Single-stage AC–AC power conversion for WECS

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This paper investigates a novel single stage AC–AC power conversion, as an alternative to multistage AC–DC–AC power conversion topology, for interfacing the wind energy conversion system (WECS) to a grid as a distributed load system. A comprehensive dynamic model of proposed AC–AC converter is developed to satisfy all the functions of the converter. A new time switching pattern and a control mechanism are described to convert a variable frequency input power proportion to the wind power to a constant frequency output power for a distributed load system in a single unit. The converter control functions are adapted to control active and reactive powers injected into the distributed load system. Based on time-domain simulations in the MATLAB environment, a comparative study has been made of the dynamic behavior of wind turbine generation system with the proposed AC to AC converter and conventional AC–DC–AC converter. The study concludes that an AC–AC converter is technically a viable option to interface a wind turbine to a distributed load system or utility grid application. A prototype of the proposed converter is developed in the lab taking variable frequency input voltage and then converting it to a constant output frequency voltage. The performance of the converter has been found satisfactory.

A general scheme of the WECS is shown in Fig. 1. Wind energy is transformed into mechanical energy by means of a wind turbine that has one or several blades. The turbine is coupled to the generator system by means of a mechanical drive train. The electronic interface circuit consists of an AC–DC rectifier at the output of PMSG to convert the variable speed AC power to DC power [4]. Typically, the DC output voltage is required to be converted into AC voltage by a DC–AC inverter. Accordingly, the overall power conditioning circuit consists of a rectifier, a DC-link capacitor and a DC–AC inverter [5,6]. However, the Total harmonic distortion (THD) of input currents is much higher in PWM based rectifier system [7]. So, the machine-side PWM rectifier could be replaced by a Diode rectifier cascaded with step-up chopper [8]. The rectifier stage of the power converter causes high distortion of the output current and voltage of PMSGs which generates several undesirable effects to the generator, such as (1) increased heating with the effect of iron and copper losses at higher harmonic frequencies; (2) loss in machine efficiency and reduction in electromagnetic torque; (3) increased audible noise emission and occurrence of mechanical oscillations [9,10]. Additionally, the total efficiency of the two-stage converter is lower because the total power has to be processed twice with two cascade power stages. Each power stage has to be rated as full output power which will increase the size and cost of the circuits. Reliability, efficiency and power factor of the system is also reduced with large input filter and high switching frequency [11,12].
The multistage operation can be avoided using a matrix converter (MC) as a direct AC/AC converter. A direct matrix converter has advantages such as compact size, efficient performance and low-input THD [13,14]. Normally, the input supply for a matrix converter has been taken as sinusoidal and balanced with fixed frequency, which is not true for wind energy application [15]. Due to variation and distortion of input supply, the load side output is also influenced which is not solved by matrix converter controller owing to absence of DC link capacitor. Unfortunately, distorted input voltages generate low-order harmonics in the output supply, which have a negative effect on the input supply [16]. The improvement in efficiency is normally achieved by fixed time switching patterns based modulation algorithms such as space vector PWM [17]. The space vector PWM is not a flexible due to its look up table method. Manipulation of duty cycle is typical to vector PWM [17]. The space vector PWM is not a flexible due to switching patterns based modulation algorithms such as space vector PWM [17]. The space vector PWM is not a flexible due to its look up table method. Manipulation of duty cycle is typical to vector PWM [17]. The space vector PWM is not a flexible due to its look up table method. Manipulation of duty cycle is typical to vector PWM [17].

Wind turbine model

The energy that could be captured from the wind by a specific turbine depends on its design particulars and operating conditions [14]. The power obtained by the turbine is a function of wind speed. The output aerodynamic torque of a wind turbine is defined by Eq. (1).

\[
T_t = \frac{P_t}{\omega_t} = \left( \frac{\rho \times r \times C_p(\beta, \lambda) \times V_x^2}{2 \times \omega_t} \right)
\]  

(1)

Here \( \rho \) is the air density, \( r \) is the radius of the turbine, \( (C_p(\beta, \lambda)) \) is power coefficient, \( V_{ws} \) is the wind speed (m/s), \( \beta \) is the blade pitch angle (degree) \( \omega_t \) is the turbine speed, \( \lambda \) is the ratio between the turbine angular velocity \( \omega_t \) and the wind speed \( V_{ws} \). This ratio is called the tip speed ratio and is given by Eq. (2).

\[
\lambda = \frac{r \times \omega_t}{V_{ws}}
\]  

(2)

In order to determine the behavior of turbine model characteristics, generic equations which relate the power coefficient with different coefficients of turbine are given as.

\[
C_p(\lambda, \beta) = C_1 \times (C_2/\lambda_1 - C_3 \times \beta - C_4) \times (\exp^{-\alpha_1/\lambda})
\]  

(3)

\[
1/\lambda_1 = \left( \frac{1}{\lambda} + 0.8 \times \beta \right) - \frac{0.035}{\beta^3 + 1}
\]  

(4)

Here \( C_1 \) to \( C_5 \) are coefficient of turbine model. The variation of \( C_p \) with tip speed ratio at various value of pitch angle is shown in Fig. 3. It can be observed from this figure, that the maximum value of \( C_p \) decreases with an increase in the value of pitch angle [21].
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