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Active Damping Method for Mitigation of Resonance Propagation in Grid-connected and Islanding Microgrid by using FLC

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Abstract

The shunt capacitor banks and underground links application can present force circulation framework resonances. At that point the effects of current controlled and voltage controlled circulated era (DG) units to microgrid reverberation spread is researched. A straight voltage controlled DG unit with a LC channel has a short out component at the chose symphonious frequencies. While a current controlled DG unit exhibits an open circuit qualities. Because of various practices at consonant frequencies, particular symphonious moderation systems are created for voltage controlled and current controlled DG units individually. A voltage controlled DG unit-based dynamic symphonious damping strategy for both framework associated framework and islanding microgrid framework is talked about in this paper. An enhanced virtual impedance control technique with a virtual damping resistor and a nonlinear virtual capacitor is prescribed. The adequacy of the proposed damping procedure is investigated by utilizing both a solitary DG unit and twofold or various parallel DG units. Here fuzzy logic is used for controlling the simpered systems tool has proved that the combined system will at the same time inject maximum power and provide dynamic frequency support to the grid.

Keywords: Active power filter, microgrid, distributed power generation (DPG), resonance propagation, virtual impedance, droop control, power quality.

I. INTRODUCTION

The snow balling use of nonlinear burdens can prompted noteworthy symphonious contamination in a force dispersion framework. The consonant contortion may energize troublesome resonances, for the most part in force frameworks with underground links and shunt capacitor banks. So as to diminish framework resonances, uninvolved channels or damping resistors can be put in appropriation systems. The alleviation of reverberation proliferation utilizing latent segments utilizing this parts are a couple surely knew issues, for example, extra speculation and force misfortune, on the grounds that an aloof channel may notwithstanding bring extra resonances on the off chance that it is the framework composed or introduced without knowing itemized about framework designs.

To get away from the appropriation of uninvolved damping gear, diverse sorts of dynamic damping techniques have been created, among them the resistive dynamic force channel (R-APF) is oftentimes considered as a promising approach to understand the well execution. Customarily, the rule of R-APF is to copy the practices of aloof damping resistors by applying a shut circle current-controlled technique (CCM) to control electronic (PE) converters.

This control class the R-APF can be simply displayed as a virtual symphonious resistor in the event that it is seen at the dispersion framework levels. The discrete tuning strategy was proposed to Conform damping resistances at different consonant requests. The R-APF basically functions as a nonlinear resistor, The procedure of different R-APFs was likewise considered, where an intriguing hanging control was intended to proposition self-ruling symphonious force sharing capacity among parallel R-APFs.

For current controlled DG units, the helper R-APF capacity can be flawlessly consolidated into the essential DG genuine force infusion capacity by altering the present reference. The ordinary CCM can barely give direct voltage support amid microgrid islanding operation, and conquer this constraint, to improve the voltage-controlled technique (VCM) was as of late made arrangements for DG units with high-arrange LCL or LC channels. It can be seen that the control strategy in directs the DG unit as virtual impedance. Which is relies on upon the current feeder impedance, when the feeder impedance is inductive. This technique couldn't give enough damping impacts to framework reverberation.

To accomplish better operation of matrix associated and islanding small scale networks, this paper considers a basic consonant engendering model in which the microgrid is set at the less than desirable end of the feeder. To decrease the feeder consonant mutilations, an adjusted virtual impedance-based dynamic damping strategy that comprises of a virtual nonlinear capacitor and a virtual resistor is likewise proposed. The virtual capacitor expels the effects of LCL channel framework side inductor and the virtual resistor is interfaced to the less than desirable end of the feeder and to give dynamic damping administration.

II. MODELING OF DG UNITS IN MICROGRID SYSTEM

The figure1 delineates the arrangement of a solitary stage microgrid framework, where a couple DG units are interconnected to the point of normal coupling (PCC) through a

long underground feeder. A basic microgrid design to demonstrate the microgrid power quality is influenced by reverberation spread. Furthermore, shunt capacitor banks and parasitic feeder capacitances are uniformly accepted dispersed in the feeder.
Note: The static exchange switch (STS) controls the operation method of the microgrid. At the point when the primary framework is disengaged from the microgrid, then the PCC nonlinear burdens should be supplied by the standalone DG units.

