An Efficient Perturbation and Observation of Maximum Power Point Tracking in Wind energy Conversion System based DFIG

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Abstract-in this paper anew adaptive perturb and observe (AD-PO) maximum power point tracking (MPPT) to avoid demerits of the traditional PO MPPT.The proposed algorithm AD-PO reach the maximum power with small time to reach maximum power point (MPP) and low fluctuation around the MPP compared to traditional PO. This algorithm is mainly depending the adaptive step-size by comparing the optimal mechanical power and the actual mechanical power. Hence, the appropriate adaptive step-size (ADSS) of rotor speed is changed related to the operating point. For the operating points far-off the MPP the difference between the maximum mechanical power and actual power is large value, a large ADSS is used. on the other hand, the controller uses a small ADSS. The proposed algorithm AD-PO is validated using a large-scale 1.5 MW based on double-fed induction generator (DFIG); as the DFIG's stator are joined direct with the electric grid As for the DFIG's rotor are joined to the electric grid passing through a back-to-back converter (BTBC). The proposed algorithm AD-PO has been implemented over a large scale WECS via MATLAB/SIMULINK. The results verify that the proposed algorithm AD-PO has high performance and enhance the overall system efficiency versus traditional P&O methods.

Index Terms DFIG ,WECS,BTBC ,MPPT ,P&O, CPO ,AD-PO

1 INTRODUCTION

Renewable energy resources (RES) represents an effective solution to the problems of traditional sources. amid the different renewable energy sources (RES), energy produced from wind (wind energy)is the most prominent renewable energy sources [1]. Several styles of wind turbines such as; fixed speed wind turbine (FSWT) and variable speed wind turbine (VSWT) .the VSWT is the most hired in the wind power field due to high performance and generating maximum power in WECS. Morover, many generators has been hired in WECS such as permanent magnet synchronous generator(PMSG)[2-4] and doubly fed induction generator (DFIG)[5, 6]. The most common generator hired in WECS applicationsis the DFIG[7]. The DFIG's startor is coupled direct to the electric nerwork and the rotor of DFIG is linked to the electric grid throgh BTBC [8].

To produce the optimum power under change of wind speed ,different maximum power point tracking (MPPT) are implemented. The MPPT techniques are the most vital control implements that utilized under the rated wind speed to enhance the extracted power from WECS. MPPT techniques are divided into two different categories ; the first type is indirect power control (IPC) and the second is direct power control (DPC).Various types of the IPC methods such as; the power signal feedback (PSF) control[9],the tip speed ratio (TSR) [10],the optimal torque control (OTC) [11], and wind speed estimation[12]. The TSR is simple method andhas high efficiency. The OTC algorithm is based on the system parameters. The DPC is utilized to extract the extreme power by observing the power changes identified with the wind speed variation [13]. Among the different DPC, the PO is the most prominent DPC methods.The perturbation and observation (PO) technique utilized to gather the optimum wind power from wind turbines under change of wind speed. PO method is characterized by its simplicity in extracting the optimum power, which it relies upon the change of the rotor speed continously and watching the varieties of power extracted until the $\Delta P/\Delta\omega$ is zero.The classic type of the P&O applied a constant step-size.as arsult of choosing this step-size there is problems apperard, in case of appliying a small step the system has slow response and also losses in extracted power will increased .and in case of , a large step applied the range of oscillation around MPP will be very large in the two cases the system efficiency will affected negetivetly [14].

it was necessary to defeat the deabacks of CPO, so variable step-size P&O (VS-PO) and adaptive step-size P&O (AD-PO) [14-17]are used.In [14], the authors have been proposed the PO MPPT method to override problems of the CPO, this method achieve maximum power with a small time. However, it depends the system parameters to obtained the kopt value at each wind speed change. In[15,16], the authors have been used an efficient the VS-POto enhance the overall efficiency .However, the big overshoot occurs at wind speed change. In [17], the authors have been suggested an AD-PO to avoid the problems of the classic P&O. However, this method uses several assumption which reduce the system efficiency .

