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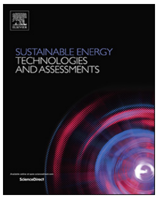

Original article

Assessment and control of wind turbine by support vector machines

Omar Dahhani[a,*], Abdeslam El-Jouni[b], Ismail Boumhidi[a]

[a] *LESSI Laboratory, Faculty of Sciences Dhar El-Mehraz, Sidi Mohammed Ben Abdellah University, B.P:1796, 30000 Atlas, Fes, Morocco*
[b] *Centre regional des metiers de l'éducation et de la formation (CRMEF), Tangier, Morocco*

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ABSTRACT

In this paper, a control strategy by support vector machines (SVM) for a wind turbine is proposed. It aims at operating the wind conversion system perfectly so that it can extract the available maximum power in wind flow under normal conditions, also, the system should be stabilised by this control when the wind is stronger. The SVM's role is identifying the behaviours of optimal electromagnetic torque and blade pitch angle with respect to wind speed changing. Therefore, data should be collected at first. Among of these data:wind speed, the matching optimal torque and pitch angle. SVM model may be designed through using these data show. Yet, SVM model ought to be used correctly through providing us optimal electro magnetic torque and optimal pitch angle for becoming wind system controller. To show the extent of reliability compared to other controllers in the literature, the method what is called sliding mode control is proposed. The latter is going to be designed and applied for comparing it with SVM. Finally, the two methods (SVM, SMC) are testified on real wind profile.

Introduction

Wind energy is the most reliable and everlasting energy source. Thanks to its cleanliness, abundance, and low cost maintenance, wind energy becomes a serious competitor of all the other renewable and conventional energy types [1]. The wind turbine is the mechanical device which convert the linear wind flow energy into rotation energy to be converted eventually to electrical energy by an electrical machine [2]. The wide turbine type is the one with three blade horizontal axis, operating in either fixed or variable rotation speed [3]. Turbines with variable speed has the ability to convert the maximum of available wind flow into electrical power. Nevertheless, the wind fast random changing profile hinders the maximum power point tracking (MPPT) [4].

Much more research studies have proposed control schemes in literature and strategies to make the task of MPPT easier [5]. SMC, linear-quadratic-Gaussian control [6], nonlinear control [7,8], H_∞ control [9] and model predictive control [10] are well-known techniques in the literature, and have a common principle of operation. To implement such techniques in reality, several sensed magnitudes which are practically imprecise are required. This reduces the wind conversion system's performance and produces instability in some cases. To overcome these methods insufficiency, some modern control techniques combining fuzzy logic and neural network are proposed to reduce sensor needs by estimating magnitudes instead of measurements [11–15]. Petkovic et al. [16] and Nikolić et al. [17] have suggested a neuro-fuzzy technique that estimate the wind speed fluctuation basing on fractal characteristics. They also have proposed an adaptive neuro-fuzzy inference system (ANFIS) as a hybrid intelligent technique that enhance the ability to learn and adapt automatically. This technique has been used not only for the identification of the wind system power coefficient [18],but for the generators, which being equipped by the continuously variable transmission, as well [19]. Despite the fact that we use an advanced hardware technology, the estimation time still need long one. But, not only does the ANFIS adopt in the estimation of wind farm efficiency [20], the selection of wind turbine wake effect [21], but many other wind related applications as wind noise estimation [22] either.

Other artificial intelligence works are concerning in upgrading the existent-classical control methods through estimating uncertainties in the wind system; they are taking them into account when seeing about with the main control law design [23]. The majority of methods mentioned above are totally based on artificial intelligence lead to better results. Yet, they do not take into consideration the strong wind scenarios and also the time response. Moreover, the previous works above use linear controllers. The latter are perfect use just at the neighbours of nonlinear system's operating points. Let alone, the parameters changing (including wind speed) are usually slowly assumed during the validation tests, even though this process is not practically satisfied.

Unlike classical, ANFIS and combined methods, SVM could be employed like an artificial intelligence approach and strong estimation methodology for non-linear problems. It has been suggested by Vapnik since 1992 [24]. In 1998, it is upgrading [25] to reach the best

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[*] Corresponding author.
E-mail address: dahhani.omar@gmail.com (O. Dahhani).

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generation ability and the highest prediction accuracy. This approach will be used to create a reliable strategy of control. The function of wind conversion system could be practically structured in four zones: I, II, III and IV that stand respectively for weak, regular, strong and violent wind speeds. The maximum power is tracked in zone II, where the wind speed is regular and the wind conversion system operates below the average of nominal conditions. At zone III, the wind is stronger, and the blade's pitch angle control is required to extract a limited power and protecting wind system material. Whereas in zone I, where wind is practically null, and zone IV, where wind is too strong, the turbine is stopped and the power generation is turned off. The designed SVM control is devoted for both zones II and III. The purpose behind using it in the control is to keep the system stability at fast changing of wind speed which is caused by unpredictable turbulences. In addition to that, it will convert the maximum available wind power at operating zone II and limit power conversion in zone III.

