

Modeling of Hybrid Systems with Renewable Energy Sources for Smart Home

Gergana Vacheva

Department of Power Electronics
 Technical University of Sofia
 Sofia, Bulgaria
 gergana_vacheva@tu-sofia.bg

Bogdan Gilev

Department of Mathematical Modelling
 and Numerical Method
 Technical University of Sofia
 Sofia, Bulgaria
 b_gilev@tu-sofia.bg

Nikolay Hinov

Department of Power Electronics
 Technical University of Sofia
 Sofia, Bulgaria
 hinov@tu-sofia.bg

Abstract—In this research a mathematical model of a hybrid system with wind generator and supercapacitor for supplying a smart home is realized. The model is described with the aid of differential equations. The simulation and numerical results are presented. The model is developed in MATLAB/Simulink environment.

Keywords—hybrid system, smart home, renewable energy.

I. INTRODUCTION

In this research the hybrid power system with wind generator and supercapacitor for supplying a smart home is presented. The basic idea is to use the supercapacitor an element for energy storage.

Basically, a wind generator (WG) consists of a wind turbine, a gear and an electric generator. The generator is connected to the basic system both ways: directly or with a frequency conversion system. When connected directly to the basic, the speed is fixed by the mains frequency, while operating with a frequency converter, the rotor speed is variable.

Classic control systems with PID controllers have been applied to several large WGs since the 1970s and 1980s. Most WGs of that time were at a constant speed and had solid transmissions and rotors with high inertia. It has been found that wind turbulence easily excites the first natural frequency of the first natural form of transmission torsion. Control systems since that time have sought to regulate power while dampening the first natural frequency by changing the angle of attack of the blades [1]. For this purpose, high-speed attack angle control systems operating in the frequency range [0.2, 2] rad/s [2] were used. These systems lead to a satisfactory reduction of the load from low-frequency wind disturbances. However, it turned out that another control system was needed to reduce the vibration of the structure caused by high-frequency wind disturbances. Most modern VGs have variable speed because they have two main advantages. They generate the maximum possible output power and use a slower control system for the angle of rotation of the blades [3].

II. MODEL OF THE TURBINE

Normally distributed random signal (white noise) with a constant component (representing the average wind speed) is added and passed through Kaimal filters and smoothing harmonic filters. A timeline simulating wind speed is the result Figure 1 in [4].

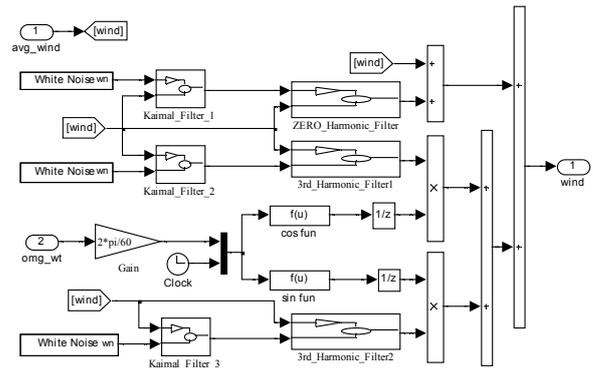


Fig.1 MATLAB-Simulink module for wind speed generation via Kaimal filter

In Figure 2 a block scheme of the system is presented. It consists of wind generator, rectifier, supercapacitor and load.

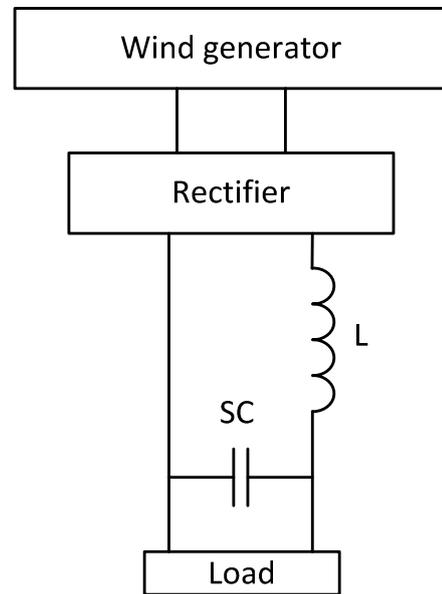


Fig.2 Block scheme of the system

A. Model of the turbine

The turbine torque can be approximated by a nonlinear dependence. After conversion into relative units, this dependence takes the form [5]:

