International Journal of Engineering Research and Reviews ISSN 2348-697X (Online)
Vol. 5, Issue 2, pp: (30-35), Month: April - June 2017, Available at: www.researchpublish.com

Analyse of VAWR Active Pitch Control Aerodynamic Force Perturbation for Blade Profile NACA0018

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Abstract: **This article gives important guidelines for vertical axis wind rotor new designed active pitch control system aerodynamic force perturbations at pitch mechanisms and servo motor. For active pitch control system servo motor power calculation is important to have information about all possible loads on the system. The research main target is using experimental data find the aerodynamic force as function of blade pitch angle. The research was provided using new designed special servo test bench with experimental blade of NACA0018 profile. Experimental data analyse provides full information about possible aerodynamic force as function of blade pitch angle. Provided functions can be used in next researches about active pitch control system servo motor power calculation or wind rotor blade angle control methods. Main experimental research conclusion provides information that aerodynamic blade force to pitch system servo motor in range of pitch angle ± 20 ° is ≈ 0 Nm. In case if pitch angle is more than 20 ° then aerodynamic force is linear function of blade length and pitch angle.**

Keywords: **NACA0018, VAWR, aerodynamic force, blade inertia.**

I. INTRODUCTION

A special attention is paid to the importance of power industry in Latvia, based on both own purposes and tasks put forward by the European Union, which are connected with energy independence, energy efficiency and specific weight of renewable energy resources [1]. All proposed requirements directly affect also Latvian power industry, its production and consumption. Primary problem of power industry is energy independence. According to 2016 data, energy import in Latvia was average 21% of generated electric power; however, this figure is variable in dependence on the reviewed period and market situation [1].

In terms of use of renewable energy resources (hereinafter referred to as RER) Latvia occupies 3rd place after Austria and Sweden due to a large volume generated by hydroelectric power plants. River resources in Latvian territory are loaded enough to even more extend electric power production by hydroelectric power stations, therefore one of prospective solutions for promotion of energy independence on national scale is the development of wind power industry in two primary directions [2]: formation of new wind parks, which is already being implemented in Western territory of Latvia where 3 largest wind parks in the country are operating; installation of low and middle power wind plants with rated electric power up to 100 kW in the decentralized way in rural and urbanized areas of Latvia.

Decentralized use of Wind Power Plant (further in text WPP) is featured by more positive factors, such as no need to construct powerful electricity transmission lines and possibility to carry out electric energy production closer to the consumer in the decentralized way throughout the country’s territory. Priority of decentralized wind energy production is medium size WPP. The WPP with nominal power size till 50 kW is the key product. In this power range is few products with horizontal axis wind rotor (further in text HAWR) and vertical axis wind rotor (further in text VAWR) [3]. For vertical axis wind rotor the biggest issue is lower power coefficient. New developments to increase the efficiency of vertical axis wind rotor is active blade pitch control system what is very common used in horizontal axis wind rotor systems [4].

Development as active pitch control system consist of new technology, control algorithm, system structure development. To realise such a big challenge one of biggest problems is aerodynamical force calculation. In active pitch system is important to be able to calculate and simulate the actual aerodynamical forces not only at pitched blade rotation axis but at the whole blade to calculate the actual effect of pitching angle to rotor efficiency. To calculate the active pitch control servo motor power is important to be able calculate all effecting forces to the pitched blade at the blade pitching rotation axis. The biggest problematic of this process is aerodynamical force calculation. Existing researches does not cover this information. New development and researches in wind industry can be covered in Latvia because of high intellectual potential [5].