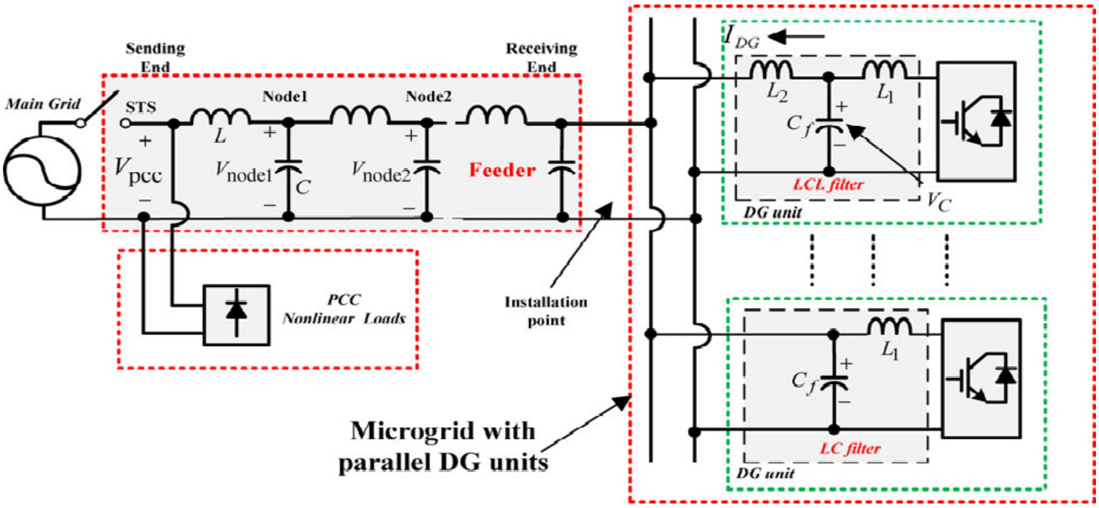


Fig.1: Simplified one-line diagram of a single phase microgrid.

A. Distributed Parameter Model in Grid Connected Operation

A lumped parameter model is not ready to depict its reverberation spread attributes. The voltage twists at PCC incite a consonant voltage standing wave along the feeders. To make the talk more clear, we expect that the microgrid in the less than desirable end of the feeder just comprises of one DG interfacing converter. In the following segment dialog, the demonstrating of resonances in different DG-unit-based microgrid is examined. With the aforementioned supposition, the proportionate circuit model of a matrix tied microgrid at the kth symphonious recurrence is displayed in figure 2, where the length of the feeder is l, kth PCC consonant voltage is thought to be hardened and Vpcck, Vk (x)and Ik(x) are the feeder kth symphonious voltage and consonant current at position x.

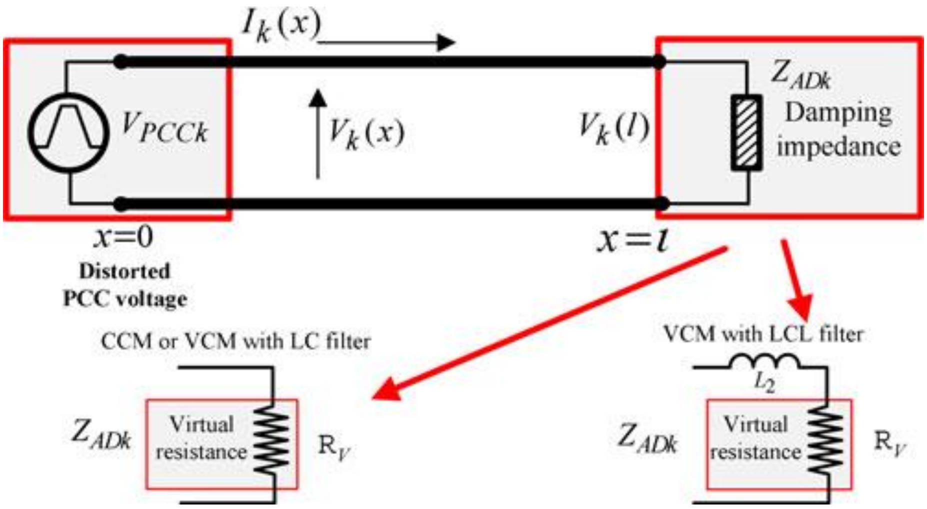


Fig.2: Equivalent circuit of a single grid-connected DG unit (k^{th} harmonic frequency).

Obtaining the harmonic voltage current standing wave equations at the harmonic order *k* is as follows

$$V_k(x) = Ae^{-\gamma x} + Be^{\gamma x} \quad (1)$$

$$I_k(x) = \frac{1}{z}(Ae^{-\gamma x} - Be^{\gamma x}) \quad (2)$$

Where *A* and *B* are constants and are determined by feeder boundary conditions. *z* and *γ* are the characteristics impedance of the feeder without considering the line resistance as

$$z=\sqrt{\frac{L}{C}} \quad (3)$$

$$\gamma = jkwf\sqrt{LC} \quad (4)$$

Where w_f is the fundamental frequency, L is the feeder equivalent inductance/km, C is the feeder equivalent shunt capacitance/km.

(1) DG Units with CCM and R-APF Control

Determine the boundary conditions of the feeder, the equivalent harmonic impedance (Z*ADk*) of the DG unit need be derived. The current reference (*I*ref) of a CCM-based DG unit can be obtained as

$$I_{reff} = I_{reff} - I_{AD} = I_{reff} - \frac{HD(S).V(l)}{Rv} \quad (5)$$

Here I_{reff} is the fundamental current reference for DG unit power control, I_{AD} is the harmonic current reference for system resonance compensation, *V* (*l*) is the measured installation point voltage at the receiving end of the feeder, *HD* (*s*) is the transfer function of a harmonic detector, which extracts the harmonic components of the installation point voltage, and *RV* is the command virtual resistance. The conventional CCM-based DG unit can be simply modelled as an open-circuit connection at the receiving end.

