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An active control technique for integration of distributed generation resources to the power grid

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ABSTRACT

This paper explores stability issues for integration of distributed generation (DG) resources to the power grid by power electronic converters. Application of power converters in power distribution systems is becoming more and more common. Stability study of this kind of systems is crucial because of the potential for negative impedance instability of interfacing converters. In addition, in a power distribution system, a converter can lead to local instabilities when interacting with other dynamic subsystems. In this paper, to investigate the stability of system, the impedance-based small-signal model of each of the subsystem is respectively achieved and then an active control technique is proposed to stabilize the system. The proposed method depends on reshaping the input impedance of the interfaced converter by injection of an active stabilization signal at the control loop of the converter. MATLAB/Simulink simulations are conducted to demonstrate the effectiveness of the proposed control technique during various operating conditions.

Introduction

Nowadays distributed generation (DG) resources as an emerging power scenario for electric power generation, are becoming more and more popular due to the increase in energy demand and limitations on power delivery ability of the grid. Extensive researches have been conducted on DG systems, which consider various aspects, including technical [1–3], economical [4,5], and environmental [6]. It is estimated that the share of these resources (such as photovoltaic, wind turbine generator, fuel cell, and micro turbine) in electrical power grids will increase considerably in the near future [7,8].

The stable behavior is one of the most important factors in power networks. In DG systems, dynamic instability usually occurs than the steady-state one because of sudden changes of load or generated power leading to the system oscillation which is needed to be died out during a short period. Oscillations persisting for a long period can be a serious threat for integration DG resources to the power grid.

Generally, power electronic converters are widely utilized for the power injection from DG resources to the power grid. Converters-based DG systems have weaknesses such as potential for negative impedance instability [9]. This kind of instability is created via the nearly ideal regulation ability of advanced power electronics. As an example, consider a dc/ac converter whose input is integrated to a power distribution bus and whose output is connected to the power grid or supplies an ac load. In small-signal model, this converter appears as a negative impedance which causes system instability [10]. Consequently, the stability analysis of converter-based power distribution systems is a more critical task than in conventional power distribution systems.

Several studies have been reported in the literature regarding the control of interfacing converters for integration of DG resources to the power grid. For instance, the effect of grid impedance variations in stability of the grid-connected converter has been presented in [11]. A PI controller has been utilized to regulate the grid currents and another $H\infty$ controller has been used to achieve high robustness against the impedance variation. In [12] a control technique based on passivity has been proposed to increase the stability in DG systems and also achieving fast transient response. In this proposed model, a single-phase converter has been utilized with T filter to improve the quality of network currents. In [13] a control strategy for the interfacing converter has been designed for grid connected DG resources. The topology of interfaced system contains five level cascaded multilevel converter with fuzzy PI regulator to control the dc bus voltage. Synchronous reference frame theory has been tailored for the calculation of reference currents. In [14] a discreet sliding mode

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controller has been suggested to control the currents supplied through the DG link. In this method, a robust servomechanism problem (RSP) voltage regulator based on μ-framework has been used for the control of DG link in the grid. A software control method has been proposed in [15] which has the capability of providing active and reactive powers with an improved and fast dynamic response. Numerous nonlinear control methods have been reported in literatures to enhance the performance of DG technology in the grid [16–18]. A *dq*-PI current controller has been presented in [19,20]. The quality of the injected current to the power grid has been influenced by the proposed current control method. A review of linear and nonlinear current control methods has been reported in [21] with explanations of their advantages and disadvantages.

This paper proposes a simple and effective control technique for interconnection of DG resources to the power grid via interfacing converters. The proposed control technique depends on reshaping the input impedance of the interfaced converter by injecting an active stabilization signal at the control loop of the converter. Small-signal analysis is conducted to assess the system stability. The effectiveness of the proposed control technique in a typical system is verified by the MATLAB/Simulink software during several operating conditions.

The remainder of this paper is arranged into four sections. The detailed impedance-based model of the system is derived in Section 'Configuration and small-signal modeling of system'. Section 'Stability analysis of system and proposed control technique' addresses the interaction dynamic and instability in the system; and the proposed active stabilization technique is presented. Furthermore, simulations are carried out to show the applicability and feasibility of the developed control approach in Section 'Simulation results'. Finally, the conclusion is given in Section 'Conclusion'.