This paper suggests an (AD-PO) algorithm wich applied on alarge scale WECS based on 1.5 MW DFIG as shown in Fig.1. This algorithm eradicates the traditional PO MPPT disavantages and mend the method of the variable step-size P&O methodss. The proposed P&O depend on the a variable step-size applied on rotor speed, the variable step depend on the difference between the maximum and the actual mechanical power $(P_{max} - P_m)$. If the operating point is far from the MPP or the ($P_{max} - P_m$) is large, the controller generate a large step-size. While the operating point move towards the MPP, the dynamic step-size reduces. The proposed algorithm (AD-PO) improve the overall efficiency compared to the VS-PO and reach the MPP with fast response of the controller and reduce the settling time and small oscillations compared.

paper is consist of 6 section as follows; section 2 introduce an the wind energy conversion system based DFIG and wind turbine model and DFIG and their mathematical equations . Section 3 illustrate the traditional P&O technique . The Adaptive P&O MPPT technique is illustrated in section 4. the simulation results to validate the suggested P&O mechanism versus the traditional P&O MPPT algorithm Section 5 . finally, the conclusion of the paper is illustrated in section 6.

2 Wind energy conversion system

Fig. 1 shows the studied system. The stator of DFIG are linked direct to the grid on other side the rotor is coupled with the electric grid via BTBC. The BTBC contains rotor side converter (RSC) and a grid side converter (GSC). The RSC force the actual rotor speed to track the optimal rotor speed. Moreover, the GSC control the DC-link voltage to be at consatnt value.

2.1 Wind Turbine model

The extracted mechanical powercan be formulated as follows[18]:

$$P_m = 1/2\ \rho\pi\ R^2 C_p(\lambda, ß) v^3{}_w \quad (1)$$

with

$$\lambda = \omega_r R / v_w \quad (2)$$

P_m refer to mechanical power, ρ is the air density, C_P is the the wind turbine power coefficient,V_W refer to wind speed , tip speed ratio represented by λ , β represent pich angle , R is turbine blade radius and $\omega_r$is speed of the rotor.

The power coefficient C_p can be formulated as follow:

$$C_p(\lambda, ß) = c_1\left(\frac{c_2}{\lambda_i} - c_3 ß - c_4\right) e^{\frac{c_5}{\lambda_i}} + c_6\lambda \quad (3)$$

where the parameters $C_1 - C_6$ are the approximated coefficient values$C_1 = 0.5167$,$C_2 = 116$,$C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$, $C_6 = 0.0068$.

And

$$\lambda_i = \frac{1}{\lambda + 0.08ß} - \frac{0.035}{ß^3 + 1} \quad (4)$$

To ensure gather optimum power throgh the WECS , the C_p must be at its optimum value which 0.48. the speed of the rotor altered according to change of wind speed, to generate the optimum power in WECS. By forcing the speed of the rotor to track the optimal speed , the needed optimum power will be acheived as illustrated in Fig. 4.

2.2 Shaft system model

The shaft system can be modelled as a singlelumped-mass system with the lumped inertia constant H_m, calculated as in[19]:

$$H_m = H_t + H_g \quad (5)$$

whereH_t is the inertia constant of the turbine and H_g the inertia constant of the generator.the following equation is for the electromechanical dynamic:

$$\frac{d\omega_m}{dt} = \frac{1}{2H_m}(T_m - T_e D\omega_m) \quad (6)$$

The rotational speed of the lumped-mass system is represented by ω_m which equal to ω_r that represent the rotor speed.ω_m and ω_r are specified in per unit. D refer to damping of the lumped system.

