A Voltage Controlled DG Unit Based Active Harmonic Damping for Grid Connected and Islanding Micro grids

Pallavi M. Bile[1], A.ShravanKumar[2]
[1]*PG Scholar, Dept. of Electrical Eng., FTC Sangola, India*
[2]*Assistant Professor, Dept. of Electrical Eng., FTC Sangola, India*

Abstract- **The use of underground cables and shunt capacitor banks may present power distribution system resonances. Due to different behaviour at harmonic frequencies, specific harmonic mitigation methods shall be developed for current controlled and voltage-controlled DG units. In this paper centers on developing a voltage-controlled DG unit-based active harmonic damping method for grid-connected and islanding micro grid systems. An upgraded virtual impedance control method with a virtual damping resistor and a nonlinear virtual capacitor is proposed. The nonlinear virtual capacitor is used to compensate the harmonic voltage drop on the grid-side inductor of a DG unit LCL filter and the virtual resistor is mainly responsible for micro grid resonance damping. The efficiency of the proposed damping method is examined using both a single DG unit and multiple parallel DG units.**

Index Terms- **Active power filter, distributed power generation, droop control, grid-connected converter, micro grid, power quality, renewable energy system, resonance propagation, virtual impedance.**

I. INTRODUCTION

The growing use of nonlinear loads can led to significant harmonic pollution in a power distribution system. The harmonic distortion may stimulate complex resonances, mainly in power systems with underground cables or subsea cables. In fact, these cables with nontrivial parasite shunt capacitance can form an LC ladder network to amplify resonances. In order to moderate system resonances, damping resistors or passive filters can be placed in the distribution networks. Nevertheless, the mitigation of resonance propagation using passive components is subject to a few well understood issues, such as power loss and additional investment. Moreover, a passive filter may even bring additional resonances if it is designed or installed without knowing detailed system configurations.

To avoid the adoption of passive damping equipment, various types of active damping methods have been developed. Among them, the resistive active power filter (R-APF) is often considered as a promising way to realize better performance. Conventionally, the principle of R-APF is to emulate the behavior of passive damping resistors by applying a closed-loop current controlled method (CCM) to power electronics converters. In this control category, the RAPF can be simply modeled as a virtual harmonic resistor if it is viewed at the distribution system level. Additionally, a few modified R-APF concepts were also developed in the recent literature. In the discrete tuning method was proposed to adjust damping resistances at different harmonic orders. Accordingly, the R-APF essentially works as a nonlinear resistor. In the operation of multiple R-APFs was also considered, where an interesting droop control was designed to offer autonomous harmonic power sharing ability among parallel R-APFs. On the other hand, renewable energy source (RES) based distributed generation (DG) units have been adopted to form flexible micro grids and their interfacing converters also have the prospect to address different distribution system power quality issues. For current controlled DG units, the supporting R-APF function can be seamlessly incorporated into the primary DG real power injection function by modifying the current reference. However, conventional CCM can hardly provide direct voltage support during microgrid islanding operation.

To overcome this limitation, an enhanced voltage-controlled method (VCM) was recently proposed for DG units with high-order LC or LCL filters. It can be seen that the control method in regulates the DG unit as virtual impedance, which is dependent on the existing feeder impedance. When the feeder impedance is inductive, this method could not provide enough damping effects to system resonance. To achieve better operation of grid connected and islanding micro grids, the paper considers a simple harmonic propagation model in which the microgrid is placed at the receiving end of the feeder. To mitigate the feeder harmonic distortions, a modified virtual impedance-based active damping method that consists of a virtual resistor and a virtual nonlinear capacitor is also proposed. The virtual capacitor remove the impacts of LCL filter grid-side inductor and the virtual resistor is interfaced to the receiving end of the feeder to provide active damping service.