Configuration and small-signal modeling of system

System configuration

Fig. 1 illustrates the configuration of the investigated system. As shown, a DG station is formed by various DG resources and battery as energy storage. A dc/ac converter is used to connect the dc bus and ac grid. In fact, the converter acts as an interface between the DG source and the power grid.

System modeling

Analysis of distributed power systems are frequently based on impedance models developed by means of averaging linearization methods. In this approach, in order to eliminate individual converter discontinuity, averaging techniques are employed first to their models. The achieved averaging models are usually nonlinear and can be linearized around a given operation point-in the form of input and output impedance-to expand small-signal linear models. Then, stability of the system can be determined through source output impedance and load input impedance. In this subsection, impedance-based small-signal model of each of the subsystem is established.

DG source

Equivalent circuit of the DG source is considered by an ideal voltage source in series with the source impedance. The output equivalent impedance of the DG source includes the dc bus capacitor C_{dc} with a series resistance R_{dc} and inductance L_{dc}. Therefore, the output impedance of the DG source is expressed by:

$$dZ_{source}(s) = \frac{L_{dc}s + R_{dc}}{L_{dc}C_{dc}s^2 + R_{dc}C_{dc}s + 1} \tag{1}$$

DC/AC converter

The current equations of the dc/ac converter can be described in the *d–q* reference frame as follows:

$$V_{ld} = (R + sL)I_{ld} - \omega L I_{lq} + V_{gd} \tag{2}$$

$$V_{lq} = (R + sL)I_{lq} + \omega L I_{ld} + V_{gq} \tag{3}$$

where V_{ld}, V_{lq}, I_{ld} and I_{lq} are the *d–q* axis converter's output voltages and currents. V_{gd} and V_{gq} are the *d–q* axis grid's voltages. s and ω are the Laplace operator and voltage angular speed, respectively.

The equations of the current controllers can be given as in (4)–(7):

$$V_{ld}^{inv} = \left(I_{ld}^{ref} - I_{ld}\right)(K_p + K_i/s) - \omega L I_{lq} + V_{gd} \tag{4}$$

$$V_{lq}^{inv} = \left(I_{lq}^{ref} - I_{lq}\right)(K_p + K_i/s) + \omega L I_{ld} + V_{gq} \tag{5}$$

$$I_{ld}^{ref} = P^{ref}/1.5V_{gd} \tag{6}$$

$$I_{lq}^{ref} = Q^{ref}/1.5V_{gd} \tag{7}$$

where K_p and K_i are the proportional and integral gains of the current PI controller, respectively.

Since the main objective of DG systems is to provide active power, Q^{ref} is considered very less than P^{ref}. Assuming high efficient dc/ac converter, applying linearization on power equation with $\overline{I_{lq}} = 0$ and ignoring the term dI_{lq}, we have:

$$\overline{V_{dc}}dI_{inv} + \overline{I_{inv}}dV_{dc} = 1.5(\overline{V_{ld}}dI_{ld} + \overline{I_{ld}}dV_{ld}) \tag{8}$$

Applying small perturbations on (2):

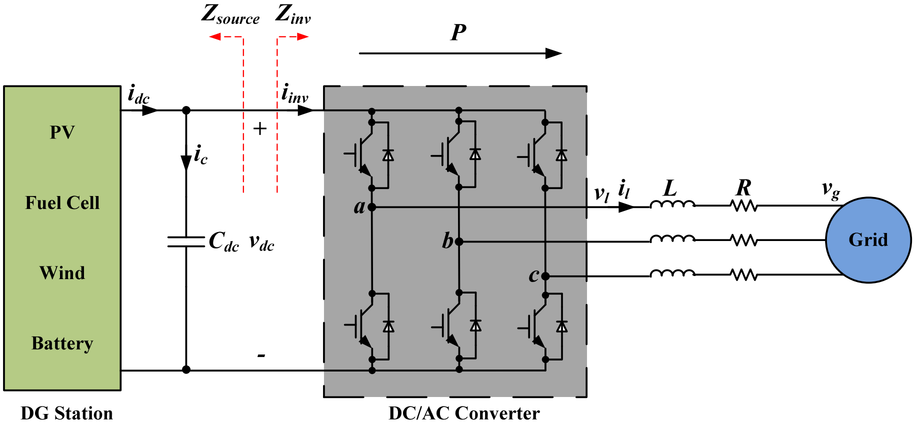

Fig. 1. System under study.