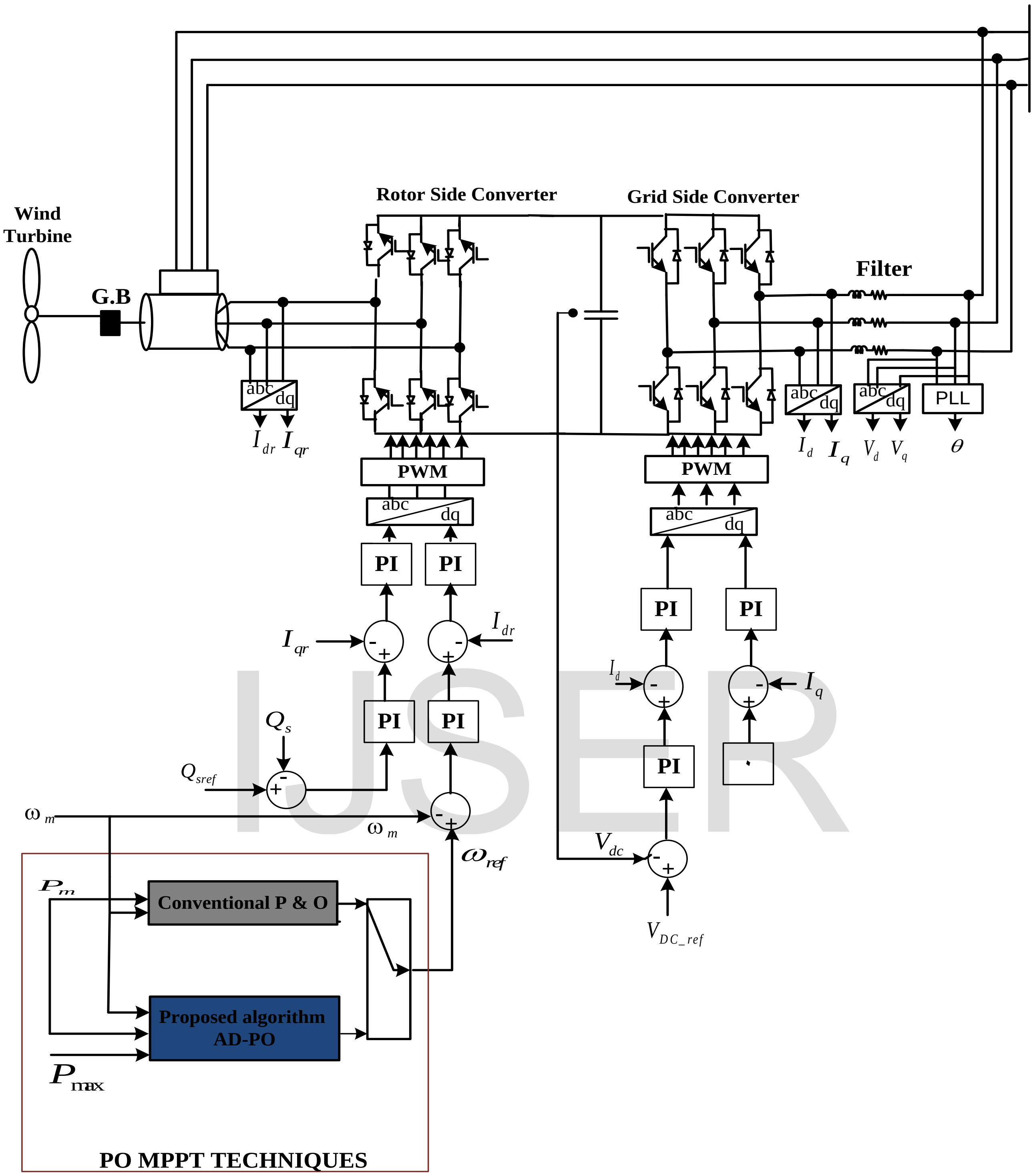


Fig. 1 . Studied System

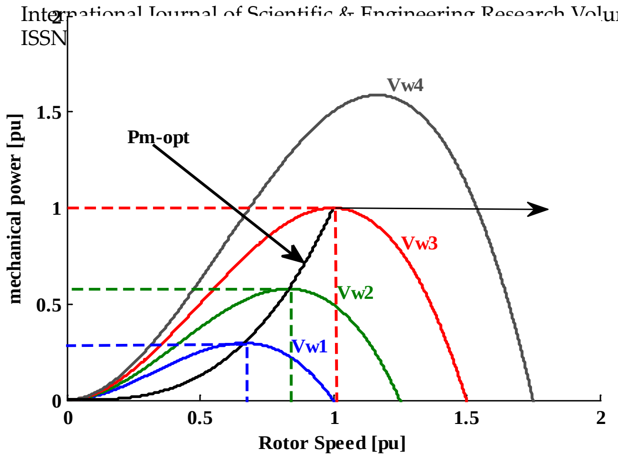


Fig. 2 Mechanical power versus rotor speed at different wind speed

2.3 DFIG Model

The equations of DFIG model can be formulated , as follow:

Stator voltage equations:

$$v_{ds} = r_s i_{ds} + \frac{d\emptyset_{ds}}{dt} - \omega_s \emptyset_{qs} \quad (7)$$

$$v_{qs} = r_s i_{qs} + \frac{d\emptyset_{qs}}{dt} + \omega_s \emptyset_{ds} \quad (8)$$

Rotor voltage equation:

$$v_{dr} = r_r i_{dr} + \frac{d\emptyset_{dr}}{dt} - \omega_r \emptyset_{qr} \quad (9)$$

$$v_{qr} = r_r i_{qr} + \frac{d\emptyset_{qr}}{dt} + \omega_r \emptyset_{dr} \quad (10)$$

where v_{sd}&v_{qs} are dq-axis voltage of the stator, v_{dr}&v_{qr} refer to dq-axis voltage of the rotor, ω_s is synchronous speed and $\emptyset_{ds}$ are stator flux dq-axis$\emptyset_{dr}$&$\emptyset_{qr}$ are rotor flux dq axis,i_{dr} ,i_{qr} are rotor current dq axis,ω_r is rotor speedi_{ds} ,i_{qs} are stator current dq axis,.r_s&r_r are stator & rotor resistances.

