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Control technique for the operation of grid-tied converters with high penetration of renewable energy resources

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ABSTRACT

This paper deals with a control technique based on inherent characteristics of synchronous generators (SG) for control of interfaced converters with high penetration of renewable energy resources (RERs) into the power grid, as a new contribution to earlier studies. To present an appropriate assessment of the proposed control technique, under dynamic operating condition, a P–Q curve is extracted and analysed based on the different components and characteristics of the interfaced converter as well as the conventional relationship between the active and reactive power. By combining the swing equation of SG and the power-based dynamic model, a P_m–Q curve is achieved and the effects of the variations of embedded virtual inertia on virtual mechanical power are assessed. Moreover, by using small-signal linearization, the grid frequency stability is investigated based on both virtual inertia and mechanical power variations. In order to assess the power sharing ability of the proposed control technique, two transfer functions are obtained and then, the impacts of variations of virtual mechanical power on the active and reactive power of interfaced converter are evaluated through Nyquist and Root Locus diagrams. Simulation results confirm that the proposed control technique can guarantee the operation of interfaced converters, based on inherent characteristics of SG, to deal with the power grid stability with high penetration of RERs.

1. Introduction

Integration of large-scale renewable energy resources (RERs) into the power grid offers several benefits i.e., economic and environmental issues. Meantime, it also raises different technical challenges regarding the grid stability and reliability due to the high variability, unpredictable fluctuation and intermittent characteristic of these sources [1,2]. Generally, RERs are connected to the power grid via power electronics converters, which the lack of inertia in these converter-based power generators, besides their peculiar transient dynamics behavior, increase their negative impacts on the power grid stability, just the opposite of the operation of synchronous generators (SGs). Consequently, the operation of converter-based generators should be controlled with some specific functionalities based on inherent characteristics of SGs; thus, successfully reaching their high penetration level in the power grid. Therefore, designing an appropriate control technique for control of interfaced converters to deal with the stability issues of power grid has been regarded as one of the main tasks between scientists in power and energy societies [3,4].

Various control targets such as the accurate power sharing and grid voltage regulation have been considered in a large-scale integration of microgrid or multi-distributed generations (DG) connections for achieving a stable performance [5,6].

In addition, along with revealing the challenges of high penetration of RERs into the power grid [7,8], several control strategies have focused on improving the stability of grid frequency and voltage magnitude. For this reason, several studies have been reported in the literature regarding the emulation of SGs characteristics by power converters [9–19].

Ref. [9] has presented a complete review associated with the main

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Nomenclature

Parameters

C	DC-link capacitor
J	Virtual inertia
k_{pp} & k_{pq}	Proportional coefficients of control components
k_{ip} & k_{iq}	Integral coefficients of control components
L	Inductance of grid interfaced converter
R	Resistance of grid interfaced converter
ω_{12}	Angular frequencies of low pass filter
α_{12}	Control factor of active power
β_{12}	Control factor of reactive power

Abbreviations

DSC	Double synchronous controller
LPF	Low pass filter
PCC	Point of common coupling
PMSG	Permanent magnet synchronous generator
RERs	Renewable energy resources
VMPE	Virtual mechanical power error
VI	Virtual inertia

Variables

i_{dq}	Interfaced converter currents
v_{dq}	Voltages of PCC
v_{dc}	DC link voltage of interfaced converter
u_{dq}	Switching functions of interfaced converter
i_{dc}	DC link current of interfaced converter
P	Active power of interfaced converter
Q	Reactive power of interfaced converter
P_{c1}	Power of DC link current and d-component voltage
P_{c2}	Power of DC link current and q-component voltage
P_{pd}	Power due to d-component voltage
P_{pdq}	Power due to d and q-component voltage
P_m	Virtual mechanical power
ω	Angular frequency
ΔP	Active power error
ΔQ	Reactive power error
ΔP_m	Virtual mechanical power error
$\Delta\omega$	Angular frequency error
P^*	Reference value of active power
Q^*	Reference value of reactive power
$P_m{}^*$	Reference value of virtual mechanical power
ω^*	Reference value of angular frequency