II. MATHERIALS AND METHODS

A. Pitch control system developments for VAWR:

VAWR technology development last years have been focusing on the efficiency. The lover efficiency comparing to the HAWT is one of the reason why VAWR is used less than the HAWT [6]. Fully new level of approach have been made in the solution of efficiency increasing. That is VAWR blade active pitch control. The approached solution is pitch control with active actuator for each rotor blade. Aerodynamical force perturbation calculation is one of the main issues to clarify the needed actual power of the actuator. As actual aerodynamical force centre depends on the wind rotor blade angle to wind speed direction. In Fig. 1. is proposed one VAWR blade active pitch control system. Blade 2 angle is measured with two possible sensors: sensor 3 mounted on the blade; sensor 5 mounted on the actuator or servo motor. Proposed actuator in this shematic is servo motor 11 with the servo drive 10 consisting of two internal interfaces: logical program control interface 6 and servo motor control power interface 9. Electric source 8 of the servo system is using slip rings on the wind rotor shaft. Blade angle calculation setpoint is calculated in the central control system 4 (Fig.1.). Using in rotor 3 to 4 blades the central control system calculates the blade angle setpoint according to rotor angle at the wind [7].

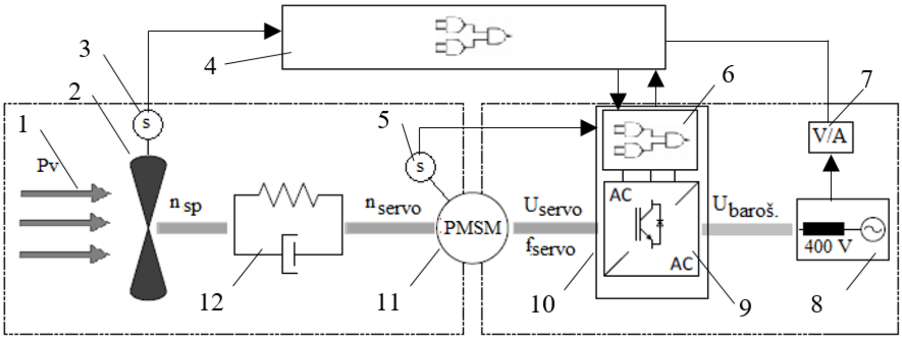

Fig. 1. VAWR pitch control system structure

1 – wind, 2 – VAWR blade, 3 – blade angle measuring sensor, 4 – central control system, 5 – servo motor speed and angle measuring sensor, 6 – servo drive, 7 – power source measuring unit, 8 – power source, 9 – servo drive motor power interface, 10 – servo drive, 11 – servo motor, 12 – gearbox and other mechanical components, P_v – wind power, n_{sp} – VAWR blade rotation speed, n_{servo} – servo motor rotation speed, U_{servo} – servo motor control voltage, f_{servo} – servo motor voltage frequency, $U_{baroš}$ – electric power voltage.

Servo motor controls the wind rotor blade angle according the calculated angle setpoint. The servo motor power is calculated according the system data: blade moment of inertia; mechanical system between the blade and the servo motor; aerodynamical wind force at the blade rotation axis. In research is analysed blade profile NACA0018 where the existing blade data shows that the blade aerodynamical centre is 25% of blade length from blade front. If active pitch control system servo motor centre is places in aerodynamical blade centre together with mass centre then on the servo motor is not working additional mechanical forces from blade [8].

B. Aerodynamical force measurement test bench, materials and methods:

Aerodynamical force experimental research is provided in Latvia University of Agriculture, city Jelgava. Research period is from May to October 2016. As wind source was used axial axis ventilator inlet air. Today's research's does not cover information about the possible aerodynamical force on the blade what makes difficult to calculate the actual needed servo motor power depending on the wind rotor blade size. With special experimental test bench is possible to measure and analyse the possible aerodynamical force perturbation to the active pitch angle control system servo motor. For signal simulation and accurate data analyse the MATLAB and MS EXCEL software's were used.

