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Coordinated control of multifunctional inverters for voltage support and harmonic compensation in a grid-connected microgrid

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ABSTRACT

In this paper, a coordinated harmonic compensation and voltage support scheme is presented for distributed generations' (DGs') interface inverters in a resistive grid-connected microgrid. Voltage support is performed by reactive power compensation which can mitigate the over/under voltage problem; furthermore, the active power curtailment is proposed in order to mitigate the overvoltage problem when the reactive power compensation is not sufficient. Harmonic compensation is achieved by using virtual admittances in selected harmonic frequencies. Reactive power and harmonic compensation currents are injected with regards to the limited capacity of the interface inverter. If necessary, the reference powers of the grid-tied inverters are changed. Voltage support and harmonic compensation can be achieved based on local or central (communication-based) measurement schemes. The effect of communication delay is also investigated in this study. Experimental and simulation results are obtained in order to demonstrate the effectiveness of the proposed method.

1. Introduction

Voltage Source Inverters (VSIs) are widely used for interfacing Distributed Generation (DG) systems to the grid [1]. The DG interfacing inverters can contribute in voltage support [2–13] and harmonic compensation [12–21] of Microgrids (MGs) and utility grids. These inverters known as multifunctional inverters inject power to the grid and the remaining capacity of the inverter can be dedicated to voltage support and power quality enhancement [10].

To fully comprehend the voltage support of the DG interfacing inverters, reactive power compensation is conventionally proposed in distribution systems [2–7,11,12] and MGs [8–10] in order to mitigate the over/under voltage problems. Overvoltage can be created because of high penetration of Wind Turbine (WT) and Photovoltaic (PV) systems [2]. In Refs. [2,3], the voltage rise problem caused by high penetration of DGs in an LV distribution system has been studied and a droop-based reactive power control is proposed for Current Controlled Mode (CCM) of VSIs. In these papers, the reactive power compensation by DGs interfacing inverters is considered. In Refs. [4,5], the voltage rise mitigation based on active power curtailment in distributed systems has been proposed. The power curtailment algorithms of Refs. [4,5] are based on local measurement and communication system, respectively. In Ref. [6], different reactive power methods for DG units are studied. The reactive power control approaches in Ref. [6] can be classified into distributed and central controller based schemes. The reactive power control of DG interfacing inverters is also studied in Ref. [7]. In this paper, only a grid-connected interfacing inverter is considered whereas in grid-tied MGs more DG units can exist while a coordinated control of the units is required. In Refs. [8,9], voltage and frequency support functions of utility scale PV systems have been proposed. In Ref. [8], the performance of a PV system in voltage sag/swell compensation is evaluated based on the small signal modeling of utility scale PV and power system. In addition, the frequency support is added in Ref. [9]. In Refs. [10,11], the voltage support by Voltage Control Mode (VCM) VSIs in a grid-connected MG has been discussed, while, while it is obvious that, PV and WT systems are integrated as CCM VSIs.

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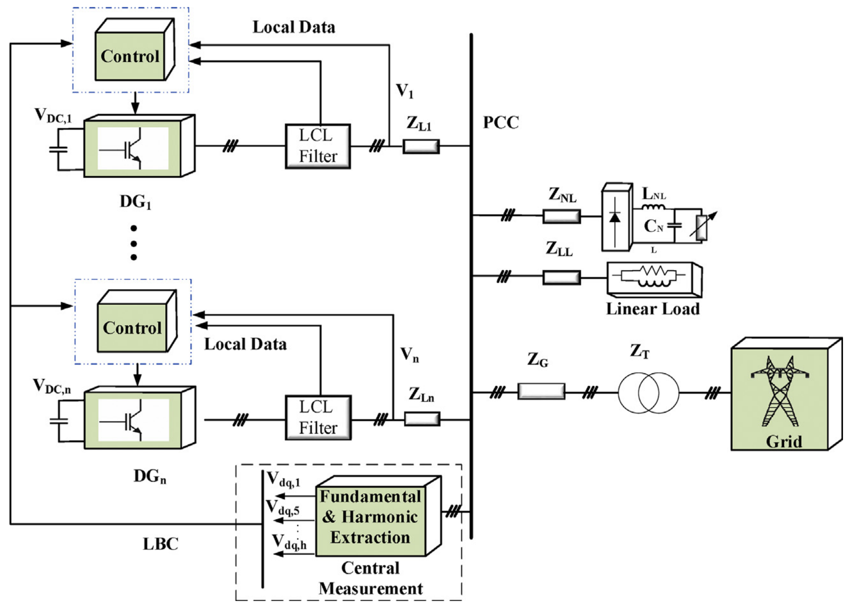

Fig. 1. General overview of the system.

