

Vertical axes wind turbine with permanent magnet generator emergency brake system simulation in MATLAB *Simulink*

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Abstract— Vertical axes wind turbines in the commercial market are used without pitch control systems and the special emergency systems should be implemented as main part in the system. The closer turbine is assembled to civil parts the safer turbine have to be. The simulations of the safety system can be useful part to get faster results and make lower costs for safety system calculations and tests. Simulation with MATLAB *Simulink* can be used for new braking system research for special VAWT. The research analyses the two braking system action on real VAWT simulation model. With new developed simulation models for emergency braking can be calculated and designed new brakes for VAWT. The simulation models works with electrical brake for PMSG and mechanical brake for low speed or high speed shaft. Simulation results for each brake type was tested with simulated signals and in the work with real turbine simulation model. The results showed that the simulation models are correct and achieved the target or the research.

Keywords— VAWT, MATLAB Simulink, Emergency brake, mechanical brake, simulation, electrical brake

INTRODUCTION

Vertical Axes wind turbines VAWT is used more and more all over the world. Global energy market makes useful to use wind turbine as an electric energy source [1]. Very much in worldwide is used the large size wind turbines and they are as far as possible from the living places or active people working zones. The VAWT is used more in the smaller scale and this makes the situation that the wind turbine is used in the places where it is more close to people [2].

Safety is the main topic of placing the wind turbine near, close, or at active people working, living zones. The closer wind turbine comes to people the more safety actions are needed. In the case to have turbine working just beside human house or kinder garden or shop or many other places in the city or village, people are concerned about the safety of themselves or they friends or relatives [3]. Many tests and analyses should be performed to prepare the wind turbine for the places to be near the people. Physical tests is the obligatory thing for every system to be produced, but before do the real actual tests on the system of the cases for the safety then many other pre-analyses and tests could be done [4].

Today we know many systems to work with for mathematical calculations or static analyse, but using MATLAB *Simulink* environment is option to test the real turbine action on some fail conditions. Using real turbine simulation model is possibility to test many safety features and system action on the specific safety process [5]. The safety always is related with functions stop as soon as possible, but because of the rotating parts of the VAWT the quick stop of the machine could make the bigger damages or even destroy the entire turbine system and make damages to human being [6].

The key of the work is to make simulation subsystem for turbine model with two main emergency stop systems, where one is mechanical and the second is electrical. The subsystem is tested and analysed by using the main simulation model of the VAWT. By the simulation results it will be possible to analyse the safety level for some specific turbine emergency brake system.

VAWT emergency system

VAWT as small and middle size wind turbine have many system forces and the components by whom is made total active torque (Fig.1.). In classic turbine process the system have two main torques. The positive torque is aerodynamically torque from the wind energy transferred into the turbine blades and the rotor what works as the source of the energy. Electrical load torque what is controlled by the MPPT controller works as normal braking torque with the function to generate as much electric energy as possible according the actual wind speed. In the normal brake condition the stop of the wind turbine is performs by the MPPT controller and it is done by using the energy by feeding the energy into the grid. In emergency case when the MPPT controller is not able to stop the turbine or is malfunction of the controller then emergency system condition triggers the two brake systems. According the specific algorithm the brakes can be used either together or separately. In normal conditions if the generator is not malfunction the system is

