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Nonlinear Passivity Based Controller

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Abstract: **-- The problem of controlling small-scale wind turbines providing energy to the grid is addressed in this paper. The overall system consists of a wind turbine plus a permanent magnet synchronous generator connected to a single-phase ac grid through a passive rectifier, a boost converter, and an inverter. The control problem is challenging for two reasons. First, the dynamics of the plant are described by a highly coupled set of nonlinear differential equations. Second, due to the use of a simple generator and power electronic interface, the control authority is quite restricted. In this paper we present a high performance, nonlinear, passivity-based controller that ensures asymptotic convergence to the maximum power extraction point together with regulation of the dc link voltage and grid power factor to their desired values.**

Index Terms: **-- Nonlinear control, passivity-based control, power control, renewable energy systems, wind speed, windmills.**

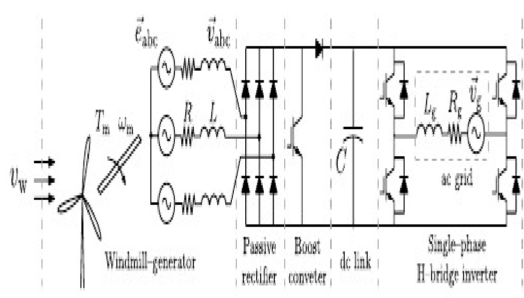
I. INTRODUCTION

Wind power is becoming increasingly popular around the world, with most of the effort focused on the development of utility scale wind power. In recent years, small-scale wind turbines (1–100 kW) have been receiving attention as serious contributors for powering homes, farms and small businesses as well as energy providers for the power grid, which is the scenario considered in this paper.

The American Wind Energy Association reported 198 MW (151 300 turbines) of installed capacity of small-scale wind power in the United States at the end of 2011. The report also states 91% of the sales in 2011 correspond to grid- connected units. Further efforts to increase the penetration of distributed wind power are being made through renewable portfolio standards and market-based schemes. Because of their higher efficiency and power density, a class of small-scale wind turbines very often use permanent magnet synchronous generators (PMSGs) built either as radial or axial flux machines. Moreover, because of cost reasons, the connection to the grid is achieved via a simple power electronic interface. In this paper, we consider a system consisting of a small-scale wind turbine plus a PMSG connected to a single-phase ac grid through a passive rectifier, a dc–dc boost converter and a single-phase H- bridge inverter.

II. DESIGN

The system consists of a wind turbine with a PMSG, a passive diode bridge rectifier, a boost converter, a dc link, and an inverter connected to the grid through a simple L filter. Although the passive rectifier injects current harmonics into the PMSG, this topology is preferred due to its low cost and simplicity of implementation. On the other hand, it is clear that it significantly reduces the available control authority.



Circuit schematic of a grid controlled wind mill system

III. CONTROL IMPLEMENTATION

The implementation of the grid-connected windmill's control scheme readily follows from the dynamical systems defined by (47) and (48). As

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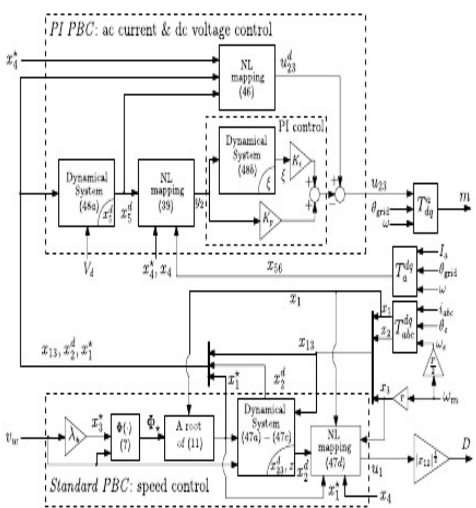
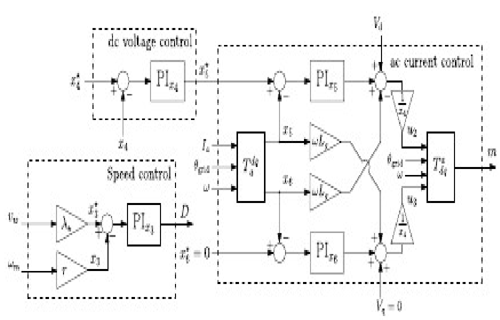
suggested in this figure, the control action is partitioned into two coupled blocks. The SPBC block controls the windmill's shaft speed (x 3) acting upon the dc–dc converter's duty cycle (D), while the PI PBC block regulates both the dc voltage and the ac grid current acting upon the H-bridge inverter's modulation index (m).The block diagram also shows the translation of physical variables into the state vector . It is assumed the full state vector is available for measurement. The block diagram's inputs are the state vector (x 16), wind speed (v w), ac grid voltage (V), and references for the dc link voltage (x 4 = 400 V) and reactive current (x 6 = 0).



