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] :

$$P_w = 0.5\,\rho\pi\,R^2\,V_w{}^3\,C_p(\lambda,\beta) \qquad (1)$$

where, P_w is power extracted from the wind, ρ 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 λ and blade pitch angle β. 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.

$$C_p = \frac{1}{2} * \left(\lambda - 0.022 * \beta^2 - 5.6\right) * e^{-0.17\lambda} \qquad (2)$$

where, λ is tip speed ratio and β is blade pitch angle. The tip speed ratio is given as :

$$\lambda = \frac{V_w}{\omega_B} \qquad (3)$$

where, ω_B is rotational speed of turbine. Usually C_p is approximated as,

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$$C_p = \alpha\lambda + \beta\lambda^2 + \gamma\lambda^3 \quad (4)$$

where α, β and γ are constructive parameters for a given turbine. It can be seen that C_{pmax}, the maximum value for C_p, is a constant for a given turbine. The torque developed by the windmill is

$$T_t = 0.5\,\rho\left(\frac{C_p}{\lambda}\right)V_w^{\,3}\pi R^2 \quad (5)$$

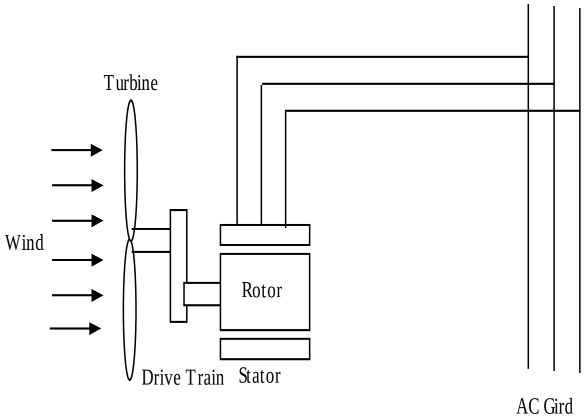

Fig. 1: Wind Power Conversion System

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.

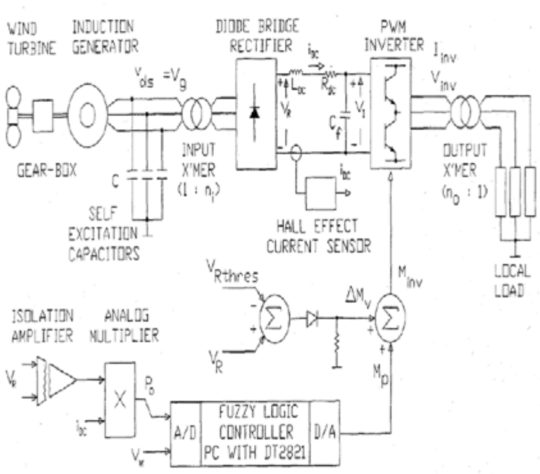

Fig. 2: Wind Energy Conversion System with Fuzzy Controller

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, SVWPM-based current controllers separate current error compensation and PWM parts clearly, making it possible to exploit the advantages of SVWPM 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 forgoing 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.

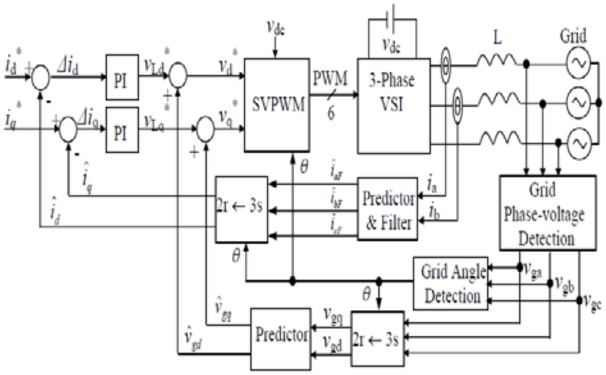

Fig.3: Block Diagram of Current Control System for VSIs using SVPWM

During the last few decades, many different maximum power point tracking (MPPT) control strategies have been developed [15-16]. This enabled the selection of the optimal MPPT for each WECS project. In addition, a number of theoretical studies have been made with the aim to establish the energy capture benefits associated with variable speed operation of WECS. A review of the recent publications show there is very little agreement on the gain in projected energy [17]. It must be mentioned here that all techniques of maximum energy capture in WECS so far have been based on signals available from an anemometer. Results of some of these studies are as given below: According to [18], the best of variable speed operation provided 4% more energy than fixed speed. Whereas the authors in [19] are more optimistic suggesting that variable-speed system provided 16% more energy than fixed speed option, in contrast, the authors in [20] claim that this gain is up to 20%. Finally, [21] says that it is 38%. To date, no conclusive evidence is available as to which system is likely to provide cheaper energy over its lifetime.

In addition to MPPT control, the efficiency of the whole WECS can be improved by increasing the efficiency of the electric generator. This can be achieved through the appropriate control of the generator flux-linkage by regulating the d-axis stator current. A fuzzy-logic control method has been presented in [22] and search control techniques have been proposed in [23] and [24]; however, the WECS response is very slow and cannot follow the fast changes of the wind. Fig.4 shows WECS Controlled System with MPPT.

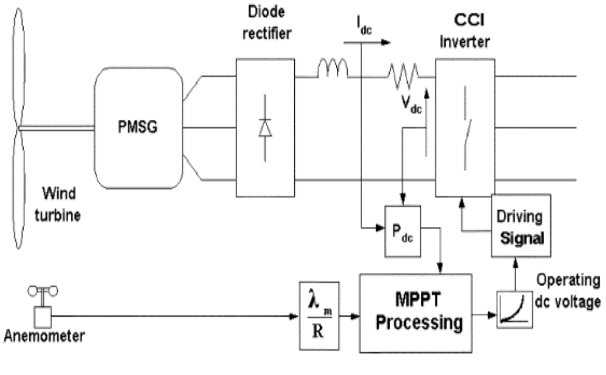

Fig.4: WECS Controlled System with MPPT

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.

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