Grid Connected Wind Energy Conversion Systems Control Strategies

Lata Gidwani

Abstract—In this paper the grid interconnection issues of AC-DC-AC inverter interfaced wind energy conversion system have been dealt. The feed-in power to the grid in Wind Energy Conversion Systems (WECS) shows always a high fluctuation resulting in power quality problems. These problems clearly show that there is a strong need for controlling various stages of WECS, such as generator control, converter control, and inverter control. This paper presents an overview of various control strategies applied to WECS. A model is discussed and its control strategy offers a proper tool for smart grid performance optimization. A rule-based fuzzy logic controller to control the output power of a pulse width modulated (PWM) inverter used in a standalone wind energy conversion scheme (SAWECS) is also discussed. Space vector pulse-width modulation (SVPWM) has been widely employed for the current control of three-phase voltage source inverters (VSI). Emphasis is placed on introducing the control techniques followed by a description of methodologies adopted.

Keywords—Wind Energy Conversion System, Standalone Wind Energy Conversion Scheme (SAWECS), Space Vector Pulse-Width Modulation (SVPWM), Pulse Width Modulated (PWM)

I. INTRODUCTION

During the last decade, due to increased energy demand and environmental concern, wind farms have penetrated the field of power generation worldwide. The wind energy conversion systems (WECS) operate in a highly discontinuous manner, depending on the wind conditions. So the feed-in power to the grid shows always a high fluctuation. This creates power quality problems. In response to the technical problems and to grid code requirements, various models and control strategies for the wind farms have been developed, aimed at optimizing the operation of the wind farms in terms of active and reactive power, maximizing the energy production, improving the power quality characteristics and limiting mechanical loads. One of the major challenges is to obtain a sufficient ride-through capability to withstand the effects of external faults. This can be achieved by setting up suitable control strategies, as well as by resorting to power electronics technologies.

The paper is organized as follows: Section 1 presents an introduction along with objectives of the present work. Various Control Strategies of WECS are described in Section 2. The simulation models developed in MATLAB Simulink are detailed in Section 3 and the results obtained from these models are explained and compared in Section 4. The conclusions drawn from these results are finally summarized in Section 5. In this paper efforts have been made to develop a brief survey on the applications of control techniques to WECS.

II. WIND ENERGY CONVERSION SYSTEMS

A wind energy conversion system connecting a wind farm with an AC network is shown in Fig. 1. The system consists of an offshore wind farm, a high pole number modular permanent magnet generator, a modular rectifier system, the intermediate high-voltage DC link and a controllable voltage source inverter (VSI). Wind energy input to the wind turbine is converted into electrical energy by a permanent magnet (PM) generator, which is rectified and then inverted by VSI to produce smooth AC voltage which can be connected to AC grid through AC grid transformer.

Here we have to discuss the wind turbine. The modelling of wind turbine will now be discussed here. The mechanical power available from a wind turbine is as follows [1]:

\[ P_w = 0.5 \rho \pi R^2 V_w^3 C_p(\lambda, \beta) \]  

where, \( P_w \) is power extracted from the wind, \( \rho \) is air density, \( R \) is blade radius, \( V_w \) is wind speed and \( C_p \) is power coefficient. \( C_p \) is given as a nonlinear function of the parameters tip speed ratio \( \lambda \) and blade pitch angle \( \beta \). The calculation of the power coefficient requires the use of blade element theory. As this requires knowledge of aerodynamics and the computations are rather complicated, numerical approximations have been developed. Here the following function will be used.

\[ C_p = \frac{1}{2} \ast \left( \lambda - 0.022 \ast \beta^2 - 5.6 \right) \ast e^{-0.17\lambda} \]  

where, \( \lambda \) is tip speed ratio and \( \beta \) is blade pitch angle. The tip speed ratio is given as:

\[ \lambda = \frac{V_w}{\omega_B} \]  

where, \( \omega_B \) is rotational speed of turbine. Usually \( C_p \) is approximated as,

Lata Gidwani is with the Rajasthan Technical University, Kota, Rajasthan, India (phone: 9414279895; e-mail: lata_gidwani@rediffmail.com).
where \( \alpha, \beta \) and \( \gamma \) are constructive parameters for a given turbine. It can be seen that \( C_{p_{\text{max}}} \), the maximum value for \( C_p \), is a constant for a given turbine. The torque developed by the windmill is

\[
T_c = 0.5 \rho \left( \frac{C_p}{\lambda} \right) V_w^3 \pi R^2
\]  

Fig. 1: Wind Power Conversion System

III. CONTROL STRATEGIES OF WECS

There are various inverter based control strategies for controlling wind energy conversion systems, which are discussed here. The voltage variation at PCC due to voltage rise/fall on the grid or change in load is the main issue in case of grid connected WECS. This inverter interfaced WECS topology provides for the constant voltage at PCC due to injection of reactive power along with the active power by the grid side inverter.