(2) DG Units with VCM and R-APF Control

The VCM-based DG units indirectly regulate the power flow through the control of filter capacitor voltage *VC*. For a conventional VCM based DG unit without harmonic damping, the voltage magnitude and frequency can be obtained from the drooping control scheme as

$$W_{DG} = W_F + D_P\ .\ (P_{reff} – P_{LPF}) \tag{6}$$

$$E_{DG} = E + Dq\ (Q_{reff} – Q_{LPF}) + \frac{kq}{s}\ (Q_{reff} – Q_{LPF}) \tag{7}$$

Here ω_{DG} and ω_f are the reference and nominal angular frequencies, *E*DG *and E* are the reference DG and nominal voltage magnitudes, *P*LPF and *Q*LPF are the measured power with low pass filtering, *Dq and Dp* are the droop slopes of the controllers. The equivalent impedance of VCM-based DG unit with an *LC* filter has previously been tuned to be resistive, by adding a DG line current (*I*DG) feed-forward term to the voltage control. Similarly, CCM can also be used to mitigate the harmonic propagation along the feeder as

$$\begin{aligned} V_{reff} &= V_{reff} - V_A \\ &= V_{reff} – R_V\ .\ (H_D(s)\ .I_{DG}) \end{aligned} \tag{8}$$

Where V_{reff} is the fundamental voltage reference derived from droop control. V_{AD} is the harmonic voltage reference for DG unit harmonic impedance shaping. I_{DG} is the measured DG unit line current (see the Figure 1). $H_D(s)$ is the transfer function of a harmonic detector, which extracts the harmonic components of DG unit line current. *RV* is the command of virtual resistance.

The following boundary conditions can be obtained

$$\frac{Vk(l)}{Ik(l)} = Z_{ADK} \tag{9}$$

$$V_K(0) = V_{PCCK} \tag{10}$$

Solving the equations 1, 2, 9 and 10 we get the harmonic propagation at the harmonic order k can be express as

$$V(x)_k = \frac{Zadk\ \cosh(\gamma(1-x)) + \sinh(\gamma(1-x))}{Zadk\ \cosh(\gamma l) + Z\ \sinh(\gamma l)} V_{PCCK} \quad (11)$$

B. Distributed Parameter Model in Islanding Operation

The VCM operation of DG units is needed for direct voltage support. When only a single DG unit is located in the islanding system, constant voltage magnitude and constant frequency (CVMCF) control can be used. Considering the focus on 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 k^{th} harmonic order is illustrated in Figure 3, where VCM-based DG unit is also modelled as an equivalent harmonic impedance using the control scheme. The nonlinear PCC load in this case is modelled as a harmonic current source at the sending end of the feeder.

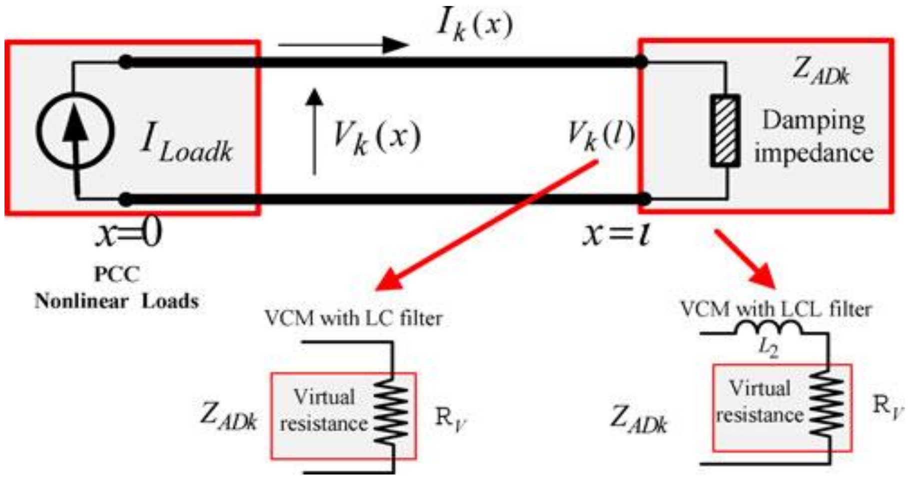


Fig. 3: Equivalent circuit of a single islanding unit (k^{th} harmonic frequency).

The knowledge of boundary conditions at both sending end and receiving end as

$$I_k(0) = I_{Loadk} \quad (12)$$

$$\frac{Vk(l)}{Ik(l)} = Z_{ADK} \quad (13)$$

k^{th} harmonic voltage distortion along the feeder can be obtained as

$$V_k(x) = \left(\frac{e^{-\gamma x}}{1 + (\frac{z - Zadk}{z + zadk}) e^{-2\gamma l}} - \frac{e^{\gamma x}}{1 + (z + zadk)/(z - zadk) e^{2\gamma l}} \right) Z_{Load}k \quad (14)$$

Equation (14) can be noticed that the voltage propagation in islanding system harmonic is also related to the DG-unit equivalent harmonic impedance.

III. ESTIMATION OF DAMPING PERFORMANCE

The performance of VCM-based DG units at different operation modes is investigated in this section.