On the other hand, use of DGs interface inverters for compensation of harmonics has been proposed in Refs. [12–22]. The harmonic compensation can be achieved based on communication systems and a central controller [12–17] or local measurement [18–22]. In the communication-based compensation, the data which is used for harmonic compensation is obtained by central controller or measurement whereas in the local compensation; the compensation is achieved without any need for communication systems. In central controller based methods, the compensation can be performed more exactly and more effectively whereas the reliability of the system is decreased and the cost and complexity of the system are increased. The method of Ref. [15] is based on central measurement of Point of Common Coupling (PCC) voltage in a grid-connected MG. In Ref. [15], the harmonic compensation is achieved by central measurement and using VCM VSIs with decentralized controller. In other words, inverters are controlled locally based on the information received from a remote bus. However, in grid-connected MGs, the interfacing VSIs of PV and WT units operate in CCM and their remaining capacity of them (which can be dedicated to harmonic compensation) changes during a day because of the maximum power point variation. The limited capacity of the inverters is not considered in Ref. [15] and the communication system failure can deactivate the harmonics compensation.

Using capacitive virtual impedance which can compensate the harmonic voltage drops of lines and filter impedances has been recommended as a local compensation for VCM VSIs in Refs. [18–20]. Using virtual admittance is recommended for the harmonic compensation by CCM VSIs in distribution system [21] and VCM VSIs in a grid-connected MG [22]. In Refs. [21,22], the control of grid-tied VCM VSI is done by using a fixed value of virtual admittance and local measurement.

In the present paper, a coordinated harmonic compensation and voltage support method are proposed for CCM VSIs in a grid-tied MG. A weak MG with high resistance is chosen as a case study. A voltage support approach with local and central measurement of PCC voltage is proposed in this paper. The voltage support algorithm can mitigate under/over voltage problems of the grid-tied MG by using reactive power control with considering the limited capacity of the inverters; furthermore, a power curtailment algorithm is proposed in order to mitigate voltage rise problem when the reactive power compensation is not sufficient. The voltage support algorithm is flexible in using central or local measurement of voltage. In addition, a harmonic mitigation method is proposed based on the virtual admittance which has also the flexibility for changing from central measurement to local measurement when the communication system failure happens or the delay of the communication system is too high.

The main contributions of the paper are listed below:

- A coordinated control of CCM VSIs for harmonic compensation and reactive power sharing/support.
- Considering the limited capacity of the inverter in harmonic and reactive power compensation.
- Voltage rise mitigation by using reactive power control and power curtailment of the DG interfacing inverters.
- Flexibility for choosing the local or remote (central) measurement.
- Considering the effect of communication system delay on power quality improvement.

Rest of the paper is presented as follows; Section 2 is focused on the general scheme of the system under study. Section 3 describes the details of the control system. Afterwards, simulation and experimental results are presented in Section 4. Finally, the paper is concluded in Section 5.

2. General scheme of the system

Fig. 1 shows the general overview of the grid-connected MG. As shown in this figure, each CCM VSI (DG_n) which can be considered as interfacing inverter of PV or WT unit is connected to the PCC via impedance (Z_{Ln}). The line impedances are considered resistive in order to simulate the distribution system lines. The MG is connected through a line and a transformer with impedances represented by Z_G and Z_T, respectively. The voltage of PCC bus is measured and the harmonics extraction is achieved using *dq* transformation. In order to increase the reliability of the communication system, low bandwidth communication (LBC) system is used; hence, the transmitted data should be in DC, as the results of the applied extraction method are DC values in *dq* synchronous reference frame. The details of PCC fundamental and harmonics extraction can be found in Ref. [15]. The fundamental and harmonic transmitted data are fed to each DG