ELECTRICAL ENERGY STORAGE SYSTEM FOR WIND TURBINES

Marius C. Georgescu
Transilvania University of Brasov
29, Bd. Eroilor, Brasov
Romania

ABSTRACT
Energy storage devices and solutions are required for power quality and balance within wind systems. In the context of rapidly expanding of distributed energy sources, the wind energy converters are in the center of interest. In this case, the direct dependence of the power generation capability for a given wind speed represents a major problem of wind energy conversion with regard to large-scale network integration. This paper proposes an overall solution which consists of a wind plant with a smart Storage Modular System (SSMS) where the wind source -as stochastic one- is coupled over a dc bus with two storage modules and a smart grid interface.
Keywords: distributed generation, energy storage, flow batteries, flywheels.

1. SYSTEM DESCRIPTION
Based on the Kai Strunz concept of Stochastic Energy Source Access Management (SESAM) introduced in [1], and in order to solve the conflict between the stochastic nature of the energy source and the need to schedule the power output, the authors proposed a Smart Storage Modular System (SSMS) able to work for a small wind turbine in networking conditions and for insulated loads.
The general block diagram of the SSMS for a small wind farm is presented in Fig. 1.

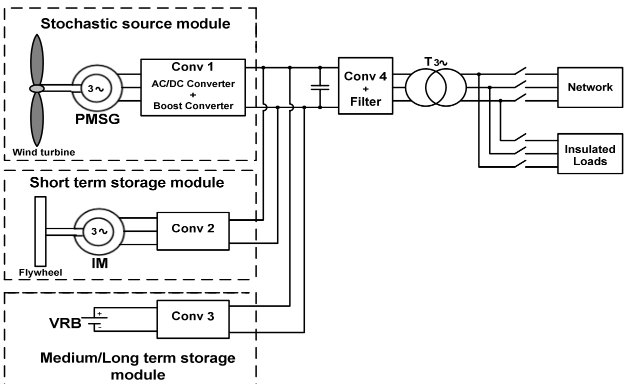

Figure 1. Block diagram of the SSMS for wind systems.

As results from the figure, the SSMS consists in the following main three modules:
- Stochastic Source Module (SSM) which comprises the renewable energy source (wind) with stochastic output;
- Short Term Storage Module (STSM) based on a flywheel with Induction Motor (IM);

• Medium/Long Term Storage Module (MLTSM) based on a Vanadium Redox flow Battery (VRB).
An auxiliary module (Converter 4 + Filter + Transformer) is represented by the Grid Interface Module (GIM) and provides connections with the main network and the insulated loads. It allows in addition both the active power transfer and the reactive power generation. The whole SSMS is managed by a Global System Control (GSC) which automatically controls all the modules through local control units (LCU) and is based on fuzzy logic algorithms. All the modules are interconnected through a dc bus. The active power and reactive power outputs to the grid are adjusted by the GIM. The GSC is hierarchically structured being associated with the LCU controllers. The GSC and LCU maintain by control the desired value of the dc bus voltage across the capacitor in order to obtain the desired output power value. The designed SSMS includes the following desirable features: based on renewable energy, active & reactive power deterministic generation, clean energy, good controllability and efficient maintenance costs.
The SSM comprises the following parts: a) the wind energy source with stochastic output; b) the Permanent Magnet Synchronous Generator (PMSG) and c) the power Converter 1.
To describe the wind energy source with stochastic output is considered an aerodynamic wind mathematical analysis based on the following main parameters:

- aerodynamic wind power

$$P_W = \frac{1}{2}\rho\pi R^2 v_{weq}^3 C_p(\lambda,\beta), \quad (1)$$

- aerodynamic torque

$$T_W = \frac{1}{2}\rho\pi R^3 v_{weq}^2 C_p(\lambda,\beta)/\lambda, \quad (2)$$

- tip speed ratio

$$\lambda = \frac{\omega_{WTR} \cdot R}{v_{weq}}. \quad (3)$$

where ρ is the air density, R the rotor blades lenght, v_{weq} is the equivalent wind speed, λ is the tip speed ratio, $C_p(\lambda,\beta)$ is the performance coefficient, β is tilting angle of wind turbine rotor and ω_{WTR} is the angular velocity of the rotor blades. The wind generator rotates with a variable speed and generates a variable power which strictly depends on the wind speed. Taking into account the speed/time characteristic of the wind generator, for a short time in the absence of storage system [7] , and the wind mathematical model Kaimal [2,3] it was depicted the aerodynamic model in Matlab/Simulink, as shown in [7]. Another important parameter for the wind turbine is the power curve as relationship of C_p and λ wich is represented in the Fig. 2.

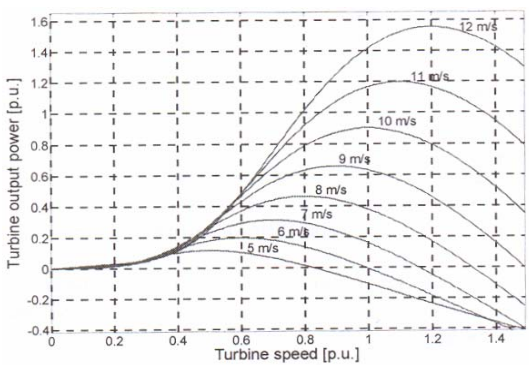

Figure 2. Wind turbine power characteristic.

For a given wind speed, the power captured by the wind turbine highly depends on C_p . Usually the power curve characteristics are included in the warranty assessement procedures as part of the wind plant commissioning. The PMSG is equiped with permanent magnets and has not damper windings.