A) Evaluation of a Single DG Unit at the End of the Feeder:

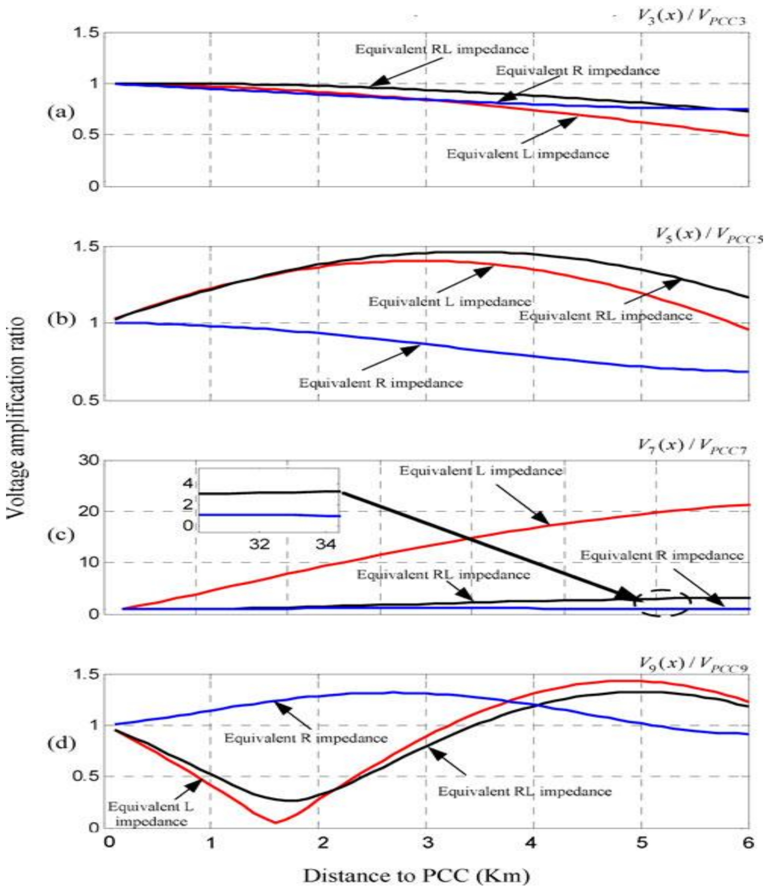


Fig.4: Harmonic voltage amplification in a single DG unit grid-connected operation

(I)Grid-Connected mode of Operation:

The performance of a grid tied DG unit with an *LCL* filter is investigated. Figure 4 is harmonic voltage distortions along a 6 km feeder. The harmonic voltage distortion factor here is normalized to the voltage distortions at PCC as $V(x)k/V_{PCCk}$, When the conventional VCM without damping is applied to the DG units, the *LCL* filter capacitor voltage is ripple free and the DG unit works as an inductor (*L*2) at the harmonic frequencies, It can be seen that the feeder is sensitive to 7th harmonic voltage distortion at the PCC. The maximum obvious 7^{th} harmonic voltage propagation is effectively reduced as shown Figure 4(c).

(II)Stand-alone mode of Operation:

A DG unit with an *LCL* filter in a standalone islanding system is examined. In contrast to the performance during grid-tied operation, the voltage distortion at PCC is not stiff in this case and it is dependent on the harmonic current from the PCC nonlinear loads. The associated harmonic propagation performance is obtained in Figure 5.

The 3rd harmonic current of PCC loads induces nontrivial harmonic voltage distortions at PCC when conventional VCM-controlled DG unit without using active damping is applied. The active damping using *RL* harmonic impedance can effectively reduce the 3rd harmonic voltage distortion. The performance at 3rd harmonic frequency, both equivalent *RL* and equivalent *R* impedances can effectively overpower the long feeder voltage distortions at 5th, 7th, and 9th harmonic frequencies.