Block diagram implementation of the proposed control scheme.



Block diagram of the PI-based benchmark control scheme

The outputs of the block diagram are the control handles, namely D and m. Moreover, blocks tagged as "dynamical system" represent differential equations whose state variables are highlighted on the right corner at the bottom of the block.

IV. BENCHMARK SYSTEM

The performance of the controller introduced in this paper is compared against an industry standard PI controlled based architecture.

A. Controllers

As stated, the performance of two different schemes of control is compared. For simplicity, we will refer as PBC controllers for the controllers whose methodology is proposed in this paper. On the other hand, the PI-based benchmark control scheme will be labeled as PI controllers. Various gains of both controllers were tuned using the well-known pole placement method. Numerical values are given below.

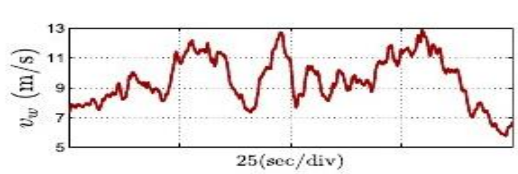
R3a = 0.8, K iw = 0.5
Kp = 0.007 01 0
Ki =. 0 0.0090 0.90

2) PI Controllers Gains

K p_x3 = 0.00967472, K i_x3 = 0.10516
K p_x4 = −4,
K p_x5 = 0.05,
K p_x6 = 0.05,

B. Wind Speed Profile

The wind speed profile is used for the simulation studies. It was constructed using real measurements collected by the National Wind Technology Center in Boulder, Colorado, USA. The wind speed was measured at 100 Hz at 36.6 m above the ground using a cup anemometer. As may be observed in the figure, the profile is rich in turbulence and exhibits gusty behavior at times.



Real wind speed profile used in the simulation studies.

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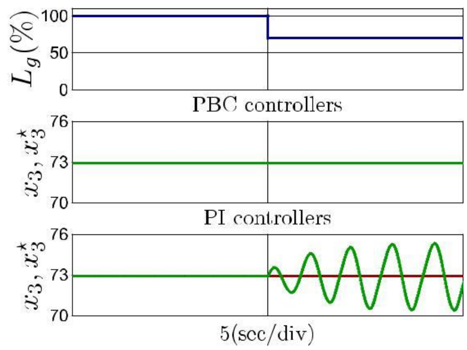

Tracking function

V. CONCLUSION

An asymptotically convergent PBC for a basic windmill system connected to the grid, which ensures maximum power extraction and regulation of the dc link voltage and injection of reactive power has been proposed. To design the controller, the overall systems have been divided in two coupled subsystems: the windmill with the PMSG and the power converters with the grid. For the first subsystem, a SPBC, was realized. The second subsystem was controlled by means of a PI controller destined to track assignable trajectories. Two modifications to a previous work were introduced to improve the transient performance of the PBC. First, we design a new version of SPBC whose domain of attraction is larger than that reported. Second, endowing the PI controller with tracking capabilities allows for a faster response with respect to the standard regulation PI.

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