TABLE I: EXPERIMENTAL TEST BENCH EQUIPMENT AND USED SOFTWARE

Nr.	Description	Name	Producer
1	Gearbox	CHM 040 71B5 7.5	Chiaravalli
2	Servo motor	MS4612N4008E43F10	ABB Oy
3	Servo drive	ACSM1	ABB Oy
4	Setpoint signal converter	NI-6008	National Instruments
5	Simulation PC	HP Nx6253	HP
6	Operating system	Windows 7, SP2	Microsoft
7	Simulation and data analyse software	Matlab R2014a, *Simulink*	Mathworks
8	Servo drive data registration software	Drive Studio 1.6	ABB Oy

Blade aerodynamical force is measured with servo motor control system. Servo drive control algorithm is very precise and that mean the data from servo drive is possible to use for additional research and analyse. Servo motor torque measurements and calculation in servo drive is possible to use as aerodynamical force measurements. Experimental test bench consists of 7 main parts. Servo motor 3 with resolver feedback sensor 7 is possible to use with or without the warm gearbox 2. The experimental blade 1 can be replaced with other blade or calibrated mass with calibrated moment of inertia for other experiments. Servo drive position command signal is simulated with MATLAB *Simulink* software on the PC 6. Simulated signal is transmitted from PC 6 with digital signal to signal converter 5. Signal converter converts digital signal to analog 0...5 V signal. Analog signal is transferred to servo drive 4.

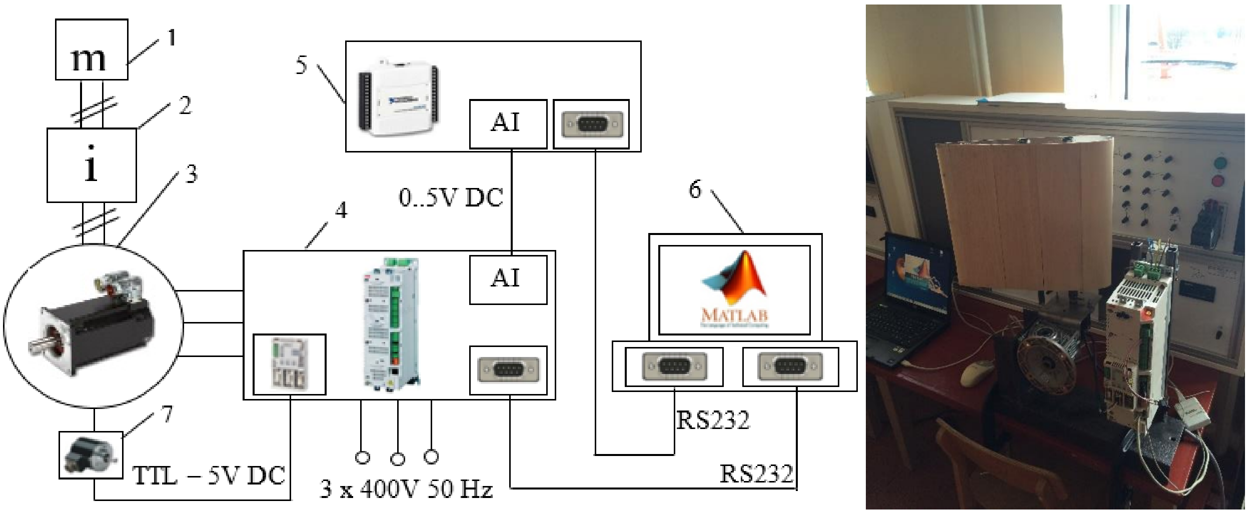

Fig. 2. Experimental test bench structure

1 – experimental object; 2 – worm gearbox; 3 – permanent magnet servo motor; 4 – servo drive ACSM1; 5 – position setpoint signal converter; 6 – PC with MATLAB software; 7 – servo motor angle and speed measuring resolver type sensor.

Experimental measurements is done for several wind speeds from 2 m s^{-1} till 7.5 m s^{-1} with interval 0.5 m s^{-1}. In One wind speed is measured force for blade angles from – 90 ° till +90 ° with interval 9 °. In each angle position is 10 min long measurements. Data statistical analyse is done in MATLAB, data graphical analyse is done in MS EXCEL software.