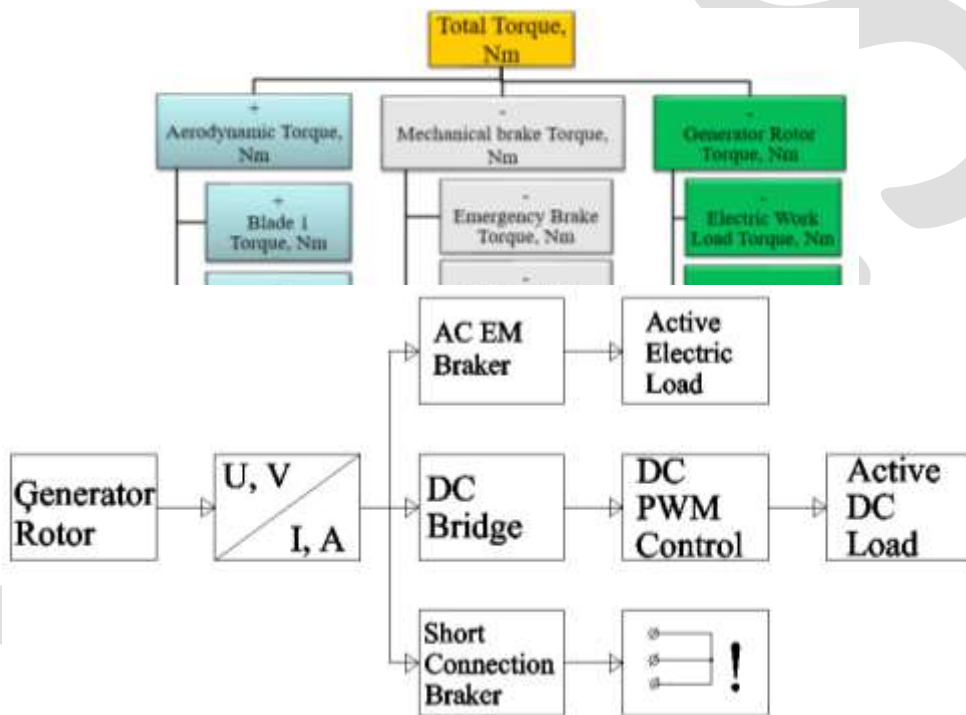
stopped with electrical brake, but very important note is that the simple electrical brake with active resistance can be used only if the wind turbine uses the permanent magnet synchronous generator. In this case with active resistor help is possible to achieve the maximal generator current and stop the turbine [7].

$$T_{sum} = T_a - ((T_{a.meh.}^1 + T_{a.meh.}^2) + T_{a.ele.isl.} + T_{sl.} + T_{a.ele.sl.}),$$

- where T_{sum} – total torque on the turbine shaft, Nm;
 T_a – total aerodynamic torque reduced on the blades, Nm;
 $T_{a.meh.}$ – mechanical emergency brake total reduced torque on rotation shaft, Nm;
 $T_{a.ele.isl.}$ – electrical short brake emergency brake reduced total torque on rotation shaft, Nm;
 $T_{sl.}$ – electric load on the generator shaft according the MPPT setpoint, Nm;
 $T_{a.ele.sl.}$ – electrical emergency brake reduced total torque on rotation shaft, Nm.

Fig.1. Wind turbine torque structure

According to the size of the active electric load the stop time will be reached. The bigger will be the size of the electric load the faster



turbine will be stopped, but important note is that generator cannot achieve bigger current than it's rated current, so that means that generator cannot achieve bigger torque than its rated torque. That is very important for understanding when the mechanical brake should trigger [8].

Mechanical brake trigger should be performed after not achieving needed turbine rotor speed ramp down time with electrical emergency brake system. That should make the main trigger for electrical emergency brake activation. The second trigger is when the malfunction is covered in the electric generator system. In that case the system should make emergency brake with mechanical brake. The important fact is that one turbine in best situation should have at least one emergency brake system. As now days is very popular to us PMSG in the wind turbine systems that makes ease way to use the electrical emergency brake system. But as every turbine have mechanical brake then make double brake system for one turbine sometimes can be too expensive.

Fig.2. Electrical emergency brake system structure

The electrical emergency brake system in normal situation is performed by the electric resistors where depending on the generator output voltage the emergency power is achieved (Fig.2.). Very important is to take into account that many active resistors nominal data information about the resistor power is shown at nominal voltage what means that in the moment when the generator speed is ramp down then the actual power of the emergency resistors is less than nominal. If the active resistors power is not calculated enough then can be situation that turbine is not stopped. The resistors can be over heated and the turbine can be damaged or destroyed [9].