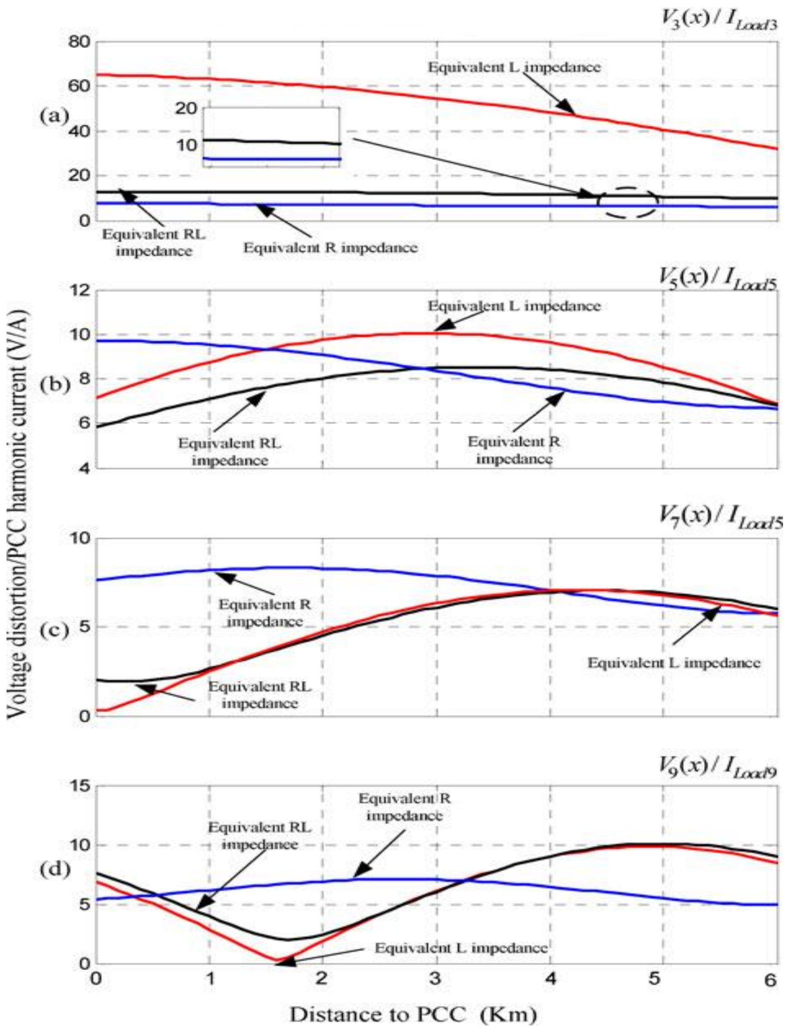


Fig 5: Harmonic voltage amplification in a single DG unit islanding operation

B. Evaluation of Multiple DG Units at the End of the Feeder

The performance of a microgrid with multiple DG units is increasingly discussed in the recent literature. In addition to achieve proper power sharing among multiple DG units, realizing superior harmonic damping performance in a collaborative manner is also attractive. For parallel DG units as shown in Fig. 1, they shall share the active damping current according to their respective power rating. However, phase angle difference between damping resistor and *RL* damping impedance may bring some harmonic circulating currents. To simplify the discussion, two VCM controlled DG units at the same power rating are used to equally share the harmonic current associated with the active damping control.

If the DG unit with an *LC* filter is controlled as a harmonic damping resistor *R* while the other one with an *LCL* filter is regulated as the *RL* damping impedance, the corresponding circuit diagram at the harmonic order *k* can be illustrated in Fig. 6. As shown, the harmonic impedances of these two DG units have the same resistive part. However, for the DG unit with an *LCL* filter, its equivalent impedance also has an inductive part $jk\omega f L2$.

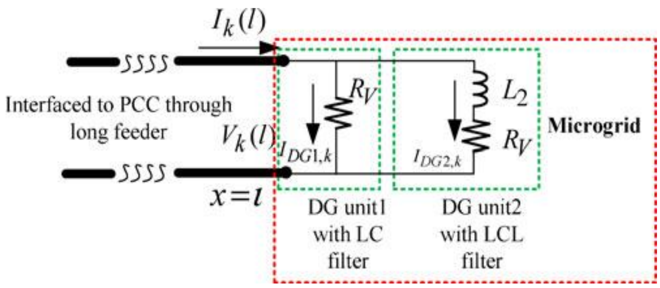


Fig. 6. Circuit diagram of a double-DG-based microgrid at the *k*th harmonic frequency.

IV. FUZZY LOGIC CONTROL

The Fuzzy logic control consists of set of linguistic variables. Here the PI controller is replaced with Fuzzy Logic Control. The mathematical modelling is not required in FLC. FLC consists of

1. Fuzzification

Membership function values are assigned to linguistic variables. In this scaling factor is between 1 and -1.

2. Inference Method

There are several composition methods such as Max-Min and Max-Dot have been proposed and Min method is used.

3. Defuzzificaion

A plant requires non fuzzy values to control, so Defuzzificaion is used. The output of FLC controls the switch in the inverter. To control these parameters they are sensed and compared with the reference values. To obtain this the membership functions of fuzzy controller are shown in fig (7).

The set of FC rules are derived from

$$u=-[\alpha E + (1-\alpha)*C] \quad (15)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable.

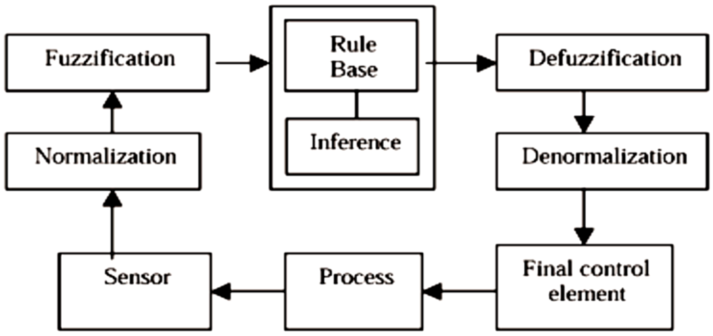


Fig. 7: Fuzzy logic Controller

A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible.