III. RESULTS AND DISCUSSION

Experimental data was analysed using averaging of data within the measuring period of 10 minutes for each blade pitch angle setpoint. Graphical data analyse results shows that the aerodynamical force acting to the pitch system servo motor depends on the pitch angle and the wind speed. In Fig. 3. is shown that the aerodynamical forces in low pitch angles are small and close to ≈ 0 Nm. The range where experimental results shows small aerodynamical force is - 20 to 20 . Other researches shows information that VAWR with 3 blades of NACA0018 profile optimal tip speed ration (further in text TSR) is 3. In this case the VAWR optimal pitch angle range is -16 ° to + 16 °. That fits in range where active pitch system servo motor aerodynamical force perturbation is ≈ 0 Nm. But that does not mean that all time of VAWR control is one TSR. In case of VAWR start or stop the TSR can be much greater or smaller than optimal angle, what makes the pitching angles much higher and then the aerodynamical forces will increases at active pitch system servo motor.

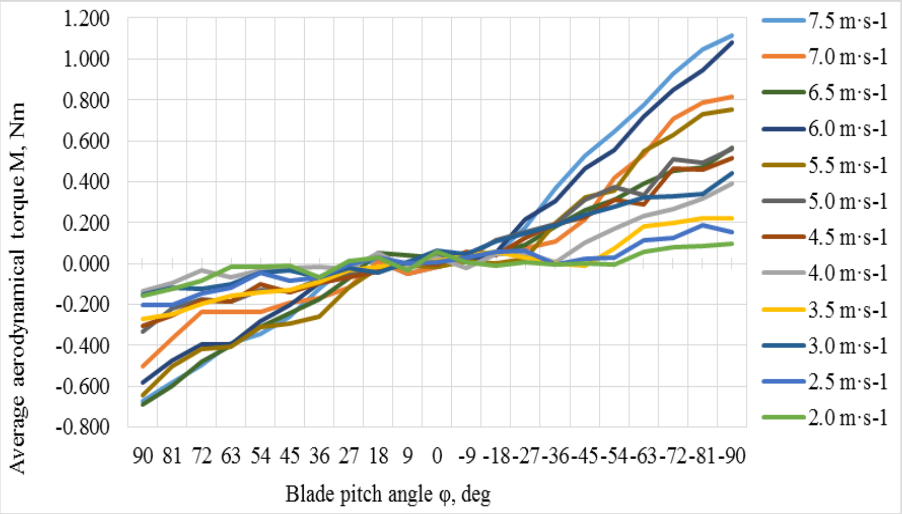

Fig. 3. Experimental average data of 10 min measurements with blade pitch angle from + 90 ° till - 90 °

Looking closer to data in Fig. 4. where aerodynamical force is as function of wind speed at each pitch angle set point. Experimental results show if pitch angle is in range -20 ° to + 20 ° then aerodynamical force acting on the pitch system servo motor is equal to ≈ 0 Nm. If pitch system angle is not more than ± 20 ° that means is not needed to use additional power for blade aerodynamical force overcome. In range where pitch angle is more than 20 ° the aerodynamical force grows as function of the pitch angle and the wind speed. Experimental results show that this aerodynamical force function is linear.