Stator flux equation:

$$\emptyset_{ds} = L_s i_{ds} + M i_{dr} \quad (11)$$

$$\emptyset_{qs} = L_s i_{qs} + M i_{qr} \quad (12)$$

Rotor flux equation:

$$\emptyset_{dr} = L_r i_{dr} + M i_{ds} \quad (13)$$

$$\emptyset_{qr} = L_r i_{qr} + M i_{qs} \quad (14)$$

as L_s,L_r represent the stator and rotor inductances and M refer to mutual inductance

Electromagnetic torque equation:

$$T_{em} = \frac{3}{2} p \left(\emptyset_{ds} i_{qr} - \emptyset_{qs} i_{dr}\right) \quad (15)$$

whereT_{em} is electromagnetic torque ,p is number pairs of poles.

The active & reactive power at stator represented as follow:

$$P_s = \frac{3}{2}(v_{ds} i_{ds} + v_{qs} i_{qs}) \quad (16)$$

$$Q_s = \frac{3}{2}(v_{qs} i_{ds} - v_{ds} i_{qs}) \quad (17)$$

whereP_s&Q_s are stator active and reactive power.

The active & reactive power at rotor represented as follow:

$$P_r = \frac{3}{2}(v_{dr} i_{dr} + v_{qr} i_{qr}) \quad (18)$$

$$Q_r = \frac{3}{2}(v_{qr} i_{dr} - v_{dr} i_{qr}) \quad (19)$$

whereP_r&Q_r are rotor active and reactive power

3. fixed P&O technique

traditional P&O method rely on the change in the curve of power and roror speed. When $dp/d\omega > 0$, the operating point on the P-□ characteristic-curveis located in the left of the MPP, the controller modify the reference rotor speed by an mounting value. Otherwise, it turn the reference speed change towards the MPP, as shown in Fig. 3. The fast response and the range of the oscillations around the MPP is aresult to the used step-size, as it can be small or a large step. Fig.4(a) and (b) in respectively illustrate the effeciency of used controller in case of small step or large step.

When the used system of P&O apply a small constant speed step-size, it has advatages of small range of oscillation but with slow response and large settling time and inrcrease the power losses. on other side if contrller used large step it will reach MPP fast than small step but with large range of oscillation. the two cases have merits and demirits but the demitists Highlights on the modified method which integrate the merits of the two situation and addresses the demirits.

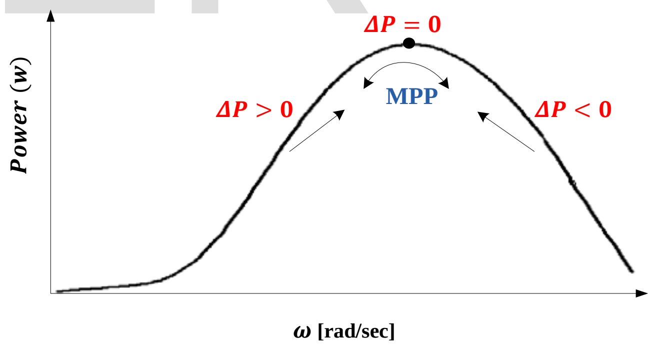
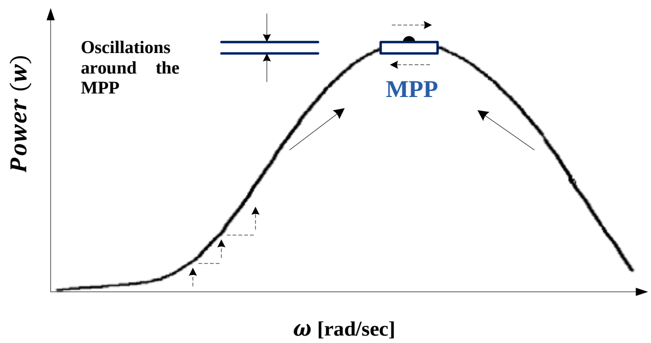
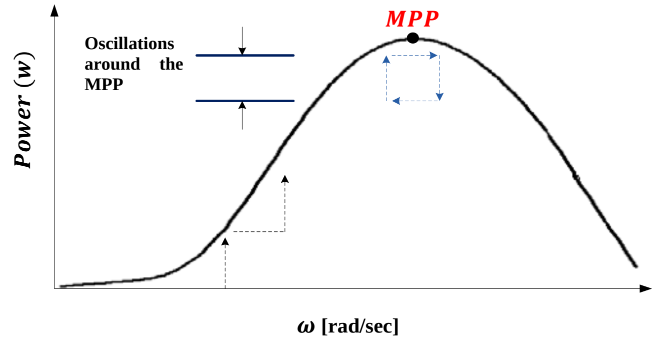