Wind energy conversion interface scheme (WECS) using a wind turbine driven self-excited induction generator and line commutated PWM inverter have been modeled, analyzed, and implemented [2-5]. In remote locations where the utility grid does not exist, stand alone wind energy conversion scheme (SAWESCS) can be used to feed the local electrical load. However, there is an appreciable amount of fluctuation in the magnitude and frequency of the generator terminal voltage due to its dependence on the rotor speed which is governed by the wind velocity and the pulsating input torque from the vertical axis wind turbine. This is objectionable to sensitive loads. Hence, the variable magnitude, variable frequency voltage at the self-excited induction generator terminal is first rectified and the dc power is then transferred to the local load through a PWM inverter. It has been shown that the power available from a WES can be approximated as a cubic function of the wind velocity [5-6]. Fig.2 shows SAWECS with fuzzy logic controller.

Fig. 2: Wind Energy Conversion System with Fuzzy Controller

Among the previously proposed current control strategies, current controllers based on the space vector PWM (SVPWM) are widely employed for three-phase PWM VSI [7-12]. As a linear current control strategy, SVPWM-based current controllers separate current error compensation and PWM parts clearly, making it possible to exploit the advantages of SVPPM independently as well as to design the overall control structure [7]. However, as an open-loop voltage-type modulator, SVPWM also has certain drawbacks compared to closed-loop current-type modulators [6-7]. For a grid-connected inverter, SVPWM-based current controllers may be sensitive to the disturbance of the grid harmonics and the nonlinearity of the system such as the switching dead time and control delay due to computation and sampling, resulting in the degraded quality of output current [10][13][14]. Moreover, SVPWM lacks an inherent over-current protection, which is especially problematic for a grid-connected inverter [10]. In order to overcome the foregoing drawbacks of SVPWM, the design of current error compensation is then critically important.

Among many previously proposed current error compensation schemes, proportional-integral (PI) regulators are popularly applied in linear controllers for current error compensation due to their simplicity and reliability. However, without appropriate compensation for the back-EMF disturbance, conventional PI regulators normally yield poor output current waveforms for grid-connected applications due to the grid harmonic disturbance and the nonlinearity of the system [8][12]. In [9], fuzzy-logic tuning PI regulators are designed to improve the dynamic response and robustness of the current controller, but the system becomes much more complicated. In [10], the authors have proposed an advanced SVPWM-based PI current controller to effectively compensate for grid harmonics disturbance and decrease the control delay using a dual-timer sampling scheme. However, there still exists a control delay which results in slight distortions of the output currents. Fig. 3 shows current control system using SVPWM for VSIs.
A WECS control scheme of combined SCIG minimum ohmic loss controller with either a search or a fuzzy-logic MPPT controller has been presented [25]. Model-based optimal efficiency control methods for an SCIG have been proposed in [26] and [27]; however, in [26], the variation of iron loss with frequency was disregarded and in [27] the accurate wind speed measurement is required. An optimized capacitance design for the dc-link of a back-to-back converter for wind turbine power generation was presented [28]. A loss minimization method (considering copper and iron losses) for an induction generator that can be used for a stand-alone system for battery charging was presented [29]. Finally, a model-based optimally controlled method for interior PM synchronous generator in combination with an MPPT algorithm has been presented [30-33].

IV. CONCLUSIONS

A comprehensive but brief survey of inverter based control strategies applied to WECS has been presented here to provide background information regarding the present research and development trends in this area. This paper describes various control methods such as converter control, generator control, and wind turbine control. Only some salient features and significant developments have been highlighted here and for proper design and evaluation for a particular application, one has to study in depth many trade-off considerations and relevant texts given in references. The current research work being undertaken by various groups is also highlighted. Hence, for solving the problem of controlling wind energy, inverter control is the most popular method.

REFERENCES