For this application is used a salient pole PMSG with the model in rotor oriented axis and the currents as state variables [4,7]. The power Converter 1 consists in a diode rectifier and a boost converter. To maximize the wind turbine output power and adjust the PMSG speed, a Maximum Power Point Tracking (MPPT) control is used [5]. Depending on the wind speed, the MPPT control adjust the power transferred to bring the turbine operating points onto the maximum power curve, as shown in the Fig. 2. This leads in changing the angular velocities ω_{WTR} in order to generate ac voltages at different frequencies. The PMSG ac waveforms are rectified in the diode converter. The boost converter (buck chopper) helps to obtain the dc bus desired voltage. Here, the capacitor is an energy buffer for the generator.

The STSM consists in a flywheel that stores kinetic energy, based on the following equation:

$$E_k = \frac{J\omega^2}{2}, \quad (4)$$

where J is the flywheel inertia which rotates with the angular speed ω.

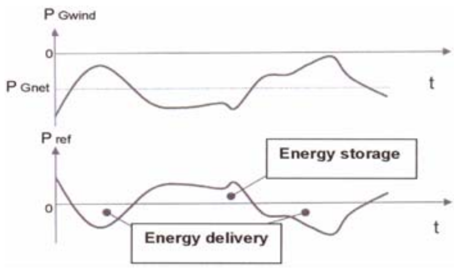

Figure 3. Waveforms to control the system flywheel -wind generator.

As indicated in Fig. 1, the Induction Motor (IM) is suitable to convert the electromechanical energy in accordance with the following waveforms (Fig. 3), where $P_{G\,wind}$ is the power provided by the wind generator (as known one), $P_{G\,net}$ is the power which is provided by the flywheel into the network and the P_{ref} is the reference power, calculated as follows:

$$P_{ref} = P_{Gnet} - P_{Gwind}. \quad (5)$$

If $P_{ref} > 0$, means that exists energy in excess which can be storred. If $P_{ref} < 0$, a lack in energy exists and it will be replaced by the storred energy. To control the IM, a DTC control scheme has been considered and implemented in the laboratory, as shown in [6,7]. The DTC is used to control the IM, because is estimated a meaning of 50% decrease in calculus time of DSPs comparable with the vector control method. The dc bus current is supplied by the Converter 2, a PWM-VSI one and is necessary to have a correct estimation of it because determines the voltage V_{dc} value which must kept constant.

The MLTSM is based on the Vanadium Redox Batteries (VRB) as storage source and the Converter 3 which provides a constant dc voltage to charge/discharge the battery. The block diagram of VRB system configuration, the control mode of the bidirectional charge controller and Simulink modelling are presented in [3,5,7]. Because the charge controller, included within the Converter 3, has been modeled as a lossless device, the VRB current is calculatet as follows:

$$I_{VRB} = \frac{V_{DC} \cdot I_{DC}}{V_{VRB}}, \quad (6)$$

where V_{DC} is the dc voltage at the output of the buck-bust converter (included in Converter 1), I_{DC} is the dc bus current and V_{VRB} is the VRB voltage.

2. PRACTICAL RESULTS

The proposed system has been mathematical modeled and computer simulated using the Matlab/Simulink software package. To validate modeling and computer simulations, by practical results, a test laboratory bench was built in the laboratory. It consists in :

- wind turbine simulator: IM motor of 3 kW, 1500–3000 rot/min controlled by a dSPACE system

DS1103;

- PMSG of 3 kW, 3000 rot/min, 8 poles, R_S = 0,11 Ω, $L_d = L_q$ = 0,97 mH, Ψ_0 = 0,1119 Wb, T = 27,3 Nm. It is lead by a DC motor and controlled by a dSPACE system DS1103
- flywheel which consists in an IM of 3 kW at 1500 rot/min controlled by a PWM inverter and using DTC for a maximum dc bus of 400-420V. The flywheel inertia is of 0,15-0,65 kgm^2. The flywheel is controlled by a dSPACE system DS 1104.
- VRB system has been replaced in the laboratory of Transilvania University of Brasov by a lead acid battery bank of 56kV/112A, 6kW.

Based on the VRB mathematical and Matlab/Simulink implemented models, are presented computer simulation results [7]. As example, at constant wind speed of 10 m/s, the turbine power of 3 kW can't supply the total power of 4 kW requested by loads. Figure 4 shows that the difference of power is supplied by the charging/discharging operating modes of VRB, which is able to maintain the power balance of the system.

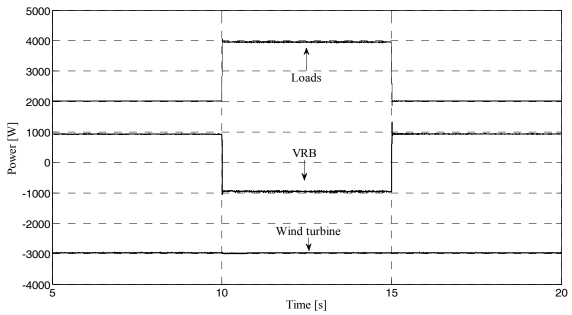

Figure 4. Power balance of the system provided by the VRB.

The VRB parameters for the maximum State of Charge (SOC) are 56 V/112 A/6 kW.

3. CONCLUSION

This paper presents a smart storage system designed and used for a wind farm, which has a modular and flexible structure. It is able to deliver power in standard networks by using as storage module a flywheel. For insulated loads the system uses as storage module a VRB one. The power transfer between the individual modules is performed over a dc bus. Through this multi-level system deterministic wind power output to the grid is made possible in different time frames. All the modular setup is controlled by a smart general system based on fuzzy logic algorithms. This one provides efficient coordination and reduces the costs.

4. REFERENCES

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