Circuit Diagram:

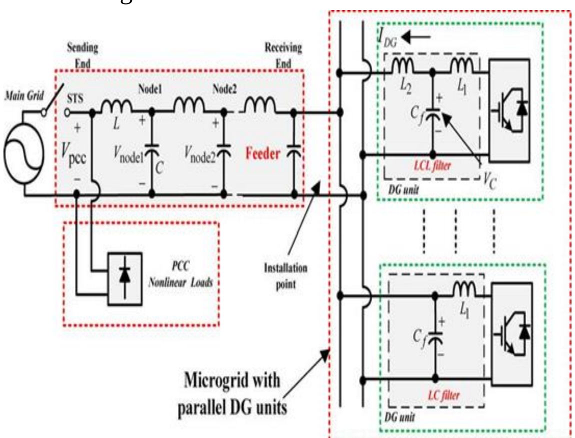

Fig.1. Simplified one-line diagram of a single-phase microgrid.

For the sake of simplicity, this paper only adopts a simple microgrid configuration to demonstrate how the microgrid power quality is affected by resonance propagation. In addition, this paper also assumes that shunt capacitor banks and parasitic feeder capacitances are evenly distributed in the feeder.

II. MODELING OF DG UNITS IN MICROGRID SYSTEM

A. Distributed Parameter Model in Grid-Tied Operation:

For a long feeder, as shown in Fig. 1, a lumped parameter model is not able to define its resonance propagation char-acteristics. Alternatively, the distributed parameter model was discussed in [3] and [6], where the voltage distortions at PCC induce a harmonic voltage standing wave beside the feeders. To make the discussion more straightforward, we assume that the microgrid in the feeder receiving end only consists of one DG interfacing converter. In the succeeding section, the modelling of resonances in multiple DG-unit-based microgrid is discussed. With the aforementioned assumption, the equivalent circuit model of a grid-tied micro grid at the kth harmonic frequency is presented in Fig. 2, where the kth PCC harmonic voltage is assumed to be stiff and Vpcck• Vk (x)and Ik (x) are the feeder kth harmonic voltage and harmonic current at position x. The length of the feeder is l

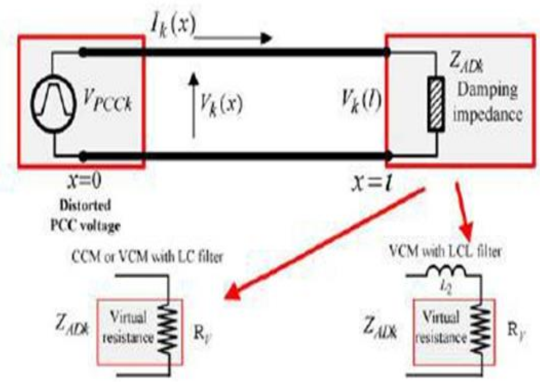

Fig.2. Equivalent circuit of a single grid-connected DG unit at the kth harmonic frequency.

It is easy to obtain the harmonic voltage–current standing wave equations at the harmonic order k as

$$V_k(x)=Ae^{-\gamma x}+Be^{\gamma x}$$

$$I_k(x)=1/z(Ae^{-\gamma x}-Be^{\gamma x})$$

where A and B are constants, which are determined by feeder boundary conditions. z and γ are the characteristics impedance [3] of the feeder without considering the line resistance as

$z=\sqrt{L/C}$

$\gamma=jk\omega_f\sqrt{LC}$

where ωf is the fundamental angular frequency and L and C are the feeder equivalent inductance and shunt capacitance per kilometer, respectively.

B. Distributed Parameter Model in Islanding Operation:

The previous section focuses on the analysis of grid-tied DG units. For an islanding microgrid system, the VCM operation of DG units is needed for direct voltage support. When only a single DG unit is placed in the islanding system, constant voltage magnitude and constant frequency (CVMCF) control can be used. Considering the focus of this section is to investigate the harmonic voltage damping in a stand-alone islanding system, a single DG unit at the receiving end of the feeder is considered. The circuit model of an islanding system at the harmonic order k is illustrated in Fig. 3, where VCM-based DG unit is also modeled as an equivalent harmonic impedance using the control scheme in . The nonlinear PCC load in this case is modelled as a harmonic current source at the sending end of the feeder [3].

