Sustainable Energy, Grids and Networks 5 (2016) 148–155

Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

journal homepage: www.elsevier.com/locate/segan

Savonius rotor based grid connected hydrokinetic power generation scheme

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ARTICLE INFO

Article history:
Received 1 April 2015
Received in revised form
17 October 2015
Accepted 14 December 2015
Available online 23 December 2015

Keywords:
Savonius rotor
Asynchronous generator
Hysteresis current controller
Current-controlled voltage source inverter

ABSTRACT

In this paper, a grid connected hydrokinetic power generation scheme with asynchronous generator coupled to Savonius rotor is presented. The Savonius rotor acts as prime mover to the asynchronous generator and thus, the proposed scheme presents a system with variable input power similar to that of a wind energy conversion system. In order to mitigate the effect of changes in input power to the generator and resulting variations in utility voltage and frequency which affects the system performance, an AC–DC–AC converter with a dc link capacitor is designed and modeled. The operation of the power converter is realized by decoupled d–q control method. A Matlab/Simulink model of Savonius rotor, asynchronous generator, power converter, LCL filters and control schemes is presented. The proposed scheme is tested under various load conditions under varying input power and the performances are observed to be satisfactory.

1. Introduction

Savonius rotor which is commonly used as wind turbine is a unique fluid mechanical device which works on drag effect mechanism rather than lift mechanism as in the case of rest of the wind turbines. Compared to all other wind turbines, it has a low power coefficient. However, considering setting of influence condition with shield plate, the power coefficient, C_p of Savonius rotor with water as a medium can be increased up to 0.47 compared to C_p of around 0.14 in case of wind system [1]. The rotor has a high starting torque and therefore, suitable for hydrodynamic applications [2]. These findings clearly show that Savonius rotor can be effectively used to generate power using hydrodynamics rather than aerodynamic concept. Generation of electricity using flowing river water is a good option as it does not require construction of dams or water storage system. The generating scheme uses the kinetic energy of natural flow of river water requiring zero head rotors. Another advantage of flowing river or stream water is that the water density is about 835 times denser than air, so for the same swept area, the available power in water current is 835 times that of wind flow of the same speed [3]. As the speed of free flowing river water is not constant but varies due to available volume of water, river span and depth of the river, a machine side converter is needed to mitigate the effect of changes in input power to the generator. Similarly, the effect of variations in utility voltage and frequency under different load conditions at the grid side may be controlled using another power converter appropriately placed. The utility grid acts as the main source of reactive power to the asynchronous generator.

In this paper, an attempt is made to generate tangible power from free flowing river water using Savonius rotor, and connect the system with utility grid. The Savonius rotor acts as prime mover to the asynchronous generator and thus, the proposed scheme presents a system with variable input power. In order to mitigate the effect of changes in input power to the generator and variations in utility voltage and frequency which affects the system performance, an AC–DC–AC converter with a dc link capacitor is designed and modeled. The schematic diagram of turbine-generator and grid system is shown in Fig. 1.

2. Savonius rotor

Savonius rotor is a high solidity rotor. It is simple and easy to construct and can be implemented in any suitable locations [4]. A typical Savonius rotor is shown in Fig. 2. The drag coefficient of the concave surface is larger than the convex surface, thus forcing the rotor to rotate. It generates much higher starting torque compared

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http://dx.doi.org/10.1016/j.segan.2015.12.004

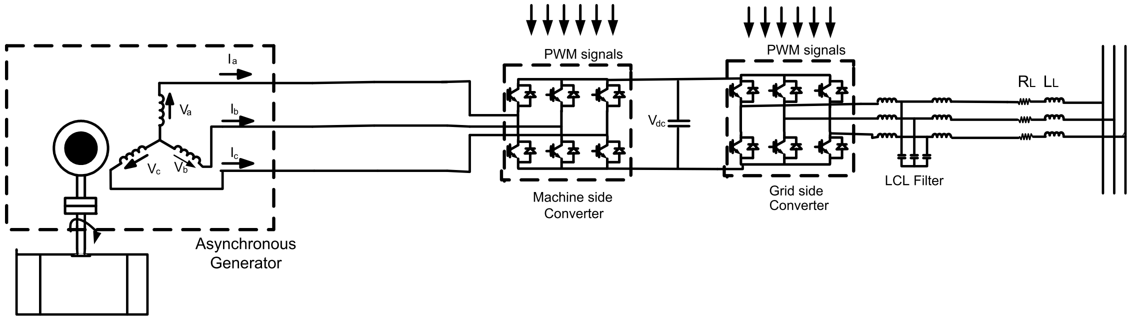

Fig. 1. Schematic diagram of turbine-generator and grid system.

