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Generator speed regulation in the presence of structural modes through adaptive control using residual mode filters

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ABSTRACT

Wind turbines operate in highly turbulent environments resulting in aerodynamic loads that can easily excite turbine structural modes, potentially causing component fatigue and failure. Two key technology drivers for turbine manufacturers are increasing turbine up time and reducing maintenance costs. Since the trend in wind turbine design is towards larger, more flexible turbines with lower frequency structural modes, manufacturers will want to develop control paradigms that properly account for the presence of these modes. Accurate models of the dynamic characteristics of new wind turbines are often not available due to the complexity and expense of the modeling task, making wind turbines ideally suited to adaptive control approaches. In this paper, we develop theory for adaptive control with rejection of disturbances in the presence of modes that inhibit the controller. A residual mode filter is introduced to accommodate these modes and restore important properties to the adaptively controlled plant. This theory is then applied to design an adaptive collective pitch controller for a high-fidelity simulation of a utility-scale, variable-speed wind turbine. The adaptive pitch controller is compared in simulations with a baseline classical proportional integrator (PI) collective pitch controller.

1. Introduction

Rated wind speed is the velocity at which maximum power output, or rated power, of a wind turbine is achieved. The power output of a wind turbine increases in proportion to the cube of the wind speed. A turbine operating at or above the rated wind speed needs a method to maintain the rated generator speed, otherwise the generator and power electronics system could overheat and the aerodynamic forces on the machine could leading to component fatigue or system failure. Region 3 is the name of the wind speed operation area where power output is regulated to the turbine's rated value [1].

The control objective for region 3 operation is to maintain power output at rated power and reduce aerodynamic loads on the turbine. Conventional utility-scale variable-speed turbines use active control in region 3 to achieve the control objectives. In its simplest form, the controller applies a constant torque at the generator and actively pitches the turbine blades to vary the aerodynamic lift, thereby maintaining the turbine's rated rotational speed and reducing aerodynamic loads. Collective blade pitch control is a well-accepted approach to regulating turbine speed and responding to changes in wind speed [2].

Wind turbine control problems can benefit from adaptive control techniques [3,4], which are well suited to nonlinear applications that have unknown modeling parameters and poorly known operating conditions. The main nonlinearities in a wind turbine model come from the nonlinear aerodynamic loads on the turbine. Creating an accurate model of all the dynamic characteristics of a wind turbine is expensive and extremely difficult, if not impossible. Additionally, wind turbines operate in highly turbulent and unpredictable conditions. These complex aspects of wind turbines make them attractive candidates for the application of adaptive control methods. Adaptive control has been applied to wind turbine control problems in the past [5–7].

In this paper, we focus on the direct adaptive control (DAC) approach developed in [8,9]. This approach has been extended to handle adaptive rejection of persistent disturbances [10,11]. A new method to reduce the destabilizing effects of flexible modes on the adaptive controller will be developed and demonstrated in this paper. We extend our adaptive control theory to accommodate modal subsystems of a plant that might inhibit the adaptive controller or cause the controlled system to become unstable. Large wind turbines are an ideal application for this new theory, in part, because they often have lightly damped, low frequency

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