$$T_m = -\frac{(V/V_{nom})^3 (C_p(\lambda, \beta)/C_{p,nom})0.9}{\omega_r}, \quad (1)$$

where

- $\lambda = \frac{(\omega_r / \omega_{r,nom})(V_{nom} / V)}{\lambda_{nom}}$ - ratio of the blade speed
- $C_p(\lambda, \beta) = 0.5176\left(\frac{116}{\lambda_1} - 0.4\beta - 5\right)e^{\frac{0.0068}{\lambda_1}} + 0.0068\lambda$,
for $\frac{1}{\lambda_1} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$;
- V - wind speed;
- ω_r - angular speed of the turbine;
- R - radius of the turbine;
- C_p - efficiency;
- β - pitch angle of the turbine blade;
- T_m - torque of the turbine;
- $A = \pi R^2$;
- ρ - density of the air;

III. MODEL OF THE ELECTRIC MOTOR

The mechanical part of the electric generator and the gear box are modeled entirely. For this purpose, the torque of the turbine shaft is brought to the moment of the shaft of the electric generator and a single-mass model is obtained. The electrical part of the generator is modeled separately.

A. Single-mass model

The presented model can be described with the following equation[5]:

$$\begin{aligned} \frac{d\omega_r}{dt} &= \frac{1}{2H}(-T_m + T_e - F\omega_r) \\ \frac{d\theta}{dt} &= k\omega_r \end{aligned} \quad (2)$$

where

- k - is a gear ratio;
- H - inertial constant;
- F - friction coefficient;
- T_e - electrical torque of the generator;
- T_m - mechanical torque of the turbine.

B. Model of the electrical part of the generator

An asynchronous generator with a wound rotor (asynchronous generator with rotor and stator power supply) is modeled [5].

The input voltages are normalized

$$\begin{aligned} u_{ab} &= U_{ab} / U_1 \\ u_{bc} &= U_{bc} / U_1 \end{aligned}, \text{ where } U_1 = 470 = \frac{575\sqrt{2}}{\sqrt{3}}.$$

After that the voltages are presented with the aid of the d - q axes (Park's transformation)

$$u_{qr} = \frac{1}{3}(2u_{ab} + u_{bc})$$

$$u_{dr} = -\frac{\sqrt{3}}{3}u_{bc}$$

$$u_{qs} = \frac{1}{3}(2u_{ab} \cos \theta + (\cos \theta + \sqrt{3} \sin \theta)u_{bc})$$

$$u_{ds} = \frac{1}{3}(2u_{ab} \sin \theta + (\sin \theta - \sqrt{3} \cos \theta)u_{bc})$$

where θ is defined by (2).

The flows in the rotor are

$$\frac{d\Phi_{qr}}{dt} = k \left(u_{qr} - \Phi_{dr}(\omega - \omega_r) + \frac{R_r}{L_r} \Phi_{qm} - \frac{R_r}{L_r} \Phi_{qr} \right)$$

$$\frac{d\Phi_{dr}}{dt} = k \left(u_{dr} + \Phi_{qr}(\omega - \omega_r) + \frac{R_r}{L_r} \Phi_{dm} - \frac{R_r}{L_r} \Phi_{dr} \right)$$

$$i_{qr} = -\frac{1}{L_r} \Phi_{qm} + \frac{1}{L_r} \Phi_{qr}$$

$$i_{dr} = -\frac{1}{L_r} \Phi_{dm} + \frac{1}{L_r} \Phi_{dr}$$

where $R_r = 0.005 pu$, $L_r = 0.156 pu$, $\omega - \omega_r = 0$

The mutual flows are

$$\Phi_{qm} = \frac{L_q}{L_r} \Phi_{qr} + \frac{L_q}{L_s} \Phi_{qs}$$

$$\Phi_{dm} = \frac{L_d}{L_r} \Phi_{dr} + \frac{L_d}{L_s} \Phi_{ds}$$

where $L_s = 0.171 pu$ and $L_q = L_d = 0.0793 pu$

The above currents and flows are use to calculated electrical units is electrical torque

$$T_e = \Phi_{qs} i_{ds} - \Phi_{ds} i_{qs} \quad (3)$$

This torque takes part as external influence in (2).