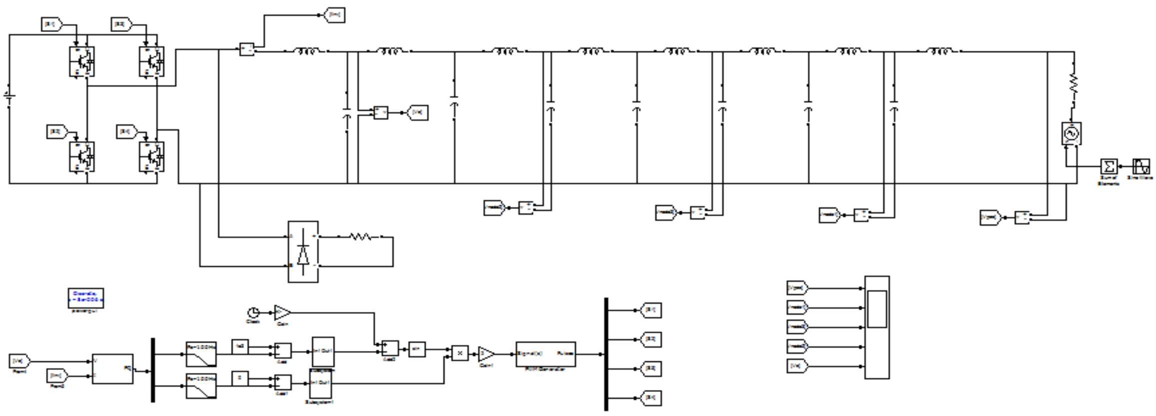


Fig.8: Simulation System Schematic Diagram.

V. SIMULATION RESULTS

Simulated results have been obtained from a single-phase low voltage microgrid by using Fuzzy Logic controller. To emulate the behaviour of six kilometres feeder with distributed parameters, a DG unit with an *LCL* filter is connected to PCC through a ladder network with six identical *LC* filter units. Each *LC* filter represents 1 km feeder. To provide some passive damping effects to the feeder, the *LC* filter inductor stray resistance is set to 0.12 Ω.

A. Single DG Unit Grid Tied Operation

At first, the performance of a grid connected DG unit with an *LCL* filter is examined. The PCC voltage in this simulation is stiff and it has 2.0% distortion at each lower order harmonic frequency (3rd, 5th, 7th, and 9th harmonics).

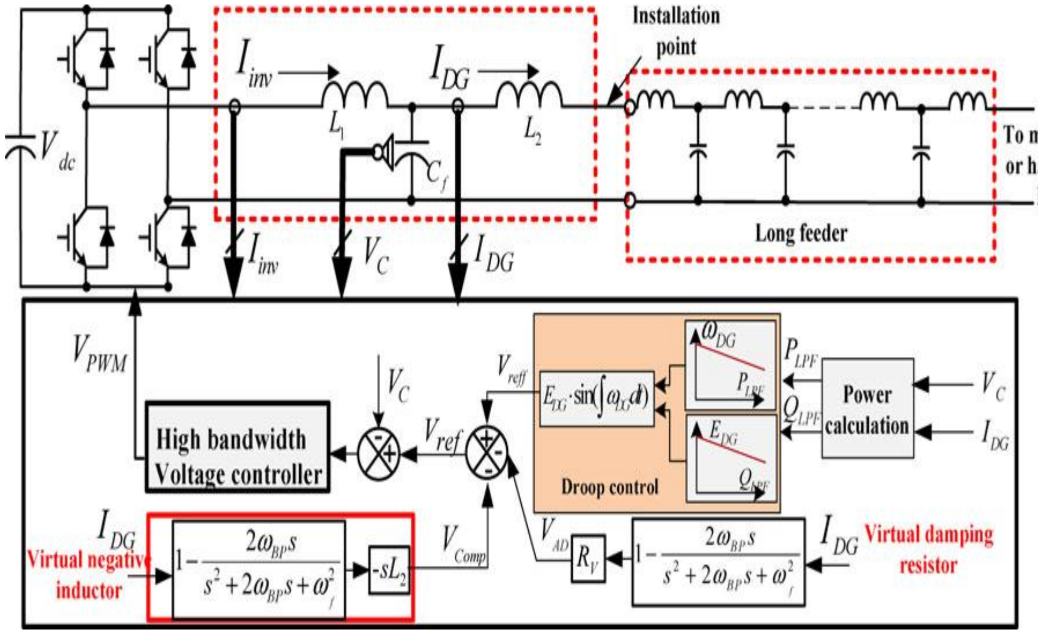


Fig.9. Mitigation of distribution feeder harmonic propagation using virtual resistor and virtual negative inductor.

Consequently, the total harmonic distortion (THD) of PCC voltage is 4.0%. 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. 10. The node numbers here represent the distance (in kilometres) from the voltage measurement point to PCC.

