A Survey on Wind Turbine Control System

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***Abstract* – By observing the wind turbine control techniques used for pitch and generator, the major part in the wind energy applications. Majority of control techniques are designed for high efficiency and cost effectiveness of the system. This paper discusses about the model wind turbine control methods from the literature review of recent papers. The aim of this paper is to identify the more advanced control architectures and its advantages.**

***Keywords:* Wind turbine; LQR Controller; Pitch Control; Torque Control.**

I. INTRODUCTION

Wind energy is one of the best source to produce electrical energy without any environmental issues in this generation. The main challenge is raised from [1]. The source because of it is a non-linear source that's why we need to control the system for the optimized output power from the generator. In this paper the overview of different control techniques of variable speed horizontal axis wind turbines is discussed for identifying an effective control technique.

The main goal of the wind turbine control system is reducing the static and dynamic mechanical loads and maintaining continuous power supply to the grid [2] for achieving this goal the blade pitch angle and generator torque is the main controllable parameters in the wind turbine to produce smooth power from the wind turbine. The disturbance loads in the turbine blade will be diminishing by varying the pitch angle. The forge will be controlled for obtaining constant speed of the rotor and produce maximized power from the generator.

The variable speed wind turbines rotational speed is vary with the wind speed. It will cause the turbine will rotate over range of wind turbine speed to limit this speed the blade pitch will be varied [3] then rotor speed will be regulated.

II. REGIONS OPERATION IN WIND TURBINE

Here, the researcher interprets the data in terms of any patterns that were observed, any relationships among experimental variables that are important and any correlations between variables that are discernible. The author should include any explanations of how the results differed from those hypothesized, or how the results were either different from or similar to those of any related experiments performed by other researchers. Remember that experiments do not always need to show major differences or trends to be important. "Negative" results also need to be explained and may represent something important--perhaps a new or changed focus for your research.

Basically a wind is a non-linear and time-varying source because of this the blade pitch will be varied by the controller command to rotate the rotor in fixed speed. Majority of this controllers are designed by blade element momentum theory by this theory the thermodynamic loads on the turbine is reduced.

The wind turbine operation conditions are divided into 3parts depend on the wind speed variations in [4] region-1. The wind speed is very low as compared to the turbine rated wind speed to make the rotor rotations as regular the pitch will be varied in this region. In region-2 the wind speed is above the rated speed of the turbine and also torque is more as compared to the previous regions here, the blade pitch is varied to control the rotor speed and output power delivered from the generator. Most of the controller designed to reduce the undesirable loads on the blade of the turbine and tower.

III. BASIC CONTROLLER FOR OPTIMAL TORQUE

Wind turbine control is started from the 19^{th} century. In 1970s model prediction control is evaluated based on the finite horizon linear quadratic regulator (LQR) for making stabilize control loss. After long research a two mass model control [5] is considered for non-linear control synthesis. It is designed based on non-linear static and dynamic state feedback. The optimal torque control is designed based on the MPPT algorithm is introduced for large commercial wind turbines. The torque according to the rotor speed is shown in below equations.

$$T_g = K\Omega^2$$

$$K = \frac{1}{2}\rho\pi R^5 \frac{C_{p,opt}}{\lambda_{opt}^3}$$

Where K is a constant derived from the aerodynamic characteristics and Cp is the power coefficient and λ opt is the tip speed ratio. The optimal torque control [6] is a simple method. It is used for mitigating the unnecessary mechanical loads on blades. At the high wind turbulences to achieve good performance a steady state method [7] is introduced to obtain optimal torque. Some researchers suggest adaptive control approach [8] to overcome uncertainty parameters, by using the adaptive value K, we obtain better performance for the system.

IV. PITCH CONTROL

The wind turbine pitch control is used to improve the efficiency. When we change the pitch angle, then angle of attack will be changed [9] then consequently the aerodynamic loads on the rotor will be changed. Also the power coefficient Cp of (λ, β) varies according to the pitch angle variations. This process will be used for power regulation from the generator and load reduction on the turbine blades.