IV. PID CONTROLLER

The generated wind energy strongly depends on the wind speed, therefore during strong wind the maximum generated output power is bigger than the nominal power of the wind generator. Therefore, the wind power generation must be limited to ensure no-load operation. A very efficient method for limiting the generated wind energy is to change the slope of the rotor blades around their longitudinal axis (change the pitch angle).

V. FULL MODEL OF THE SYSTEM IN MATLAB/SIMULINK

In order to teach the model of the whole system in Simulink-MATLAB environment, the models of the turbine, the gear, the generator and the PI controller and the load are combined, fig.3.

The model of the wind speed from point two is placed in the block "Wind Model ZA-2". The average wind speed is fed to the input of this unit, and a random realization of this speed

is obtained at the output. The turbine model is placed in the "Wind Turbine" block. The model of the electrical part of the generator and the single-mass model are located in the block "Asynchronous Machine".

VI. SIMULATION RESULTS

In Fig. 4. the load current, the current of the supercapacitor and the bus current are presented. It can be observed that when the curve of the load increase, the supercapacitor operate in

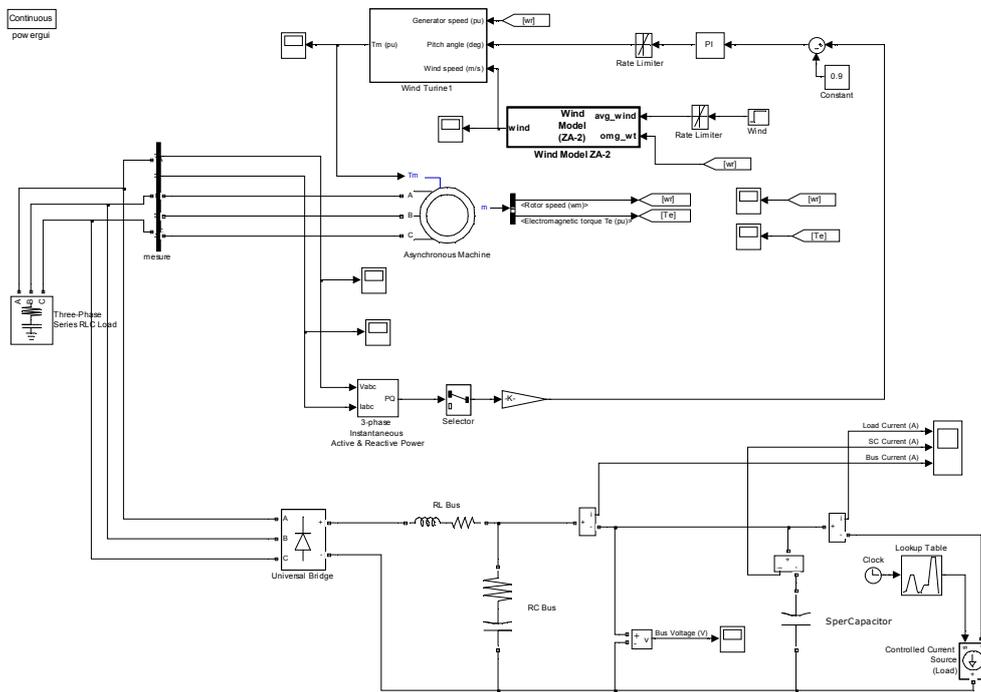


Fig.3. Block scheme of the system in Simulink-MATLAB

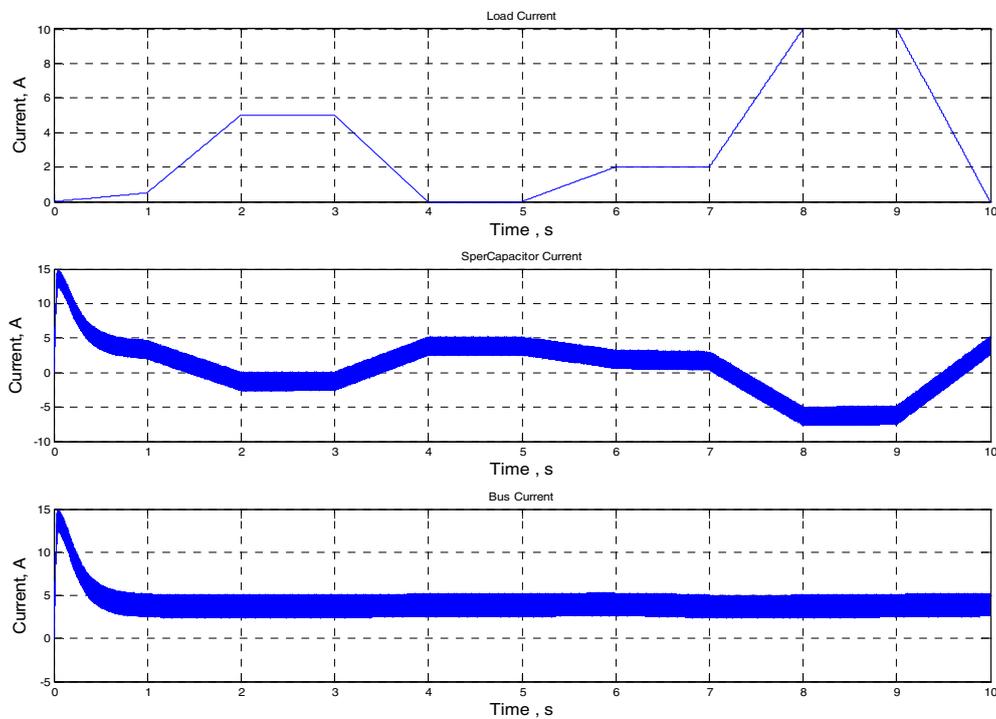


Fig.4. Load current, current of the supercapacitor and bus current

