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Energetic Optimization of Variable Speed Wind Energy Conversion Systems by Extremum Seeking Control

G. Mahaboob Subahan[1], T.Varaprasad[2], V.Lakshma Naik[3]

PG Student [EPS], Dept. of EEE, SVPCET, Puttur, Andra Pradesh, India[1]

Assistant Professor, Dept. of EEE, SVPCET, Puttur A.P., Andhra Pradesh, India[2]

Assistant Professor, Dept. of EEE, BIT IT, Hindupur Anantapur, Andra Pradesh, India[3]

ABSTRACT: Power optimization and control for grid-coupled wind energy conversion systems (WECS) has been extensively studied for variable speed wind turbines. However, existing methods widely use model-based power optimization algorithms in the outer loop along with linear control techniques in the inner loop. The transient performance of this combination is dependent on the system's operating point, especially under fast varying wind regimes. We employ extremum seeking (ES) in the outer loop, which is a non model-based optimization approach, to perform maximum power point tracking, i.e., extract maximum power from WECS in their sub rated power region. Since the convergence rate of the ES design may be limited by the speed of the system dynamics, we also design a nonlinear controller, based on the field-oriented control concept and feedback linearization that yields improvement in convergence rate by two orders of magnitude. The outer ES loop tunes the turbine speed to maximize power capture for all wind speeds within the sub rated power operating conditions.

KEYWORDS: Adaptive systems, nonlinear control systems, power control, wind power generation.

I. INTRODUCTION

AVARIABLE speed wind turbine (WT) generates power in two different regions, sub rated power region and rated power region. In the sub rated power region, the maximum achievable turbine power is a function of the turbine speed at any given wind velocity. To achieve maximum power point tracking (MPPT), i.e., extract maximum power, an optimization algorithm is needed and is often used in conjunction with a controller that guarantees other closed-loop desired performance specifications. In this paper, we focus on the optimization and control of a wind energy conversion system (WECS) composed of a WT, a squirrel-cage induction generator (IG), and a matrix converter (MC). The MC, which is a replacement for the conventional rectifier–inverter combination (ac–dc–ac), features no energy storage components, has bidirectional power flow capability and controllable input power factor It connects the IG to the power grid, and along with the presented control/optimization design, steers the WT to its maximum power point (MPP) by controlling the electrical frequency and voltage amplitude of the stator of IG, which in turn leads to a variation in the turbine speed. It also assists in voltage regulation or power factor correction by controlling the reactive power transfer to the grid. A design for a system similar to the one we consider here has been presented and is based on a speed-sensor less power signal feedback (PSF) algorithm. The speed-sensor less PSF algorithm uses lookup table values that are dependent on the system model and parameter values.

In addition, accuracy of the method depends on the accuracy and resolution of the data obtained for the lookup table. Furthermore, the control design employs Jacobian linearization, and uncertainty in the system dynamics and/or variations in the working conditions cause the system to move away from its MPP. Another method based on fuzzy logic principles and four-leg-improved MC model, used for performance enhancement and efficiency optimization, is presented. Model-dependent designs have the drawback that the optimization algorithm and controller need to be redesigned carefully for each WECS. To overcome these difficulties, we present an extremum seeking (ES) algorithm, which is: 1) nonmodel based and 2) with easily tunabledesign parameters. Furthermore, ES shows promising results for a wide variety of applications ES designs for MPPT of WECS are also presented but differ from the design in this

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paper in several respects, including assumptions on the system model, transient performance, and performance robustness.