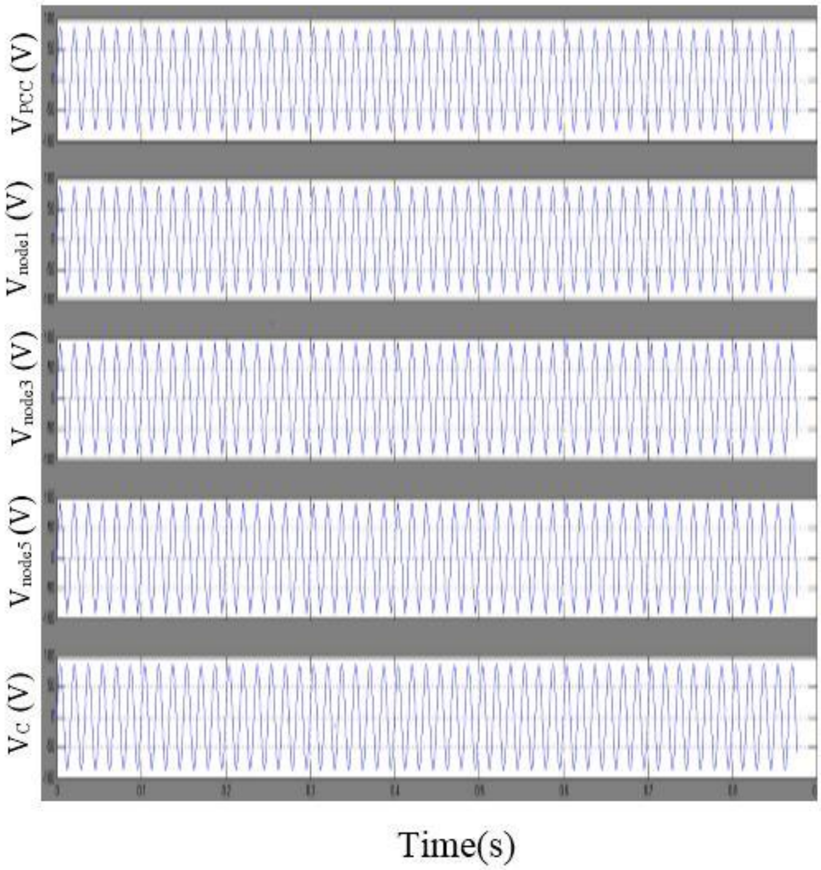


Fig.10. Harmonic voltage amplification during a single DG unit grid connected operation (without damping) [from upper to lower: (a) PCC voltage (THD = 4.0%); (b) node 1 voltage (THD = 4.56%); (c) node 3 voltage (THD = 10.91%); (d) node 5 voltage (THD = 12.59%); (e) DG unit filter capacitor voltage (THD = 0.38%)].

It can be seen the 7th harmonic voltage is more obviously amplified at the nodes 3 and 5. This is consistent with the analysis in Fig. 4(c), where the feeder is sensitive to the 7th harmonic voltage at PCC. At the same time, the DG unit *LCL* filter capacitor voltage is almost ripple free as shown in channel (e), as no damping control scheme is applied to the DG unit. 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 (*L*2) are compensated and the DG unit behaves as a damping resistor at the end of the feeder. However, compared to the situation without any damping in Fig. 10(e), the capacitor voltage of the DG unit as shown in Fig. 11(e) is distorted due to the regulation of virtual harmonic impedance.

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. When the conventional VCM without damping is adopted, the performance of the system is obtained in Fig. 12.

Similar to the grid tied operation, the voltage waveforms at PCC, nodes 1, 3, and 5, and DG unit filter capacitor are shown from channels (a) to (e), respectively. It can be easily seen that the third voltage distortions are more obviously amplified. This performance is also consistent with the theoretical analysis in Fig. 5. It demonstrates that the third harmonic distortion observed in Fig. 12 is effectively suppressed.

