A Robust Back-Stepping Stabilization Scheme for Virtual Synchronous Generators in Weak Grids

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***Abstract*—This paper presents a new control scheme for virtual synchronous generators connected to weak grids. The proposed approach consists of two major parts. The first part holds a cooperative linear and nonlinear controller in order to emulate the synchronous generator behavior such that by preparing virtual inertia, power and frequency oscillations get damped. The second part deals with a control scheme for voltage and current inner loops. Both control schemes are based on the back-stepping method, while in the latter sliding mode controllers in the *dq* reference frame are also used. The controller system design is such that in addition to tracking reference commands, it is robust to system model uncertainties and disturbances. In the process of controller design the system stability is also considered. The desired performance of the proposed control scheme for a virtual synchronous generator connected to weak grids in the presence of disturbances and uncertainties in model parameters is demonstrated through simulation results.**

Keywords— back-stepping method; virtual synchronous generator; sliding mode controller; weak grids

I. INTRODUCTION

Recently, using distributed generators (DG) to feed local loads or to deliver power to medium and low voltage grids attracts a great deal of attention. Inverter-based DGs comprise a centerpiece of DG resources, in which a power conditioning system including a PWM inverter with high switching frequency and an output filter for debilitation of switching harmonic components is utilized [1].

Hence, controlling the frequency and balancing the power of the system is the converter's accountability. Therefore, power electronic converters will have a consequential effect on power system so that the converter-interfaced generation will supersede traditional synchronous generators. This replacement may lead to the reduction of total system inertia and results in decrease of system stability. Consequently, the idea of emulating the behavior of traditional Synchronous Generator (SGs) by power electronic converters and adding virtual inertia to the grid grows up. Short term energy storage along with a power electronic converter and a proper control mechanism is known as Virtual Synchronous Generator (VSG) [2].

Beck and Hesse published the first precise proposal for Virtual Synchronous Machine (VSM) in 2007 [3]. The traditional mechanical swing equation in [4] which delineates the simplest VSM implementations emulates only the inertia and damping of a SM. Although this approach guarantees a simple control system structure, it complicates the implementation of current limiters and protection features for the case of grid faults and other severe transients [5].

Because of its recursive design methodology for nonlinear feedback control, the Back-stepping Control (BSC) approach has attracted so much attention recently. The idea of BSC design is to select recursively some appropriate functions of state variables as virtual-control inputs for lower dimension subsystems of the overall system. Each BSC stage results in a new virtual-control design, expressed in terms of the virtual-control designs from preceding design stages. When the procedure is terminated, a feedback design for the true control input results that achieves the original design objective by virtue of a final Lyapunov function, which is formed by summing up the Lyapunov functions associated with each individual design stage [6]. In [7], control of voltage source converters (VSC) HVDC for wind farm integration based on adaptive BSC method for stabilizing the DC cable voltage, to achieve an stable power transmission is proposed. [8] adopts the BSC design for a high-performance inverter with the functions of stand-alone and grid-connected power supply modes. A robust adaptive BSC design for PWM voltage source rectifier is presented in [9]. A supplementary controller based on BSC for PSS in multi-machine system is introduced in [10]. An adaptive BSC with friction compensation scheme is presented in [11], for the third-order linear dynamic model used for the ac motor control system design, to compensate the unknown system parameters and disturbances. In [12], a control topology to enable integration of VSCs in weak grids is tendered.

Being an influential tool for nonlinear robust control design, many researchers have benefited from Sliding mode control (SMC) so far. [13] offers a controller in an integrated procedure rooted in both BSC and SMC principles for a leader–follower multi-agent system. An intelligent BS-SMC system using radial basis function network for a two-axis motion control system using permanent magnet linear synchronous motors is proposed in [14]. A field-programmable gate array (FPGA)-based adaptive BS-SMC is suggested in [15] to control the mover position of a linear induction motor drive to compensate for the uncertainties including the friction force. A hybrid microgrid architecture and its power