Testing of the emergency cases in real life can be expensive and dangerous as well as the high wind conditions can be achieved not very often. This makes big challenge to test very accurate the emergency system work on the specific wind turbine model. The best way how to test the emergency system before real life final test is to make the test with the simulation system. The

usage of the MATLAB Simulink in this case would be very important as by help of the Simulink platform can be tested the system together under mathematical model in real time or non-real time simulation.

The Simulink model shown in the pictures is developed for accurate electrical emergency brake simulation (Fig.3.). The actual active torque from the electric emergency brake model is calculated by the transient process over generator current time constant what is calculated as electrical time constant of the generator taking into account the generator active phase resistance and the inductivity. Depending on the generator voltage and electrical brake active resistance the electric power is achieved P , W . but depending on the actual rotation speed of the generator the actual braking torque is calculated for the shaft of the turbine rotor.

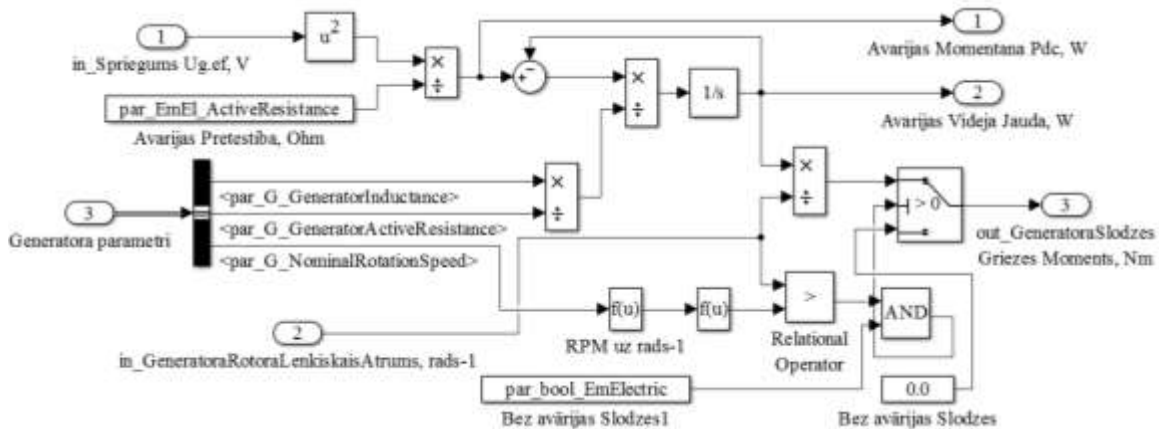


Fig.3. Electrical brake system *Simulink* model structure

In case of using the gearbox for the wind turbine rotor speed multiplication to generator then active braking torque should be reduced to the active shaft part where is calculated the active aerodynamical torque. If aerodynamical torque of the wind turbine model is reduced to the generator shaft then electrical braking torque is at the same point in the system with aerodynamical torque.

Mechanical brake MATLAB Simulink model is develop by using the transfer function for the torque transient process for the brake mechanical work (Fig.4.). Most of the mechanical brakes is designed by using the electrical actuators. The transient process of the mechanical system to achieve the maximal system brake torque depends on the speed of the system mechanics. After emergency is triggered the mechanical emergency brake start command is triggered and the mechanical brake system starts to apply the brakes. That takes time and for wind turbine very fast stop is not good as that can damage the wind turbine system. The mechanical emergency system should achieve the maximum braking torque in limited period of time.