Fig. 3.Traditional P&O MPPT controller operation



(a)TraditionalP&O with small fixed speed step-size



(b) Traditional P&O in case of large fixed speed step-size

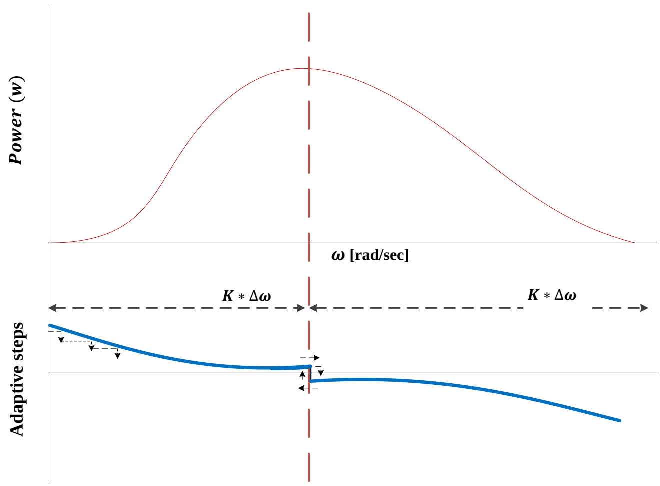
Fig. 4.Traditional P&O method

4 proposed adaptive P&O technique

To avoid the limitations of traditional P&O MPPT ,this paper suggests a high response and an efficacious PO method. The adaptive-step size perturb and observe (AD-PO) method is performed. The proposed algorithm AD-PO based on the adaptive ratio K . The adaptive ratio K depend on the variation between maximum and actual value of the mechanical power as follow;

$$K = \frac{P_{m_{opt}} - P_m}{P_{m_{opt}}} \tag{20}$$

where $P_{m_{opt}}$ is the optimal mechanical power. The optimal mechanical power is calculated according to [20].The adaptive step-size of rotor speed($k * \Delta\omega$) varies due to the operating point. While the operating point is approaching towards the MPP, the adaptive ratioK decreases to reduce the steady state oscillations. İf the system opertate on the P-□ slope near from the MPP, the controllerapplies the small adaptive ratio K.Otherwise, the controller applies a large adaptive ratio K. The proposed algorithm (AD-PO) improve the overall efficiency versus the classic P&O MPPT and tracks the MPP with small settling time and small oscillations compared.The strategy of the suggested method rely on the operating point and the adaptive ratio K.The main procedure of the proposed algorithm is illustrated in the flowchart as shown in Fig. 6.