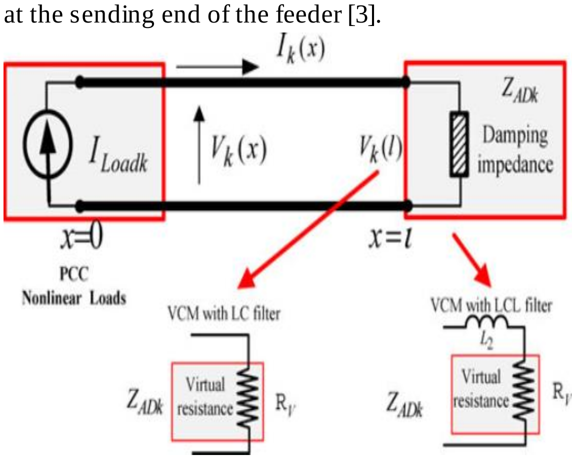

Fig.3.Equivalent circuit of a single islanding DG unit at the kth harmonic frequency

With the knowledge of boundary conditions at both sending and receiving ends as

Ik(0)=ILoadk

(V_k (l))/(I_K (l))=Z_ADk

The voltage propagation in an islanding system harmonic is also related to the DG-unit equivalent harmonic impedance In order to maintain satisfied voltage quality, the equivalent harmonic impedance of islanding DG units shall also be properly designed

III. SIMULATION RESULT

Simulated results have been obtained from a single-phase low voltage micro grid where a few DG units are interconnected to the point of common coupling (PCC) through a long underground feeder. For the sake of simplicity, this paper only adopts a simple microgrid configuration to demonstrate how the microgrid power quality is affected by resonance propagation. [Note that the static transfer switch (STS) controls the operation mode of the micro grid. When the main grid is disconnected from the micro grid, the PCC nonlinear loads shall be supplied by the standalone DG units.

A. Single DG Unit Grid-Tied Operation:

At first, the performance of a grid-connected single DG unit with an LCL filter with damping and without damping is observed.

a) Single DG Unit Grid-Tied Operation Without damping

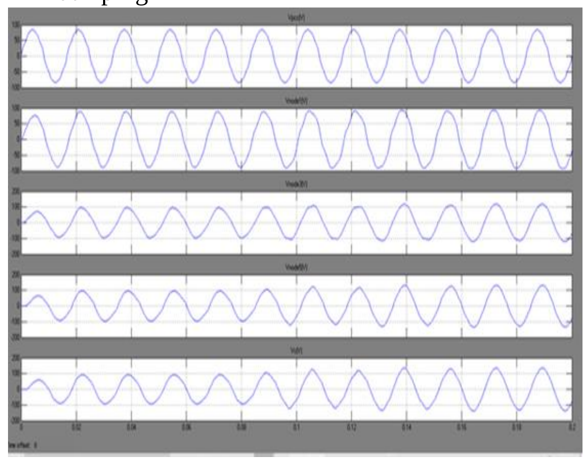

Fig.4. During a single DG unit grid connected operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD = 4.04%); (b) node 1 voltage (THD = 4.57%); (c) node 3 voltage (THD = 3.13%); (d) node 5 voltage (THD = 2.93%); (e) DG unit filter capacitor voltage (THD = 2.07%)]

b) Single DG Unit Grid-Tied Operation With damping

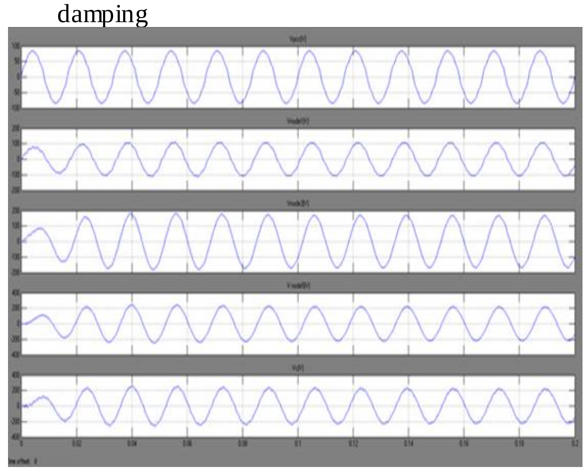

Fig.5. During a single DG unit grid connected operation harmonic voltage amplification (with damping) [from upper to lower: (a) PCC voltage (THD = 4.03%); (b) node 1 voltage (THD = 3.71%); (c) node 3 voltage (THD = 1.39%); (d) node 5 voltage (THD = 1.03%); (e) DG unit filter capacitor voltage (THD = 3.16%)]