concepts of virtual SGs and their ability at controlling the power grid with the high level of DGs penetration. A coordinated control-based energy storage system combined with virtual SGs has been proposed in Ref. [10] to provide emulation of SG for power converters. Numerical simulations have been used in Ref. [11] to illustrate a specific virtual synchronous machine-based concept along with its related mathematics for controlling power converters in smart grid application. A generic model has been proposed for a two-stage grid-connected PV system that is able to provide both droop-based response and inertia emulation and a linearized small-signal model for evaluating stability of the proposed PV power control loop [12]. As it has been known that the lack of inertia leads to deteriorating the operation of traditional grid-connected current control with high penetration of RERs, Ref. [13] has investigated the dynamics abilities of the droop control and virtual synchronous generator (VSG) by the use of small-signal models and finally an inertial droop control strategy has been proposed based on this comparison.

In the way of emulating the inertia of SGs [14], Ref. [15] has proposed a control technique based on a generic inertia emulation scheme to provide stable operation for multi-terminal voltage-source-converter (VSC)-based high voltage direct current (HVDC) systems. Based on a virtual inertia (VI) control, performance of the PMSG has been compared with a doubly fed induction generator-based wind power system in Ref. [16] and also two control strategies based on the dynamic and adaptive fuzzy-based schemes have been proposed. In Ref. [17], the inertia constant, DERs frequency droop coefficient and the load frequency controllers' parameters have been modeled as a multi-objective optimization and finally solved by multi-objective optimization algorithm. To develop SG-based controllers [18], Ref. [19] has designed a synchronverter-based control technique for HVDC application.

This paper firstly proposes a dynamic model based on the active and reactive power of the interfaced converter. Then, the proposed model is used to be combined with the SG swing equations for designing a control technique based on emulated behaviors of SG in power grid.

In fact, the proposed control technique presents a new model of power electronics-based SG to guarantee a stable operating condition for the power grid with high penetration of RERs, which is the main contribution of this work over the other existing works in this area.

This paper is organized as the following steps. The power-based dynamic model, the proposed SG-based control technique, and the P–Q curve and its related discussions are presented in Section 2. The P_m–Q curve is presented in Sub-section 3. A. Also, evaluation of the grid

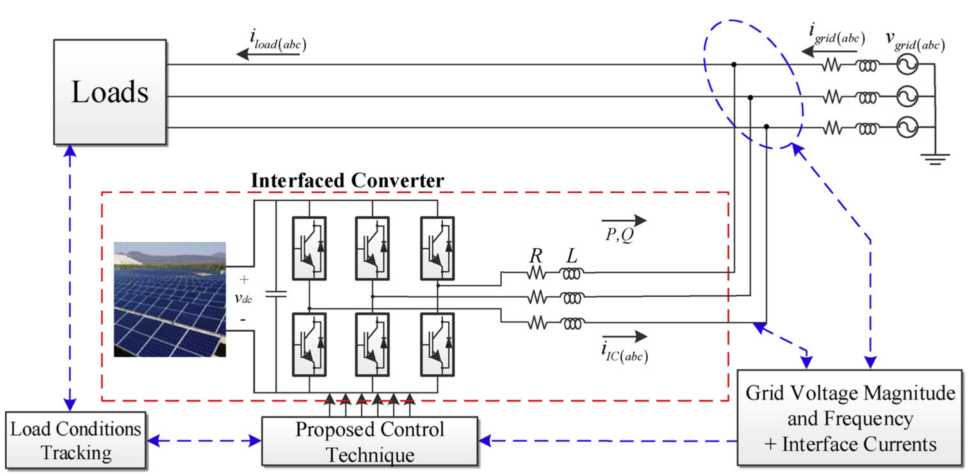

Fig. 1. General structure of the proposed model.