discharging mode. The curve of the bus current is nearly to constant value.

In Fig. 5. The voltage of the generator and the voltage of the supercapacitor are presented.

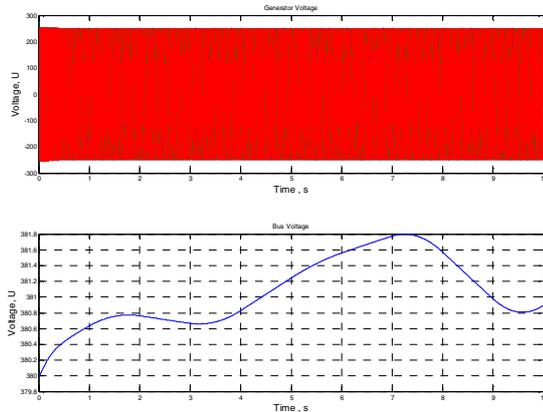


Fig.5. Generator voltage and supercapacitor voltage

VII. NUMERICAL RESULTS

In the model of the turbine are used the following data $\lambda_{nom} = 8,1$, $V_{nom} = 9 \text{ m/s}$, $C_{p,nom} = 0,48$ and $\omega_{r,nom} = 1 \text{ pu}$. In the one mass model the data are $k = 377$, $H = 5,04 \text{ kg.m}^{-2} \cdot \text{rad}^{-2}$ and $F = 0,01 \text{ pu}$, and in the mast model the used data are $\omega_0 = 7,74 \text{ s}^{-1}$, $n = 0,008 \cdot \omega_0$, $m = 400 \text{ kg}$, $M = 20000 \text{ kg}$, $l = 72 \text{ m}$ and $EJ = 10^{10} \text{ Nm}^2$. The modeled asynchronous generator has nominal power equal to $S = 2,1,5 \text{ MVA}$, interphase voltage $U = 575 \text{ V}$ and frequency equal to $f = 60 \text{ Hz}$.

VIII. CONCLUSION

In this research a mathematical modelling of a hybrid system including wind generator and supercapacitor for application in smart home are realized. The basic idea of this study is to use the wind generator for supplying loads with maximal power of 10 kW. When the necessary energy is not enough it is used a supercapacitor for providing the absent power. Similarly, the redundancy of the energy can be stored in the supercapacitor. The proposed solution is suitable for supplying lighting, cooling, heating and others in smart home.

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