Adaptive P&O MPPT technique

Fig. 5.Adaptive P&O MPPT technique

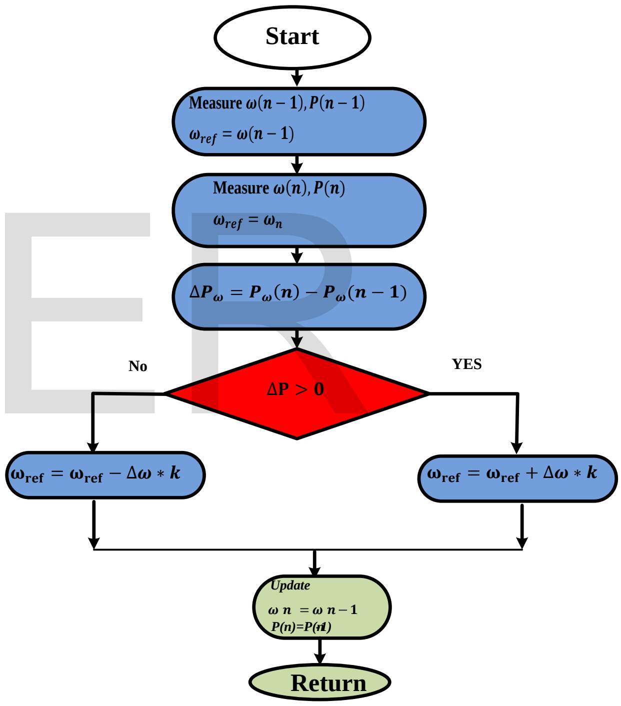


Fig. 6. the proposed adaptive P&O method Flow chart

5 Simulation results and discussion.

The suggested algorithm (AD-PO) has been examined under step-wind speed. The change of the wind speed is with average of 11 m/sec. The simulations results obtained from the adaptive P&O (AD-PO) techniques wich simulted versus the traditional constant step-size P&O with its two cases of small and large step. the system parameters illustrated in Table I.

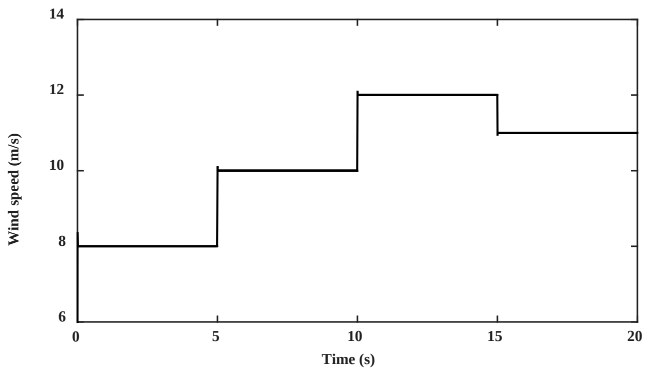
TABLE I SYSTEM PARAMETERS[21]

SPECIFICATION OF WIND TURBINE

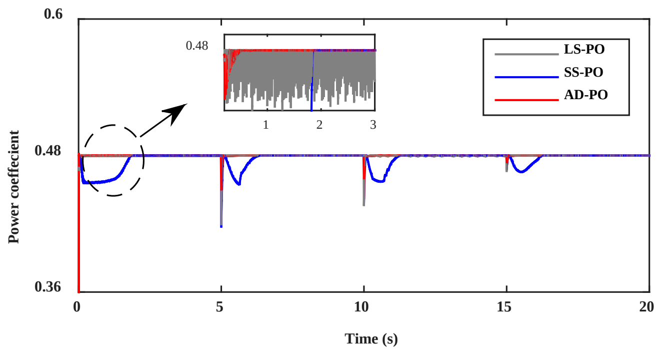
The coefficients C_1 to C_6	$C_1 = 0.5176$	$C_2 = 116$
	$C_3 = 0.4$	$C_4 = 5$
	$C_5 = 21$	$C_6 = 0.0068$
The radius of the blade	$R = 35.25\ m$	
Air density	$\rho = 1.225 kg/m^3$	
Optimal tip speed ratio	$\lambda_{opti} = 8.1$	
lumped inertia constant	H_m=4.4 s	
damping lumped	D=0 p.u	
Maximum powerCoefficient	$C_{p-max} = 0.48$	
DFIG PARAMETERS		
Maximum power	$P = 1.5\ MW$	
Number of pole pairs	$n_p = 3$	
Resistance of stator	$R_s = 0.023\ p.u$	
Stator inductance	$L_s = 0.18\ p.u$	
Moment of inertia	$H = 0.685\ s$	
Mutul inductance	$M = 2.9\ p.u$	
DC BUS AND GIRD PARAMETERS		
Dc-link voltage	$V_{dc} = 1150V$	
Dc link capacitor	C = 0.01 F	
Grid voltage	$V_g = 575$ V	
Grid's frequency	F = 60 Hz	
Grid 's resistance	$R_g = .003$ pu	
Grid's inductance	$L_g = .3$ pu	