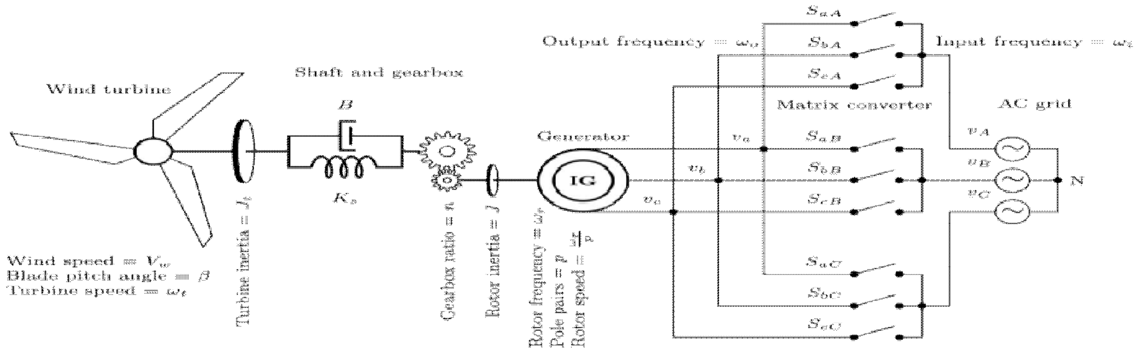

Fig. 1: WECS including WT, gear box, IG, and MC

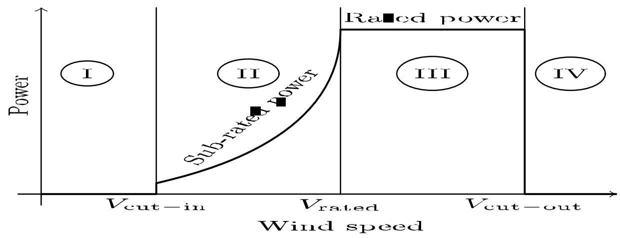

Fig. 2. Typical power curve of WT including four operating regions.

Parameter to tune MPP. The turbine power is the cost function for the ES algorithm, and electrical frequency and voltage amplitude of the stator of IG are controlled through the MC to reach desired closed-loop performance. As a result of including the inner loop, the overall design has faster response time, and further more magnetic saturation of the IG is avoided. In comparison with model-based designs, ES better handles model uncertainty in the turbine power map, resulting in improved power extraction. To the best of our knowledge, this is the first work in the literature that combines the MPPT with nonlinear control design that has good performance robustness to uncertainty, and faster transient performance, allowing for power tracking under rapidly varying wind conditions. The rest of this paper is organized as follows. An introduction to modelling of the WECS with concentration on the squirrel-cage IG dynamics in stationary reference frame and the MC is discussed in Section II. Our nonlinear controller design is discussed in Section III, and the ES algorithm in Section IV. Simulation results to verify the effectiveness of the proposed scheme are presented in Section V, and our conclusion is presented in Section VI.

II. WIND ENERGY CONVERSION SYSTEM

A schematic diagram of a WECS including WT, IG, and MC is shown in Fig. 1. WTs work in four different regions, as shown in Fig. 2. In Region I, the wind speed is too low for the turbine to generate power. Region II, also called the sub rated power region, lies between the cut-in speed and rated speed. Here, the generator operates at below rated power. The theoretical shape of this curve reflects the basic law of power production, where power is proportional to the cube of the wind speed. In Region III, the power output is limited by the turbine; this occurs when the wind is sufficient for the turbine to reach its rated output power. Region IV is the period of stronger winds, where the power in the wind is so great that it could be detrimental to the turbine, so the turbine shuts down

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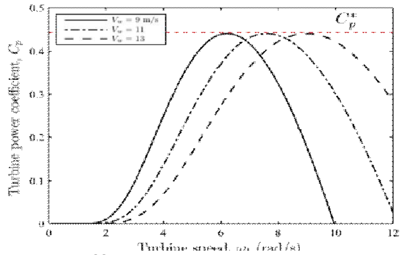

Fig. 3. Variation of turbine power coefficient versus turbine speed for different wind speeds where $\beta = 0$. The maximum value of the power coefficient is $C*_p$.

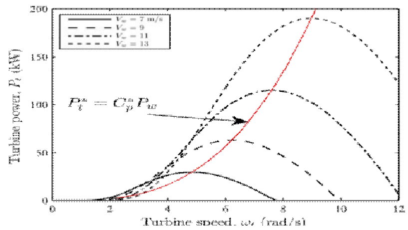

Fig. 4. Variation of the turbine power versus turbine speed for different wind speeds where $\beta = 0$. The MPP moves on $C*_p Pw$ curve, which shows the characteristic of the sub rated region

III. CONTROLLER DESIGN

In many motor drive systems, it is desirable to make the drive act as a torque transducer wherein the electromagnetic torque can nearly instantaneously be made equal to a torque command. In such a system, speed or position control is dramatically simplified because the electrical dynamics of the drive become irrelevant to the speed or position control problem. In the case of induction machine drives, such performance can be achieved using a class of algorithms collectively known. When flux amplitude, The power coefficient $Cp(\omega t,Vw)$ and wind speed function $Vw(t)$ are bounded $C3$ functions with bounded derivatives. Hence, the mechanical torque, Tt , is a bounded $C3$ function with bounded derivatives. Based on the selected outputs and having Assumption 1 satisfied, we apply feedback linearization with the following change of variables to WECS dynamics The closed-loop system is input– output decoupled and linear. The input–output map consists of fourth-order and third-order systems. This allows for an independent regulation (or tracking) of the outputs using control signals. Transient responses are now decoupled also when $|\lambda|$ref is varied, even independently of ωref$t$. This is an improvement over FOC.