V. COLLECTIVE PITCH CONTROL

It is a modern method of wind turbine pitch control. In this method, the pitch angle command is given to the system. By this, the same control action is done by the all the blades of the turbine. A symmetric simulation based PID controller is designed. It is working by the selected PID control gains [10] .An adaptive pitch control with concern disturbance reduction is designed in [11]. This controller is extended with a residual mode filter (RMF) to provide smooth operation at turbulent wind conditions. A hybrid fuzzy PI control [12] is designed to reduce power fluctuations in off-shore wind forms. Fault tolerant capability is essential at the wind turbine operates at down times for this reason. A fault tolerant control (FTC) is introduced in [13]. This research proposes both active and passive fault tolerant pitch control. A more sophisticated approach [14] is determined based on the neural network for handling the non-linearity present in the system. When the non-linearity’s in the source model predictive control (MPC) is designed for optimizing the system from source non-linearity’s. It shows better performance results as compared to the traditional PID controller. Also, it will show the effectiveness of feed forward collective pitch control.

VI. INDIVIDUAL PITCH CONTROL

Individual pitch control is a latest development in wind turbine control, which has been researched from last two decades. This type of techniques will makes the wind turbine control system an inherently multiple-input-multiple-output (MIMO) system and used to eliminate damage in turbine blades[15]. The control arrangement is required individual pitch commands and sensors individual pitch control window little adjustments in pitch angle of each blade for decreasing the stresses on blades. Some researchers proved and practically implemented the control system by using individual pitch control [16]. The comparison between feed forward individual pitch control and feedback individual pitch control based on h-infinity control synthesis is done in [17]. It results are showing reduction in equivalent loads for reducing the turbine damage. The most advanced model predictive control is introduced in [18].This control technique mainly focused on individual pitch control applications in off-shore wind form. It is designed based on the repetitive control method. It is an advanced control technique. A recent control technique is introduced based on NERL’s (National E-repository limited).Experiment is introduced in [19]. This test results shows an effective load reduction on turbine blades and improves the generation efficiency as much as possible.

VII. STANDARD CONTROL TECHNIQUES FOR OPTIMIZING THE GENERATOR OUTPUT

The wind turbine is rotating with the different speeds due to fluctuating in wind due to this reason the generator speed also changed consequently. By this the generator will gives fluctuated output power. This fluctuated power will generate harmonics in the grid. To reduce this harmonics In [23] a controller is designed to control doubly fed induction machine(DFIG) coupled to wind turbine. This controller aimed to control power factor of the DFIM by decoupling the active and reactive power generated by the machine. In [24] a new control technique is proposed for wind turbine to capture the maximum power without the wind speed sensor. To determine the optimal operating DC voltage of a current controlled inverter by controlling the modulation index(MI) of the PWM inverter by this the overall captured energy will be optimized. And to achieve good performance in rotor speed regulation and power regulation from the generator in wind farm a multi variable wind turbine controller is presented in [25] this controller has only single control input i.e pitch angle of the turbine blades it is used to control the nonlinear torque from the wind turbine.

In [26] discussed an overview of the modern wind turbine control system and recent development of active power control(APC). And other discussed point is the recent industry trends and research in wind turbine control systems for grid integration and frequency stability. A new concept of wind turbine control is discussed based on a known benchmark model this solution has used for recent industrial usages. A modern fault tolerant control(FTC) [27] could use to increase reliability of the modern wind turbines. A synchronous integration damping controller [28] is introduced for wind turbine. it is working based on well-known PI control structure this controller will concentrated on sub synchronous integration(SSI) mitigation and comparing the generation side converter(GSC) and rotor side converter(RSC) to perform damping action and also provide small and large signal stability analysis for robustness of the controller. To determine optimal parameter selection for optimizing the wind generation drop control strategy [29] is introduced it will be working based on the optimal parameter tuning. In order to reduce fluctuation of frequency in wind farm micro grid system a coordinated control of blade pitch angle with combine model predictive control(MPC) [30] is used for blade pitch angle control. This controller is stabilizing the power production from the wind turbine generator. In [31] a sliding mode controller based controller is introduced to reduce the chattering issue of sliding mode approach and improves current THD of the grid connected inverter. The power control of PMSG is carried out by boost converter united power factor method. A guaranteed performance control method [32] is introduced to control the variable speed of DFIG driven wind turbines. This controller will achieved both transient and steady state performance the main goal of this controller to optimize the extracted power from wind turbine and regulation of the stator reactive power and electromagnetic torque will optimized by reference obtained from the MPPT algorithm. An inductance emulating control [33] is introduced to control the DFIG based wind turbine. The main aim of this controller is to smoothing the electromagnetic torque at presence disturbances by controlling the rotor side controller(RSC).

