	-1.05
10	-1.37	-1.4	`-1.42

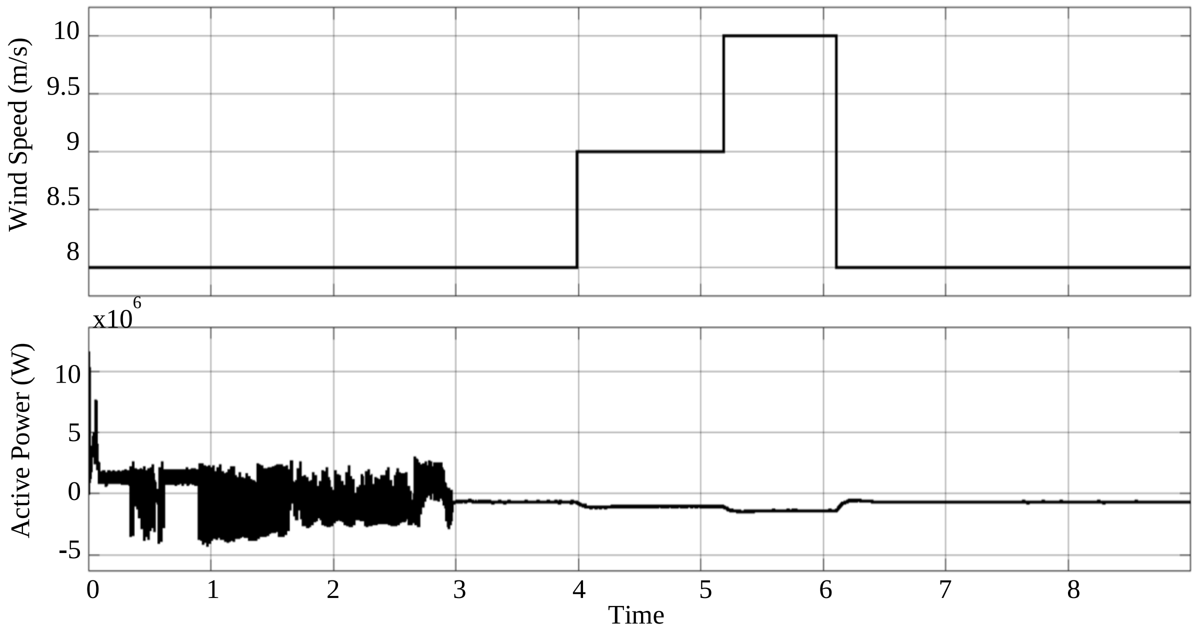

Fig. 11 Sensitivity of PSO-based MPPT with changes in wind speed between 8 m/s to 10m/s

The dynamics of the control technique are evaluated by subjecting DFIG to varying wind profiles, such as step increase step decrease and is revealed in figure 11. Figure 11 reveals that the PSO technique is sensitive to wind profiles and can fast-track MPPT. This indicates that the improved PSO-based MPPT technique has increased the output power extracted from the generator compared to the traditional OT controller. The output power of DFIG with and without MPPT is tabulated in Table 1.

10. Conclusion

This paper describes the Improved PSO-based MPPT technique and OT control-based MPPT technique and their deployment in extracting power from DFIG that is grid connected. The above table shows that MPPT using the Improved PSO technique is marginally superior in transporting maximum power and has superior dynamics compared to OT control.

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