IV. MPPT USING ES

There are three main MPPT techniques for WECS: wind speed measurement (WSM), P&O, and PSF. Measurement of wind velocity is required in WSM method. It is clear that accurate measurement of wind velocity is complicated and increases the system cost. Since the P&O method adds delay, it is not practical for medium- and large-inertia WT systems. To implement PSF control, maximum power curve (maximum power versus turbine speed) is required. The maximum power is then tracked by turbine speed control [5]. Fig. 6 shows a typical block diagram of P&O using direct FOC for the IG [9], [36]. To implement FOC scheme, the rotor flux magnitude $|\lambda|$ and its angle ϕ are identified by the rotor flux calculator based on the measured stator voltage (vo) and current (io). The turbine speed reference ωref$e$ is generated by the MPPT scheme.

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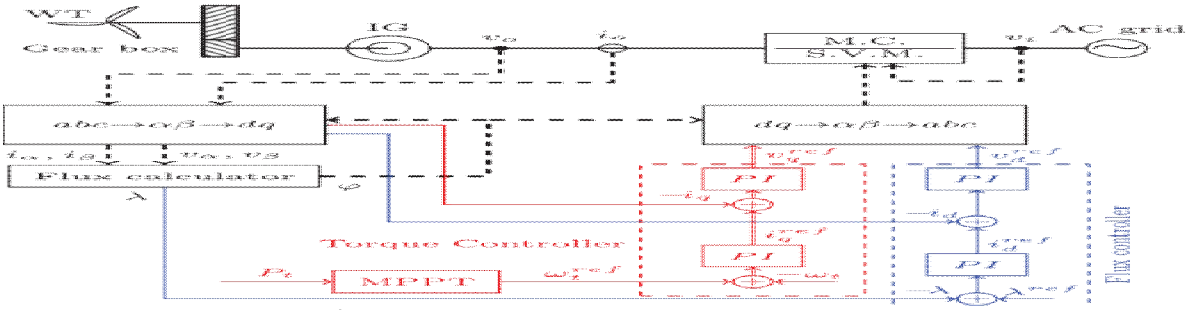

Fig.5. MPPT for a WECS based on P&O using conventional direct FOC.

The abc→$\alpha\beta$ and its inverse follows from (31) and (34). The $\alpha\beta$→do and its inverse follows from (81). The flux calculator uses (51) and (55). The controllers are proportional-integral.
first space into two new subspaces. As for all the points within the left space, their x values area unit lower compared with points within the right space. The k-d tree may be a fairly effective organization structure for the k-dimension knowledge. It's a specific advantage within the search field regarding the high-dimension space, such as the k nearest neighborhood search. Therefore, the k-d tree will be applied within the high-dimension space-searching algorithm of the patch.

A. Matching

Freeman et al.[1] purpose the missing high-resolution details can't be predicted with solely the local information alone , as a result of if we tend to pre-process an input low-resolution image then break it in to several patches and search the missing high-frequency details, we'll notice the searched high-frequency patches quite totally different see the subsequent Fig. 5. This shows the local patch information isn't enough to predict the detailed information of the high-resolution , however the result of the spatial neighborhood ought to be taken under consideration. In our technique , throughout the method of breaking the low-frequency image by raster scan order, each patch should be part overlapped by its neighbor to keep the accordance of the space neighborhood Fig. 6.

To overcome challenges attached with the conventional power control and optimization algorithms and to remove the dependence of the MPPT algorithm on the system modelingand identification, we propose ES algorithm, which is a non model-based real-time optimization technique to MPPT of WECS. First, we present ES without the inner-loop control to clarify the advantages of the proposed controller on the closed-loop performance of the system. The proposed models for power coefficient and turbine power in (3) and (4) are for simulation purposes. In this paper, we assume that we have access to turbine power measurements and we can manipulate the turbine speed through the MC. Furthermore, we do not have a model of the power coefficient or turbine power. However, we know that the turbine power map has one MPP under any wind speed, which helps us to present the following assumption.