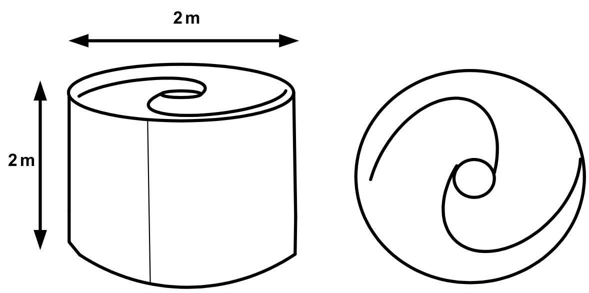

Fig. 2. Savonius rotor.

to other vertical axis turbines [5]. This type of turbine is self-starting and provides high torque at low speeds. The power output is given by [6]

$$P = 0.5C_pA\rho V^3 \tag{1}$$

where, P is power output (W), ρ is the density of water (kg/m^3), $A(=1/2\ 2 \times \pi \times D/2 \times H)$ is the swept area of rotor (m^2), V is the velocity of water (m/s) and C_p is the power coefficient.

The peripheral rotor velocity is

$$U = \omega \times R. \tag{2}$$

Tip speed ratio is given by

$$TSR = \frac{\omega D}{2V} \tag{3}$$

where, ω is the angular velocity, D is rotor diameter (m) and V is water velocity (m/s). Coefficient of torque (C_t) is given by

$$C_t = \frac{C_p}{TSR}. \tag{4}$$

Here C_p is taken as 0.25.

Shaft torque (T_{sh}) is given by

$$T_{sh} = \frac{P}{\omega} = \frac{0.5\, C_p\, A\, \rho\, V3}{2\Pi N/60}. \tag{5}$$

Fig. 3 shows the schematic diagram of generating unit consisting of turbine and asynchronous generator. The water velocity is initially assumed 1.40 m/s. At time $t = 0.3$ s it is increased to 1.5 m/s; at instant $t = 0.5$ s it is reduced to 1.48 m/s and finally at $t = 0.9$ s, it is adjusted to 1.47 m/s. The generator speed is fed back forming a closed loop to account for typical drooping characteristics of asynchronous machine. The turbine is modeled in Matlab/Simulink using (4). Fig. 4 shows the variations of water velocities.

3. Machine side converter

The generated voltage and frequency of the machine varies with the varying velocity of river water. This, in turn, would result in unbalanced voltage and frequency at the utility side. Therefore, it is essential to determine the real and reactive power requirements of the generating machine in order to compensate for the varying voltage and frequency at its terminal and rated currents through its windings. This is realized by the use of an IGBT based current controlled voltage source inverter (CC-VSI) along with a dc link capacitor in the machine side. The triggering pulses to the three-legged IGBTs are varied in accordance with the varying input power. The variation in the dc link capacitor voltage presents the direct axis component of current from the machine. The peak value of the line-to-line voltage from the machine is computed and compared with the reference peak value ($415\sqrt{2}$ V). The difference between these two quantities is the reactive power required by the machine or is the amount of quadrature axis component of current to be supplied to the machine. These two axes reference currents namely I^*_{ds}, I^*_{qs} are converted into three-phase form by inverse Park's transformation [7]. The '$\cos(\omega t)$' and '$\sin(\omega t)$' terms needed for Park's transformation are derived with the help of a phase locked loop (PLL) which is fed from unit templates of line voltages of the generator. The three-phase reference currents thus obtained are compared with the actual load currents in a hysteresis current controller to yield the firing signals for the switching devices in the CC-VSI. The fluctuation in capacitance voltage is due to power consumed by the devices in the CC-VSI and filter resistance.

3.1. Generation of unit voltage templates

The line voltages (V_{ab}, V_{bc} and V_{ca}) of the generator terminals are considered sinusoidal and therefore, their amplitudes are computed as

$$V_{tactual(peak)} = \sqrt{\frac{2}{3}\left(V_{ab}^2 + V_{bc}^2 + V_{ca}^2\right)}. \tag{6}$$

The unit template voltages are derived as

$$u_a = \frac{V_{ab}}{V_{tactual(peak)}} \tag{7a}$$

$$u_b = \frac{V_{bc}}{V_{tactual(peak)}} \tag{7b}$$

$$u_c = \frac{V_{ca}}{V_{tactual(peak)}}. \tag{7c}$$

3.2. Quadrature-axis component of reference source currents

The ac voltage error $V_{err(n)}$ at nth sampling instant is given by

$$V_{err(n)} = V_{tref(peak)(n)} - V_{tactual(peak)(n)} \tag{8}$$