When the conventional VCM method without damping is applied to the DG unit, the harmonic voltages at PCC, nodes 1, 3, 5, and DG unit filter capacitor are presented in Fig. 4. When the proposed control method with a virtual nonlinear capacitor and a virtual damping resistor is applied to the DG unit, the harmonic voltage drops on the LCL filter grid-side inductor (L2) are compensated and the DG unit behaves as a damping resistor at the end of the feeder. The results in Fig. 5 show that the resonance along the feeder is mitigated.

B. Single DG Unit Islanding Operation:

In addition to grid-connected operation, the performance of a single DG unit in islanding operation is also investigated. In this case, the PCC load is a single-phase diode rectifier and it is supplied by the DG unit through long feeder. the performance of a islanding DG unit with an LCL filter with damping and without damping is observed.

a) Single DG Unit Islanding Operation Without damping

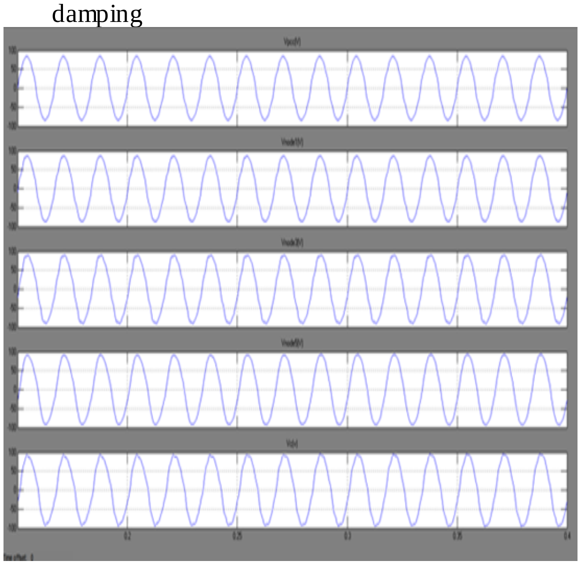

Fig.6. During a single DG unit islanding operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD =4.03%); (b) node 1 voltage (THD = 3.87%); (c) node 3 voltage (THD =3.95%); (d) node 5 voltage (THD = 3.17%); and (e) DG unit filter capacitor voltage (THD = 4.65%)].

b) Single DG Unit Islanding Operation With damping

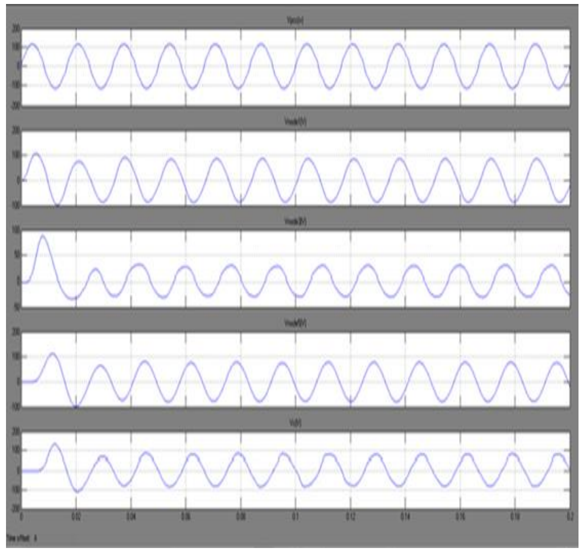

Fig.7. During a single DG unit islanding operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD =4.03%); (b) node 1 voltage (THD = 2.05%); (c) node 3 voltage (THD =3.82%); (d) node 5 voltage (THD = 0.59%); and (e) DG unit filter capacitor voltage (THD = 2.59%)].