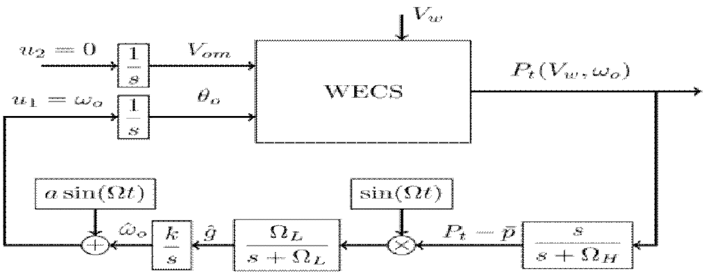

Fig. 7. MPPT for a WECS based on ES without the inner-loop control

A schematic diagram of MPPT for WECS with ES without inner-loop nonlinear control is shown in Fig. 7. Remark 4 implies that the power is parameterized by ω o, which is estimated by ES loop. The other input for WECS that generates the voltage amplitude has been set to zero, which means the stator voltage has a constant peak amplitude.
Our proposed ES scheme with the inner loop control is shown in Fig. 8. In this case, the reference inputs of the inner-loop control are ωreft and $|\lambda|$ref. From Assumption 2, we know that the MPP is parameterized by the optimal turbine

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speed at each wind speed, which is estimated by the ES loop. The other control input $|\lambda|$ref defines the level of the flux linkage of the rotor, which prevents IG from magnetic saturation.

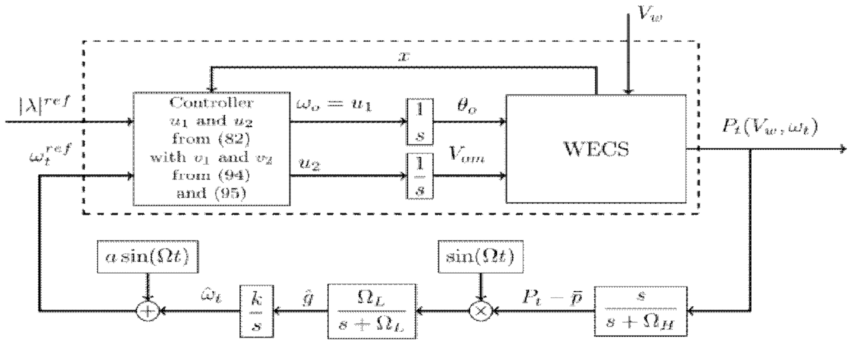

Fig. 8. ES for MPPT in WECS with the inner-loop control.

V. SIMULATION RESULT

As we mentioned earlier, response time of the ES design without the inner loop is considerably slow, which results

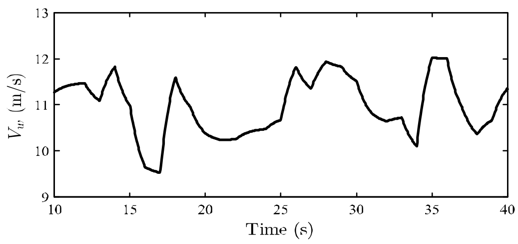

Fig. 9. Variation of wind speed versus time.

in a very low power efficiency. However, we present one simulation that compares the response of the design without the inner loop, as shown in Fig. 7, to our proposed algorithm, as shown in Fig. 8, which shows the role of the inner loop.. Higher values of *a* reduce the precision of the MPPT, as shown in Theorem 2. We show a time frame of 30 s to visualize the differences between our proposed algorithm and the two other algorithms, properly.

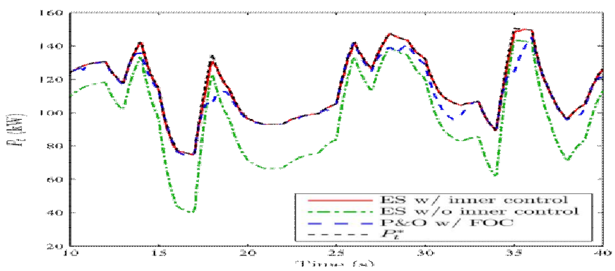

Fig. 10. MPPT, (solid red line) our proposed algorithm, (dashed-dotted green line) ES without inner loop, (dashed blue line) conventional P&O with FOC, and (dotted black line) maximum power available to the WECS.