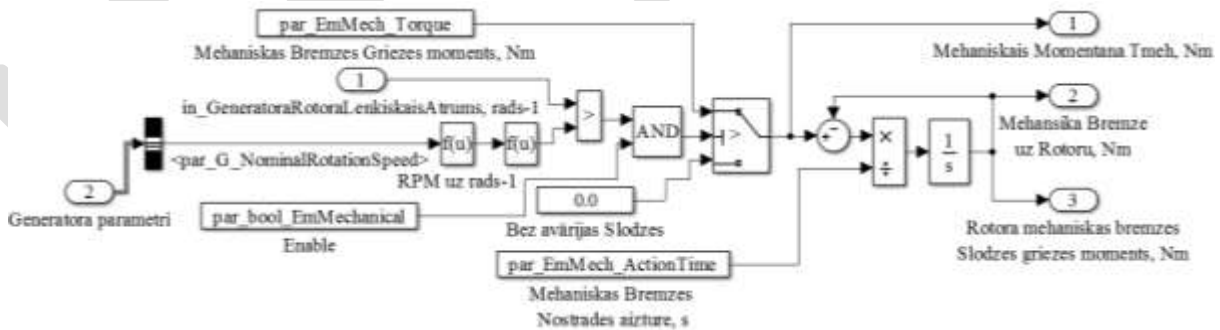


Fig.4. Mechanical brake system *Simulink* model structure

VAWT emergency system simulation result analyse

System model simulation is done first of all testing the each system simulation model separately and after that setting the emergency systems in to the VAWT simulation model to test the emergency system simulator. The first test is the electrical emergency brake system simulation with constant electrical voltage and constant generator electrical parameters. The emergency trigger is triggered at time $T=0.018$ when generator speed goes over rated rotation speed. The simulation

measurement's shows how depending on the size of the active resistance of the emergency brakes changes the transferred output power of the brake system (Fig.5.). Simulation results shows that the electrical simulation model is correct and can be used in the total VAWT system model.

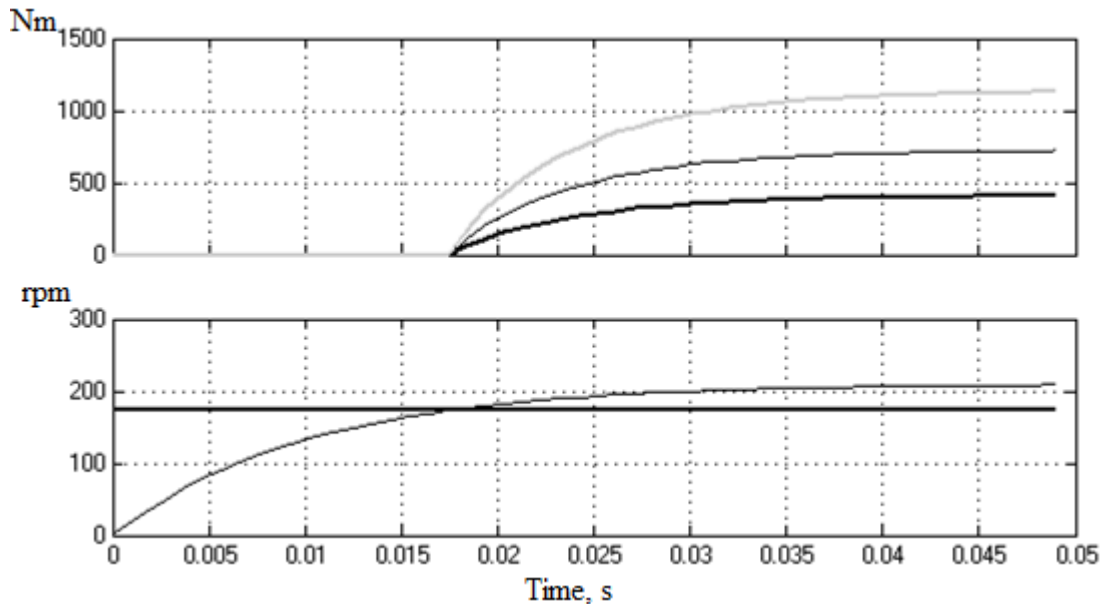


Fig.5 Electrical brake system simulation results with simulated input signals

Mechanical emergency brake system simulation model is simulated with emergency trigger at time $T = 0.18$ when generator is going in over speed mode. The system is mechanical closing the brake pads and the torque is achieved after the brake actuator is at the end position. Simulation results shows the system work at three different mechanical brake work time but the same maximal toque. The more actuator time is needed the later the maximal torque is achieved what is shown over the simulation records in the scope (Fig.6.). The simulation results shows that the developed mechanical emergency brake simulation model is correct and can be used for total VAWT simulation in simulation model.