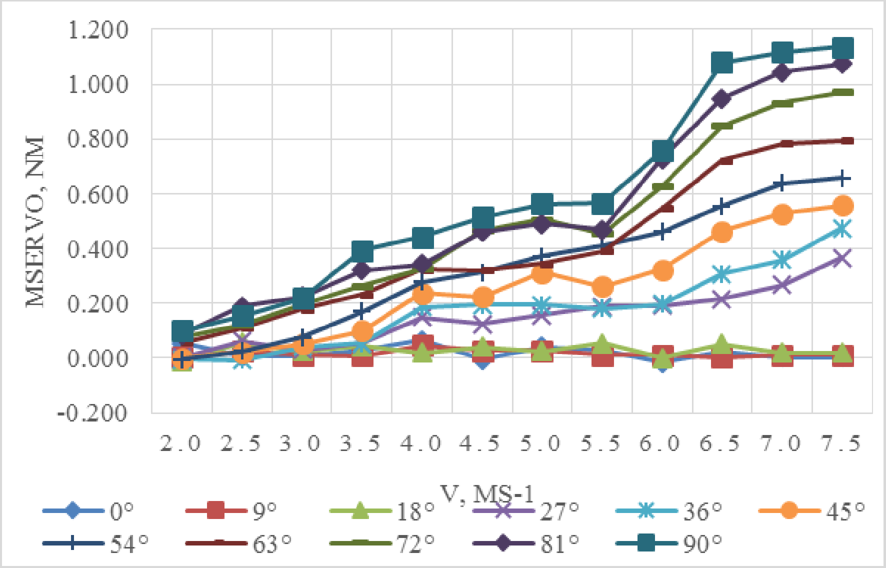

Fig. 4. Experimental average data of 10 min measurements with blade pitch angle from 0 ° till 90 °.

Aerodynamical force measurements at lower wind speed are with bigger scatting. That is result of the wind speed scatting in hand made wind tunnel. In Fig.5. is experimental results at wind speed 3.5 and 5.5 m s^{-1}. At this wind speed the aerodynamical force function are depending on the pitch angle range. In case the pitch angle is negative then function describing the aerodynamical force at servo motor is with determination coefficient R^2 = 0.8359 and R^2 = 0.974. In positive pitch angle range the determination coefficient is higher R^2 = 0.9721 and R^2 = 0.9721. Maximal reached value of aerodynamical force is 0.2 Nm at wind speed 3.5 m s^{-1} and 0.7 Nm at wind speed 5.5 m s^{-1}.

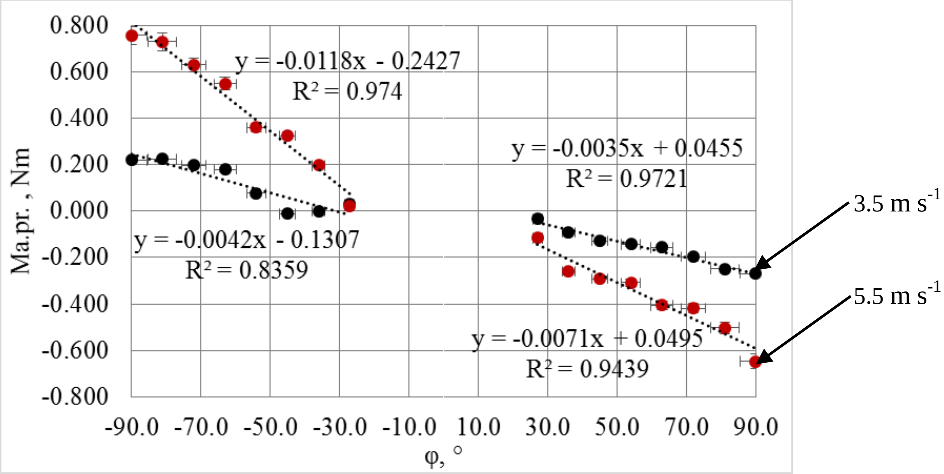

Fig. 5. Aerodynamical torque at servo motor as function of pitch angle $M_{a.pr.} = f(\varphi)$ with v = 3.5 and 5.5 m s^{-1}

In Fig. 5. Experimental data is with smaller scatting and the functions describing the aerodynamical force at pitch system servo motor is with higher determination coefficients 0.974 in negative range and 0.9439 in positive range. In both direction of pitch angle the functions is close symmetrical and that is right as the NACA0018 blade is symmetrical. Servo motor control with servo drive effects the measurements of the electrical torque of the servo motor. Servo motor in test bench is used in SYNCHRO mode what means the positioning algorithm target is follow master position what comes as analog signal [9]. In the position control mode there is small motor voltage and frequency scattering what effects a bit the scattering of the actual servo motor torque. That is reason why is important that the measurements are averaged and the servo drive positioning algorithm is stable and have smooth but fast position control.