Step-change wind speed

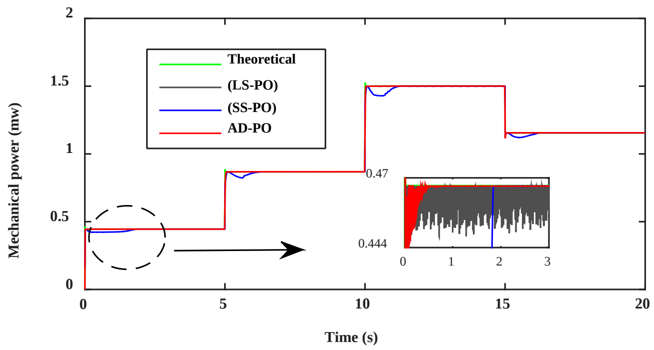
Fig 6 display the results of step wind speed . the variation of the wind speed is in average speed 11 m/s as shown in Fig. 6a. However, theC_p is at its optimum value 0.48 as shown in Fig. 6b, which means extract the maximum power over simulation times as depicted in Fig. 6c. what's more, the speed of the rotor forced to reach the the optimum rotor speed under viruation of wind speed as seen in Fig. 6d.In other hand, the small oscillations in AD-POwith (0.05 rad/sec) and small settling time (300 msec) compared to the LS-PO and SS-PO.The suggested algorithm (AD-PO)treat the limitation in the SS-PO and the LS-PO. The simulations results proved that the proposed algorithm AD-PO has high performance and enhance system efficiency compared to the traditional PO MPPT .



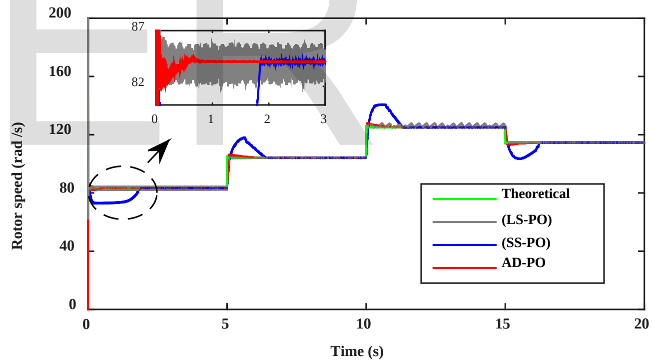
(a) Wind speed profile



(b) Power coefficient Cp



(c) Mechanical power



(d) Rotor speed

Fig. 6 results with step change wind speed

6 Conclusion

In this approach , an effective dynamic perturb and observe (AD-PO) algorithm has been proposed for MPPT of DFIG based WECSs. The proposed algorithm AD-PO is able to avoid the drawbacks of conventional PO MPPT technique and has small time response and oscillations decreased around the MPP.The proposed algorithm AD-PO based on the adaptive ratio Kwhich the adaptive ratio varies according to the operating point on the P-□ slope. The controller has succeededto select the appropriate adaptive ratio in different operating regions. In the far regions of the MPP, the system of P&O has successfully selected large adaptive ratio to reach the MPP with a small time. In addition, in the close regions of MPP, the controller has proved its efficiency for selecting the small adaptive ratio to reach the maximum power without any oscillations. The suggested method has been inspected on a large scale WECS using MATLAB/SIMULINK software. To validate the fast and more efficient performance of the suggested P&O, it has been liken with the traditional PO method. the High performance and simplicity of system make the suggested P&O the better than other methods. also, the suggested technique approved that it has small response time and oscillations reduction, as aresult of these merits the performance of the system enhanced and effeciency versus other method is the highiest . its clear in results that there is adiffirence in the effeciecy wich rised from 84 % to 88.2%.