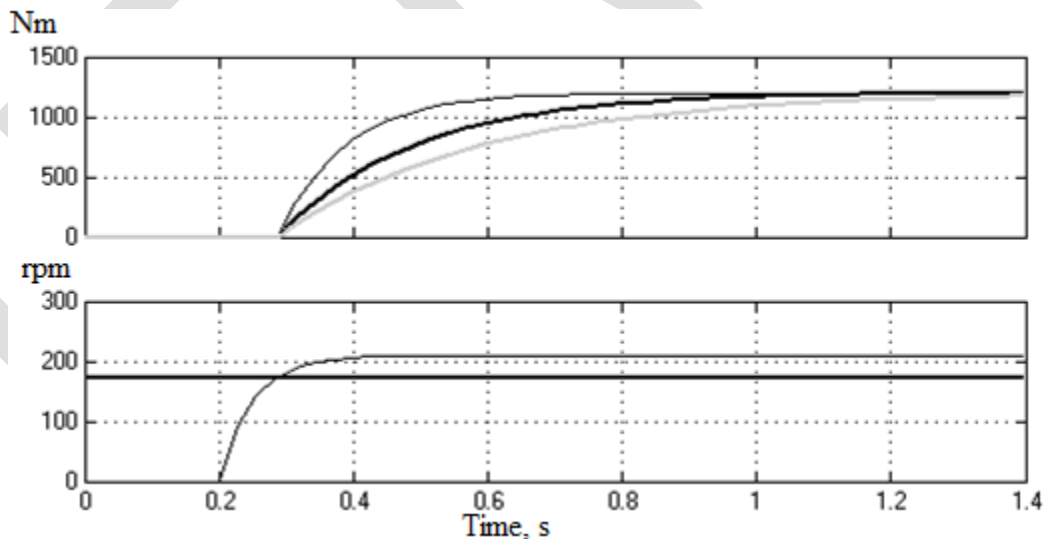


Fig.6 Mechanical brake system simulation results with simulated input signals

VAWT simulation model is developed and described in many other papers and researches for VAWT system simulation. The main goal for using developed simulation model is that the simulation model will show more accurate the new developed emergency braking systems models. Usage of not appropriate VAWT simulation model can give wrong results at the emergency system model verification what is important to be tested with as accurate as possible as the subsystems can be used for another wind turbine simulations.

First simulation is done by testing the electrical brake. As electrical brake theoretically can achieve big electrical brake torque but physically that cannot be more then generator maximal electrical torque. The VAWT simulation model is sated up with

generator maximal torque 1248 Nm and the gearbox ratio $i = 4.28$. The emergency system is triggered in the time $T = 5$ s.

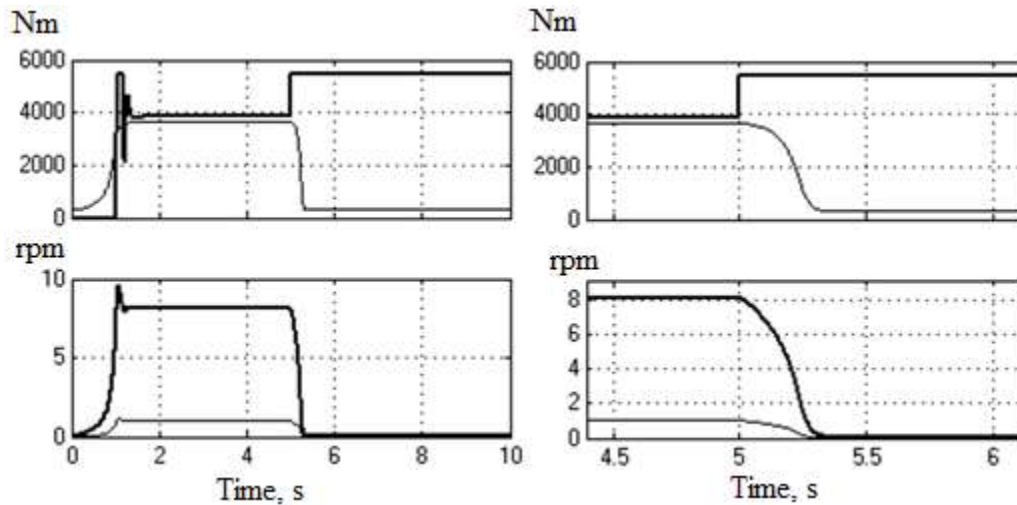


Fig.7 Electrical brake system simulation results integrated in VAWT simulation model