MPPT is the ability to convert the maximum of available wind power as quick as possible. MPPT methods function are based on two main steps. The first one is to perform an algorithm which locating the optimal point relying on several measurements of wind speed, rotation speed, output power etc. The second step focuses on the calculation of the control signal through one of different proposed algorithms in the literature. These MPPT strategies of control, which are based on signal feedback loop, need several seconds for response time and require further materials to be practically performed. let's illustrate, An open loop control strategy which is simple and accurate at the same time could be functional. The present work, asses a new approach of control by SVM. For every specific wind speed, there is only one corresponding optimal control variable. The direct relationship that gathers the wind speed and the control variable may introduce several other system variables and parameters. This could require additional hardware and reduce the performance of the system. The SVM is introduced to surmount this drawback. It will model the behaviour of wind speed with double feeding induction generator (DFIG) optimal electromagnetic torque. It also is considered to be the first component in control variable. A similar SVM model is designed for the pitch angle control which is considered to be the second component in the control variable. In this context, a SVM controller with one input (wind speed) and two outputs (torque and pitch angle) is obtained. Only thirty samples are concerned in the design of the proposed controller since the simplicity remains an important criterion. In order to compare SVM with the standard existing controllers in terms of fast tracking and stability, another control by sliding mode for DFIG based wind turbine is also designed and tested.

The paper is organised as follow; in section '*Wind turbine modelling*', model of wind power conversion system is presented. The control strategy by the SVM is designed and practical steps for implementation are explained in section 'Control strategy'. At the same one, sliding mode control is designed. Concerning the SMC's stability is totally proved by Lyapunov approach. Simulation results of theoretical and practical wind profiles tests and their discussions are presented in section '*Simulation results and discussion*'. The last section is devoted for the conclusion.

Wind turbine modelling

The amount of power intercepted by a turbine placed into a draft is important. The equation of aerodynamics is given as:

$$P = \frac{1}{2}\rho A V^3 \tag{1}$$

Where ρ is the air density ($\rho \sim 1.025\ \mathrm{kg/m^3}$), A is the swept area (the surface of the rotor facing the air stream) and V is the wind velocity. If the surface is $20\ \mathrm{m^2}$, from the Eq. (1), it is predictable that for 5, 10 and 15 m/s velocities the turbine intercepts 80, 644 and 2173 KW, respectively. The turbine must operate efficiently over a large power range especially with surges and occasional turbulences where the wind speed is in a fast-changing.

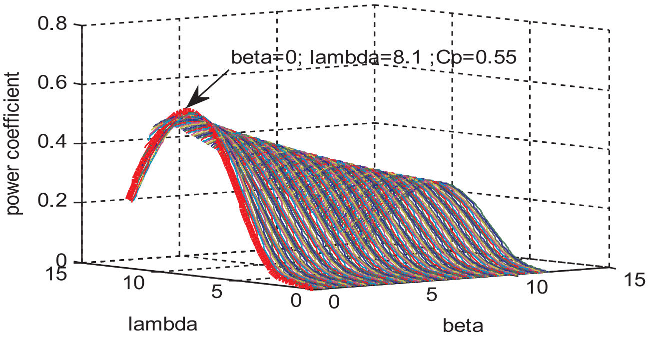

Fig. 1. Power coefficient as function of tip speed ratio and pitch angle.

The captured power in mechanical form into the turbine shaft is expressed as:

$$P_m = \frac{1}{2}C_p \rho A V^3 \tag{2}$$

Where C_p is the power coefficient. It is practically included between 0.35 and 0.5[12]. This factor is limited by the turbine aerodynamic form.

The mechanical part of a variable wind speed turbine is considered in this paper. The aerodynamic torque is expressed by the mechanical power (2) divided by the turbine rotation speed:

$$T_a = \frac{1}{2}C_p \rho A R V^2/\lambda \tag{3}$$

The power coefficient C_p depends on the blade pitch angle β and tip speed ratio λ as illustrated in Fig. 1. At zone II (below nominal conditions), parameter β must equal zero to convert the maximum power, and λ is expressed as follows:

$$\lambda = \frac{\omega_t R}{V} \tag{4}$$

Here ω_t is the turbine rotation speed and R is the turbine rotor radius.

The rotor dynamics is a first order differential equation, expressed by the mechanical (aerodynamic) torque T_a, low speed shaft torque T_{ls} and the angular rotor speed:

$$J_r \dot{\omega}_t = T_a - T_{ls} - K_r \omega_t \tag{5}$$

K_r and J_r are respectively the rotor external damping and the rotor inertia.

The equation of generator electromagnetic torque T_{em} is given by:

$$J_g \dot{\omega}_g = T_{hs} - T_{em} - K_g \omega_g \tag{6}$$

Where ω_g and T_{hs} are respectively the DFIG rotor rotation speed and the high speed shaft torque. J_g and K_g are the generator inertia and the generator friction coefficient.

The mechanical part of variable wind speed turbine illustrated by two-mass model in Fig. 2, is presented in state space as follows [26,27]:

$$\begin{bmatrix} \dot{\omega}_t \\ \dot{\omega}_g \\ \dot{T}_{ls} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \omega_t \\ \omega_g \\ T_{ls} \end{bmatrix} + \begin{bmatrix} b_{11} \\ b_{21} \\ b_{31} \end{bmatrix} T_a + \begin{bmatrix} b_{12} \\ b_{22} \\ b_{32} \end{bmatrix} T_{em} \tag{7}$$

Where $a_{11} = -K_r/J_r$; $a_{12} = 0$; $a_{13} = -1/J_r$; $a_{21} = 0$; $a_{22} = -K_g/J_g$; $a_{23} = 1/(n_g J_g)$; $a_{31} = B_{ls} - K_{ls} K_r/J_r$; $a_{32} = (K_{ls} K_g/J_g - B_{ls})/n_g$; $a_{33} = -K_{ls}(J_r + n_g J_g)/(n_g J_g J_r)$; $b_{11} = 1/J_r$; $b_{21} = 0$; $b_{31} = K_{ls}/J_r$; $b_{12} = 0$; $b_{22} = 0$; $b_{32} = K_{ls}/n_g J_g$;