REFERANCES

1. [1] E. H. Abdou, A.-R. Youssef, S. Kamel, and M. M. Aly, "Sensorless Wind Speed Control of 1.5 MW DFIG Wind Turbines for MPPT," in 2018 Twentieth International Middle East Power Systems Conference (MEPCON), 2018, pp. 700-704.
2. [2] H. H. Mousa, A. R. Youssef, and E. E. Mohamed, "Model predictive speed control of five-phase permanent magnet synchronous generator-based wind generation system via wind-speed estimation," International Transactions on Electrical Energy Systems, p. e2826, 2019.
3. [3] A.-R. Youssef, "Wind Speed Estimation MPPT Technique in Grid-Connected Wind Energy Conversion System," in 2018 Twentieth International Middle East Power Systems Conference (MEPCON), 2018, pp. 723-728.
4. [4] A.-r. Youssef, M. Sayed, M. Abdelwhab, and F. Khalifa, "Control Scheme of Five-Phase PMSG Based Wind Turbine," in MEPCON'2014, 2014.
5. [5] A. S. Ali, M. M. Ali, A.-R. Youssef, and G. T. Abdel-Jaber, "Comparative Study of Different Pitch Angle Control Strategies for DFIG Based on Wind Energy Conversion System," International Journal of Renewable Energy Research (IJRER), vol. 9, pp. 157-163, 2019.
6. [6] M. M. M. Ali, A.-R. Youssef, G. Abdel-Gaber, and A. S. Ali, "Adaptive Fuzzy-PID Based Pitch Angle Control of Wind Turbine," in 2018 Twentieth International Middle East Power Systems Conference (MEPCON), 2018, pp. 1110-1114.
7. [7] B. Yang, L. Jiang, L. Wang, W. Yao, and Q. Wu, "Nonlinear maximum power point tracking control and modal analysis of DFIG based wind turbine," International Journal of Electrical Power & Energy Systems, vol. 74, pp. 429-436, 2016.
8. [8] I. Munteanu, A. I. Bratcu, N.-A. Cutululis, and E. Ceanga, Optimal control of wind energy systems: towards a global approach: Springer Science & Business Media, 2008.
9. [9] F. Taveiros, L. Barros, and F. Costa, "Back-to-back converter state-feedback control of DFIG (doubly-fed induction generator)-based wind turbines," Energy, vol. 89, pp. 896-906, 2015.
10. [10] M. Sleiman, B. Kedjar, A. Hamadi, K. Al-Haddad, and H. Y. Kanaan, "Modeling, control and simulation of DFIG for maximum power point tracking," in 2013 9th Asian Control Conference (ASCC), 2013, pp. 1-6.
11. [11] A. Ghaffari, M. Krstic, and S. Seshagiri, "Power optimization and control in wind energy conversion systems using extremum seeking," IEEE Transactions on Control Systems Technology, vol. 22, pp. 1684-1695, 2014.
12. [12] A.-R. Youssef, M. A. Sayed, and M. Abdel-Wahab, "MPPT Control Technique for Direct-Drive Five-Phase PMSG Wind Turbines with Wind Speed Estimation," variations, vol. 21, p. 22, 2015.
13. [13] E. Koutroulis and K. Kalaitzakis, "Design of a maximum power tracking system for wind-energy-conversion applications," IEEE Transactions on Industrial Electronics, vol. 53, pp. 486-494, 2006.
14. [14] S. M. R. Kazmi, H. Goto, H.-J. Guo, and O. Ichinokura, "A novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems," IEEE Transactions on Industrial Electronics, vol. 58, pp. 29-36, 2011.
15. [15] A.-R. Youssef, A. I. Ali, M. S. Saeed, and E. E. Mohamed, "Advanced multi-sector P&O maximum power point tracking technique for wind energy conversion system," International Journal of Electrical Power & Energy Systems, vol. 107, pp. 89-97, 2019.
16. [16] H. H. Mousa, A.-R. Youssef, and E. E. Mohamed, "Variable step size P&O MPPT algorithm for optimal power extraction of multi-phase PMSG based wind generation system," International Journal of Electrical Power & Energy Systems, vol. 108, pp. 218-231, 2019.
17. [17] R. I. Putri, M. Pujiantara, A. Priyadi, T. Ise, and M. H. Purnomo, "Maximum power extraction improvement using sensorless controller based on adaptive perturb and observe algorithm for PMSG wind turbine application," IET Electric Power Applications, vol. 12, pp. 455-462, 2017.
18. [18] T. Ghennam, K. Aliouane, F. Akel, B. Francois, and E. Berkouk, "Advanced control system of DFIG based wind generators for reactive power production and integration in a wind farm dispatching," Energy Conversion and Management, vol. 105, pp. 240-250, 2015.
19. [19] W. Qiao, "Dynamic modeling and control of doubly fed induction generators driven by wind turbines," in 2009 IEEE/PES Power Systems Conference and Exposition, 2009, pp. 1-8.
20. [20] Mousa HH, Youssef AR, Mohamed EE. "'Adaptive P&O MPPT algorithm based wind generation system using realistic wind fluctuations"'. International Journal of Electrical Power & Energy Systems. 2019 vol. 112, pp.294-308.
21. [21] Y. Liu, L. Jiang, Q. Wu, and X. Zhou, "Frequency control of DFIG-based wind power penetrated power systems using switching angle controller and AGC," IEEE Transactions on Power Systems, vol. 32, pp. 1553-1567, 2017.
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