Simulation recorded results shows the system ability to stop the wind turbine with the simulated electrical brake with active resistance $R = 1 \Omega$. As the turbine simulated Inertia was $250 \text{ kg} \cdot \text{m}^2$ then the turbine was stopped in 0.35s. In the time of stopping the turbine the turbine TSR is decreasing and the C_p is getting lower what makes the aerodynamic torque decrease on the wind turbine rotor. The braking torque achieved on the generator is at maximal generator torque and reduced to the rotor slow speed shaft that is 5341 Nm (Fig.7).

Simulation test for the mechanical emergency brake system was performed with the same VAWT simulation model and the same turbine settings and wind speed simulation. The mechanical brake was triggered at time $T = 5$ s. The Maximal brake system torque was 10000 Nm and the brake was assembled on the high speed shaft of the wind turbine.

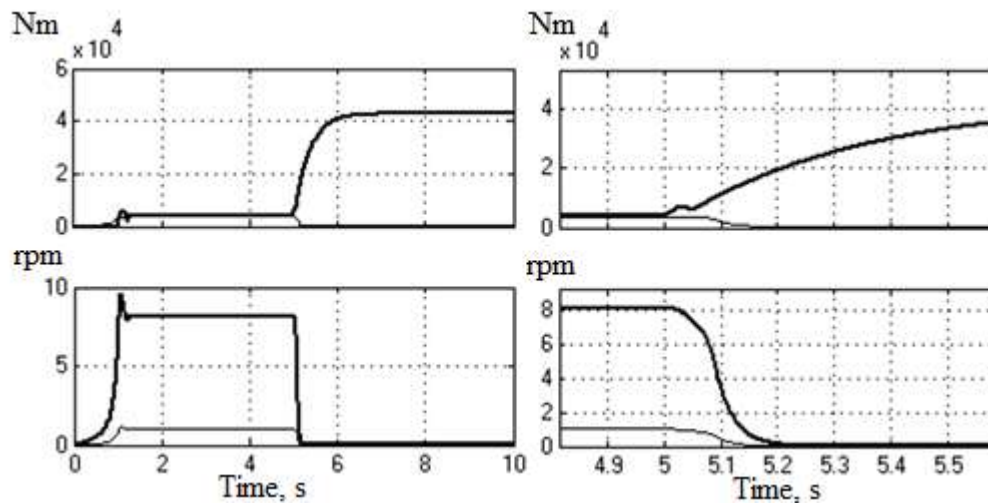


Fig.8 Mechanical brake system simulation results integrated in VAWT simulation model

Simulation recorded results shows that with this type of mechanical brake system with closing speed 1 s achieved the maximal torque with in 1s and reduced brake torque on the low speed shaft was 42 800 Nm, what stopped the wind turbine with in 0.2s (Fig.8.). what makes the conclusions for this turbine simulation that this turbine don't need so high torque wind turbine as the turbine stopped already at time 0.2s and the brake maximal torque was achieved in time 1s. That means the brake maximal torque can be reduced as minimums for 50%.

Both real VAWT simulation results with emergency brakes showed that the developed new simulation models for the emergency brakes are accurate and can be used in other VAWT or HAWT simulation models.

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CONCLUSION

Developed MATLAB *Simulink* models shows that the simulation of the VAWT model with emergency brakes is correct and can be used in further emergency equipment tests and developments and used for final engineering calculation test. Simulation model used for emergency system simulation and mathematical test is flexible and easy to use without additional risk to destroy the equipment or attack to the human health what is the most important point in case of system failure. Simulation model is higher level testing solution comparing to the static mathematical calculation. Simulation model gives option to test system in dynamic and with variable process perturbations and system actions.

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