When the conventional VCM method without damping is applied to the DG unit in islanding mode, the harmonic voltages at PCC, nodes 1, 3, 5, and DG unit filter capacitor are presented in Fig.6. When the proposed control method with a virtual nonlinear capacitor and a virtual damping resistor is applied to the DG unit, the harmonic voltage drops on the LCL filter grid-side inductor (L2) are compensated and the DG unit behaves as a damping resistor at the end of the feeder. The results in Fig. 7 show that the resonance along the feeder is mitigated.

IV. CONCLUSION

In this paper, a voltage controlled dg unit based active harmonic damping for grid connected and islanding micro grids is investigated. To actively mitigate the resonance using DG units, an enhanced DG unit control scheme that uses the concept of virtual impedance is proposed. Specifically, the capacitive component of the proposed nonlinear virtual impedance is used to compensate the impact of DG unit LCL filter grid-side inductor. The resistive component is responsible for active damping.

REFERENCES

[1] H. Akagi, H. Fujita, and K. Wada, "A shunt active filter based on voltage detection for harmonic termination for radial power distribution system," IEEE Trans. Ind. Appl., vol. 35, no.4, pp. 682–690, Jul./Aug. 1995.

[2] K. Wada, H. Fujita, and H. Akagi, "Consideration of a shunt active filter based on voltage detection for installation on a long distribution feeder," IEEE Trans. Ind. Appl., vol. 38, no. 4, pp. 1123–1130, Jul./Aug. 2002.

[3] P.-T. Cheng and T.-L. Lee, "Distributed active filter systems (DAFSs): A new approach to power system harmonics," IEEE Trans. Ind. Appl.,vol. 42, no. 5, pp. 1301–1309, Sep./Oct. 2006.

[4] T.-L. Lee and P.-T. Cheng, "Design of a newcooperative harmonic filtering strategy for distributed generation interface converters in an islanding network," IEEE Trans. Power Electron., vol. 42, no. 5, pp. 1301–1309, Sep. 2007.

[5] T.-L. Lee, J.-C. Li, and P.-T. Cheng, "Discrete frequency-tuning active filter for power system harmonics," IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1209–1217, Apr. 2009.

[6] T.-L. Lee and S.-H. Hu, "Discrete frequency-tuning active filter to suppress harmonic resonances of closed-loop distribution power system," IEEE Trans. Power Electron., vol. 26, no. 1, pp. 137–148, Dec. 2010.

[7] N.Pogaku and T. C. Green, "Harmonic mitigation throughout a distribution system: A distributed-generator-based solution," IEE Proc. Gener. Transmiss. Distrib., vol. 153, no. 3, pp. 350–358, May 2006.

[8] C. J. Gajanayake, D. M. Vilathgamuwa, P. C. Loh, R. Teodorescu, and F. Blaabjerg, "Z-source-inverter-based flexible distributed generation system solution for grid power quality improvement," IEEE Trans. Energy Convers., vol. 24, pp. 695–704, Sep. 2009.

[9] Y.W. Li, D. M. Vilathgamuwa, and P. C. Loh, "Design, analysis and realtime testing of a controller for multibus microgrid system," IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1195–1204, Sep. 2004.

[10] Q.-C. Zhong and G. Weiss, "Synchronverters: Inverters that mimic synchronous generators," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1259–1267, Apr. 2011.

[11] J. He and Y. W. Li, "Analysis, design and implementation of virtual impedance for power electronics interfaced distributed generation," IEEE Trans. Ind. Appl., vol. 47, no. 6, pp. 2525–2538, Nov./Dec. 2011.

[12] Y. W. Li and C. N. Kao, "An accurate power control strategy for power electronics- interfaced distributed generation units operating in a low voltage multibus microgrid," IEEE Trans. Power Electron., vol. 24, no.12, pp. 2977–2988, Dec. 2009.