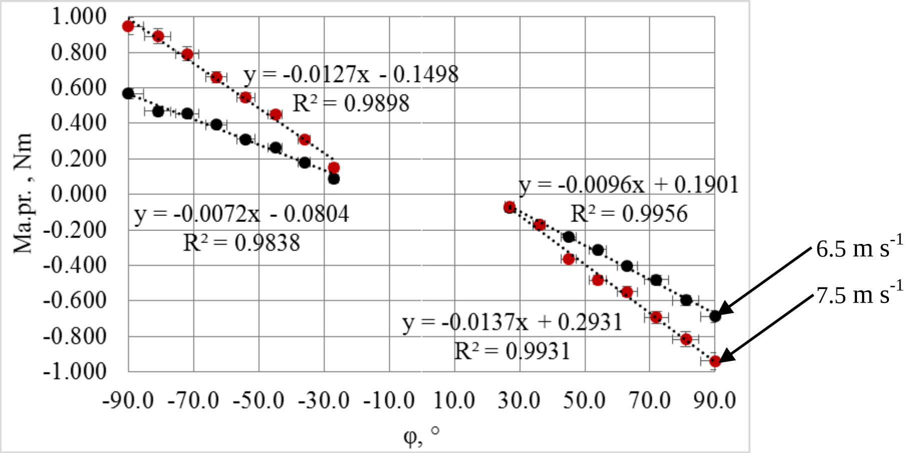

Fig. 6. Aerodynamical torque at servo motor as function of pitch angle $M_{a.pr.} = f(\varphi)$ with v = 6.5 and 7.5 m s^{-1}

In Fig. 6. is results from experimental results with wind speed 6.6 and 7.5 m s^{-1}. Experimental data is with small scatting and the function determination coefficients are higher than at lower wind speeds. Experimental results shows aerodynamical force linearity depending of the blade pitch angle. The maximal reaching aerodynamical force is 1 Nm for 0.4 m long blade. In case is used longer rotor blade as example 2 m with the same chord length then the aerodynamical force perturbation can reach till 5 Nm. Wind rotor blade pitch system pitch angle can reach over the ± 20 ° in case of VAWR control over nominal wind speed. In this case the wind linear speed is greater than the tip speed of wind rotor blade and the TSR is decreasing. That mean the pitching angle can increase and reach even 90 °. This is important condition to have additional active pitch angle servo motor power.

Experimental results show data for the experimental blade with length 0.4 m and blade chord 0.2 m. The blade chord 0.2 m passes for the blade length of around 2 m as blade chord should be about 10 % of blade length. In case of accurate aerodynamical force value calculation the linearization function output data must be multiplied with factor depending of the blade length.

IV. CONCLUSION

Experimental research data and results is important for pitch system servo motor power calculation. This research output functions of aerodynamical force perturbation can be used for calculation in other methods or mathematical equation or simulation models. Experimental results shows that VAWR active angle pitch system servo motor aerodynamical perturbation force is equal to ≈ 0 Nm when is used NACA0018 profile blade and pitching angle is ± 20 ˚. In experimental results is shown that the aerodynamical force is linear function of the blade pitching angle. To achieve this goal is important to set blade pitching centre 25% of blade chord distance from blade front. For VAWR blade active pitch system is important that the blade pitch centre is in one centre together with blade centre of gravity. In case if this condition is not fulfilled then on the blade because of high rotation can appear additional mechanical forces.

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