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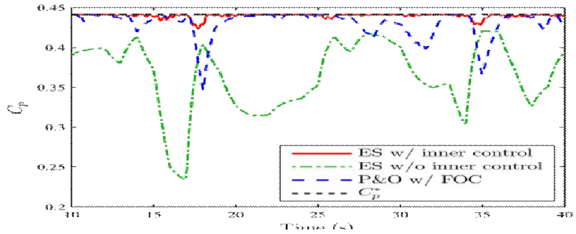

Fig. 11. Variation of power coefficient, (solid red line) our proposed algorithm, (dashed-dotted green line) ES without inner loop, (dashed blue line) conventional P&O with FOC, and (dotted black line) maximum power coefficient

Algorithm by adding different amount of perturbation to the rotor and stator resistance and inductance. We present one of our robustness simulations with a 100% increment in rotor resistance at time 15 s and then back to its nominal value at time 25 s. While as shown in Fig. 12, the performance of the proposed algorithms remains unchanged, the conventional MPPT algorithm is not able to attenuate the effect of the disturbance, as shown in Fig. 13.

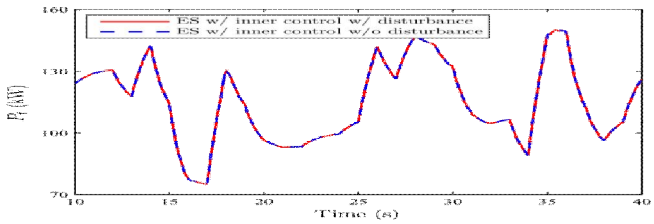

Fig. 12. Robustness analysis with a 100% increment in the rotor resistor at time 15 s and back to its nominal value at time 25 s for the proposed algorithm. Variation of turbine power (solid red line) with perturbation and

(dashed blue line) without perturbation.

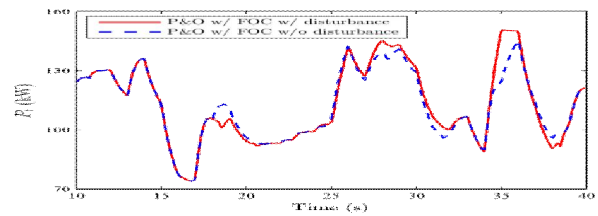

Fig. 13. Robustness analysis with a 100% increment in the rotor resistor atime 50 seconds

Complexity of the proposed algorithm. Clearly higher power efficiency is our aim and to this end, we have to sacrifice the simplicity in favor of harvesting more energy. Since the WECS runs for a long period of time, a small improvement in power efficiency guarantees extracting a higher energy level and leads to cost reduction of the WECS.

VI. CONCLUSION

We presented an ES algorithm to extract maximum power from a WECS for wind speed from cut-in wind speed to rated wind speed. The design employed an inner-loop nonlinear controller based on field-oriented approach and feedback linearization technique to control the closed-loop transient performance, with respect to which the ES had to be tuned. Without this inner-loop control, the convergence rate of the closed-loop system would be much slower. This optimization control algorithm can readily be extended to other classes of WECS without major changes.

REFERENCES

[1] P. M. Anderson and A. Bose, “Stability simulation of wind turbine systems,” *IEEE Trans. Power App. Syst.*, vol. 102, no. 12, pp. 3791–3795, Dec. 1983.
[2] K. B. Ariyur and M. Krsti´c, *Real-Time Optimization by Extremum Seeking Feedback*. New York, NY, USA: Wiley, 2003.
[3] A. Banaszuk, K. B. Ariyur, M. Krsti´c, and C. A. Jacobson, “An adaptive algorithm for control of combustion instability,” *Automatica*, vol. 40, no. 11, pp. 1965–1972, 2004.

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[4] S. M. Barakati, “Modeling and controller design of a wind energy conversion system including a matrix converter,” Ph.D. dissertation, Dept. Electr. Comput. Eng., University of Waterloo, Waterloo, ON,
Canada, 2008.
[5] S. M. Barakati, M. Kazerani, and J. D. Aplevich, “Maximum power tracking control for a wind turbine system including a matrix converter,” *IEEE Trans. Energy Convers.*, vol. 24, no. 3, pp. 705–713,
Sep. 2009.

BIOGRAPHY

G. MAHABOOB SUBAHAN he received the B.Tech (Electrical and Electronics Engineering) degree from the Jawaharlal Nehru Technological University, Anantapur in 2013 and Pursuing the M.Tech(Electrical power system) from Jawaharlal Nehru Technological University, Anantapur in 2015.