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***Abstract*—In wind energy conversion systems (WECS), the turbine captures part of the wind energy and converses it to mechanical energy through a dynamic interaction with the electrical generator which in turn converts this mechanical energy to electrical energy. Therefore, the dynamics of the wind turbine is very important in research and development of the overall WECS. Having a real wind turbine or a site with convenient wind conditions is not always a guaranteed option for conducting research. Hence, it is very desirable to create wind turbine dynamics through wind turbine emulation. In this paper, a wind turbine emulation system using a permanent magnet synchronous motor (PMSM) is designed, simulated, implemented, and tested experimentally. The PMSM is torque-controlled using field orientation technique. A three-phase IGBT inverter with closed loop current PI-controllers is used to drive the PMSM. A dSPACE DS1104 DSP prototyping platform is used to handle the real-time execution of the control programs. The system is tested and the torque-speed characteristics of the emulated wind turbine are verified experimentally at different feeds of wind speeds and generator loads.**

***Index Terms*—Wind energy conversion system, wind turbine emulator, PMSM control.**

I. Introduction

A wind turbine emulator (WTE) is an equipment which is used for producing a real wind turbine characteristics in the laboratory. This emulator emulates the dynamic and static behavior of the real wind turbine without the need of natural wind resource and actual wind turbine.

For the purpose of research tests, a system is designed to emulate the wind turbine characteristics. The emulator can be coupled with an electrical generator to compose a complete wind energy conversion system (WECS) in a similar way like an actual wind turbine by generating torque similar to the aerodynamic torque at a given wind speed. Obviously, more control and flexibility are provided using emulators since selectable wind profiles, speeds and repeatable testing conditions can be conducted easily as desired without the need to a natural wind resource or too expensive wind turbine equipment. Squirrel cage induction motor (SCIM), permanent magnet synchronous motor (PMSM) and DC motor are usually used for emulating wind turbines in the laboratory [1]-[7]. These motors are controlled to have power curves similar to the wind turbine characteristics.

In this paper, a PMSM is selected to implement the emulation. The paper explains in sufficient details the different aspects of the implementation as follows: section II presents the wind turbine mathematical model. Sections III and IV give the details of PMSM control using field orientation technique including the design procedure of the PI current controllers. In section V, the experimental setup is described and the system testing results including the verification of the torque-speed characteristics of the emulated turbine and the experimental results of some testing scenarios are presented. Section VI provides the conclusion of this paper.

II. Wind Turbine Model

The wind turbine is the crucial mover of the WECS. Thus, the modeling of wind power is vital in studying and improving WECS. The mechanical output power of the wind turbine is given by (1) [8].

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v_w^3 \quad (1)$$

where ρ is the air density in (Kg/m^3), R is the radius of the rotor's swept area in (m), C_p is the power coefficient and $v_w$is the wind speed in (m/sec). The power coefficient is defined as the ratio of the turbine mechanical power to the power available by the wind. This coefficient is a function of *TSR* (λ) and the pitch angle of the blades (β) in (deg). The *TSR* is the ratio of the blade tip-speed divided by the wind speed as illustrated in (2).