VIII. MODERN CONTROL TECHNIQUES FOR FREQUENCY REGULATION

The wind turbine is integrated with the grid the power system presents some challenges like flickering in generation and harmonics presents in the grid. These problems are caused both power system stability and power quality problems. To overcome this problems a new pitch angle control topology [34] based on the fuzzy logic control is introduced to limiting the turbine output power and generator speed in the full load region. By using this controlling method the rotor running sped is constant without ripple components. The proposed controller in [35] is implemented for existing wind turbine generator. Advantage of this controller it working without requiring additional actuators to adjust the pitch angle. The controller is working for linearizing the nonlinear power system and improving the frequency regulation and gives robustness of the system. In [36] a multiple vector model predictive power control(MV-DMPPC) is used for wind turbine control. It is designed based on fully field programmable gate array(FPGA) real time system. the main control objective in this controller is optimization of both the light and phase of equivalent vector of power converter of PMSG. An integrated control [37] is proposed to investigate power regulation and provide enhanced active power support and improves system stability. The controller is working based upon optimized power point tracking(OPPT) control scheme.

In [38] the widely used control scheme is adopted for controlling the stator flux of the doubly fed induction generator(DFIG). In this scheme three commonly used stochastic estimation methods are investigated. There are used to DFIG power system control and it is working based on dynamic estimation with filter algorithms. A fault tolerance control scheme [39] is introduced for reliable regulation of generator torque. This control approach is designed based on the fuzzy model reference adaptive control. These type of control approaches is used for large offshore wind farms. A synchronous control method [40] is adopted for DFIG based wind farms. This control method is used to solve stability problems and improving power factor of the system. for improving the reliability of the offshore wind farm an averaged electro thermal model controller is developed in [41]. This controller will designed based up on the modified wind turbine control strategy. The main purpose of this controller is evaluating performance integration with conventional new turbine model. A new soft stalling control strategy [42] is designed for small wind turbines which operating in high wind speeds. The proposed method is working based upon limiting the current/torque values of the electrical machine the main objectives of this controller cost effective of the micro wind turbine because of this controlling of current/torque by the rotor side controller(RSC) the voltage and current sensors are available in low cost.

The stator flux characteristics and their influence on controllability of wind turbines is discussed in [43] a virtual damping flux based low voltage ride through(LVRT) control strategy is introduced to smooth the electromagnetic torque from wind turbine. it is working based on the conventional vector control. A virtual synchronous control is presented in [44]. This is designed for DFIG based wind turbines. This controller will be designed based on the widely used phase locked loop(PLL) synchronizing technique. It will enhance the grid frequency stability and provide desired inertial response of the system. an active structural control [45] is proposed to load reduction of floating wind turbines. For optimizing the system this will designed. It is working based up on the H∞ control synthesis. The main advantage of this control approach is it will reduce the wind turbine fatigue loads.

IX. Latest Developments In Wind Turbine Control

The early research on wind turbine control is started in middle of 1990s.After long research, different model control techniques are employed to control the wind turbine [20,21]. Some simulations for smart router applications are designed based on the H-infinity control synthesis to stabilize the system from non-linearity's. Majority of researches focused on the cost effectiveness in large commercial wind turbines. For this reason, some authors consider only smart concepts. This type of control system will work on reducing the auxiliary loads on turbine blades. By this, smart rotor could works to rotate generator shaft.

X. Conclusion

This paper summarizes in different control techniques of wind turbines and regions of operations and also associated control concepts. This paper mainly reviewed on only two methods,pitch control and torque control for speed regulation of the shaft and uncertain load mitigation on blades. In this paper, also presented latest improvements in wind turbine advanced control methods.

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