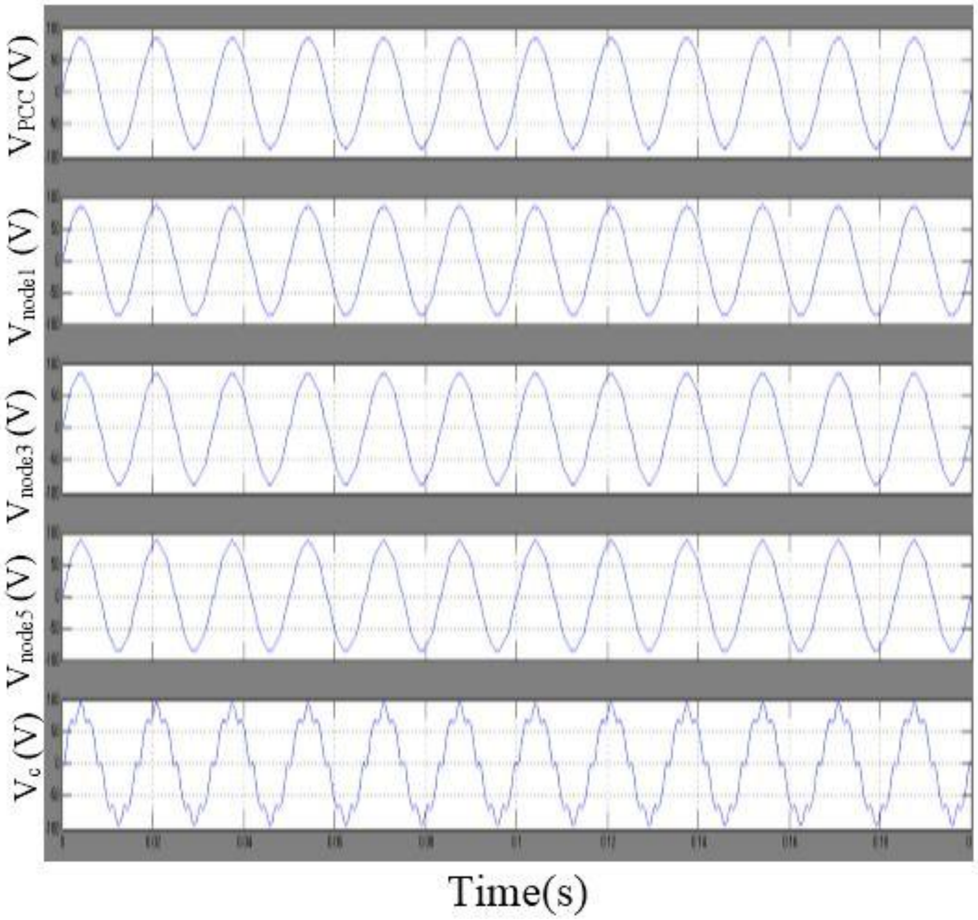


Fig.11. Harmonic voltage amplification during a single DG unit grid connected operation (with virtual nonlinear capacitor and resistor based active damping) [from upper to lower: (a) PCC voltage (THD = 4.0%); (b) node 1 voltage (THD = 4.1%); (c) node 3 voltage (THD = 3.7%); (d) node 5 voltage (THD = 3.2%); and (e) DG unit filter capacitor voltage (THD = 5.4%)].

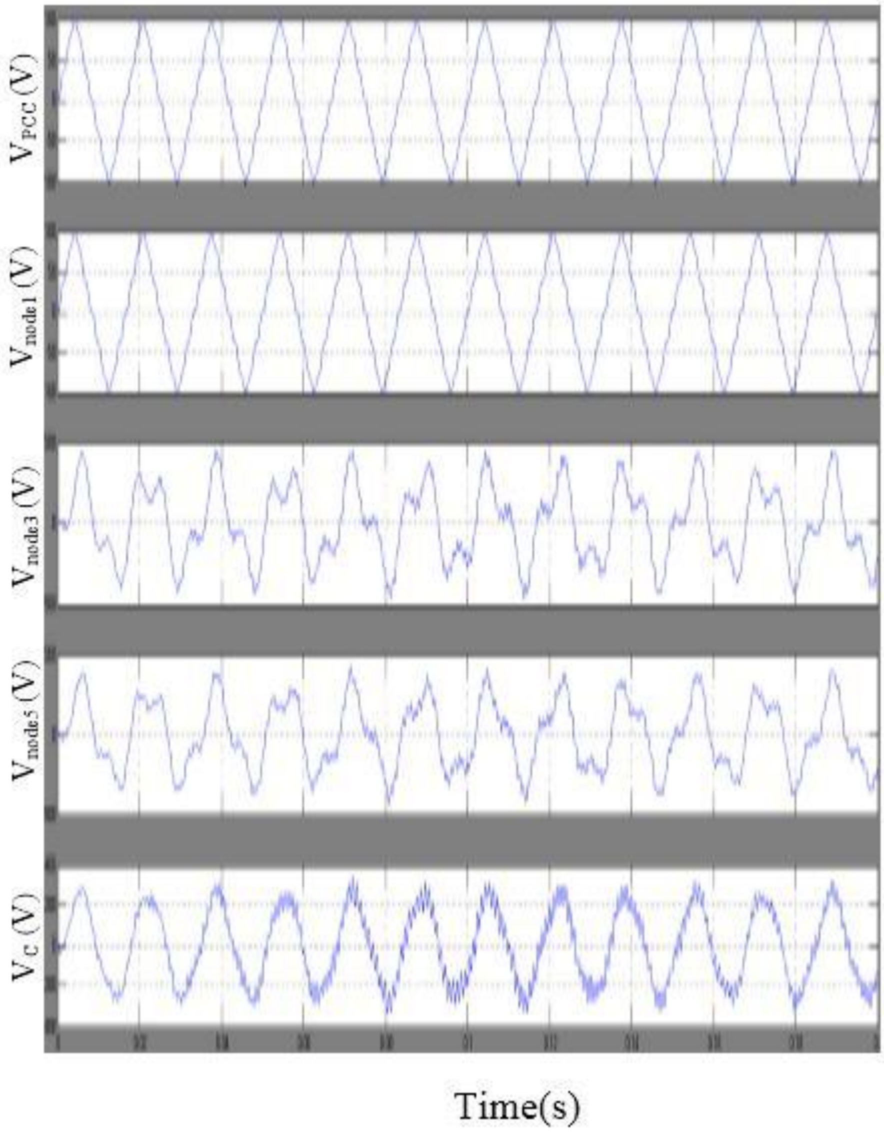


Fig.12. Harmonic voltage amplification during a single DG unit islanding operation (without damping) [from upper to lower: (a) PCC voltage (THD = 15.2%); (b) node 1 voltage (THD = 14.7%); (c) node 3 voltage (THD = 11.9%); (d) node 5 voltage (THD = 10.5%); and (e) DG unit filter capacitor voltage (THD = 1.6%)].

C. Multiple DG Units Grid-Tied Operation

To verify the circulating harmonic current between multiple DG units, two grid connected DG units at the same power rating are placed at the receiving end of the feeder. In this simulation, DG unit 1 is interfaced to the feeder receiving end with an *LC* filter while DG unit 2 has an *LCL* filter. The PCC voltage harmonics are selected to be the same as that in Fig. 10. When both DG units are operating without any virtual impedance control, DG unit 1 essentially behaves as short circuit at the harmonics and DG unit 2 works as an equivalent inductor *L*2, The voltage waveform along the feeder is shown in the first column of Fig. 14. In this case, there are some voltage distortions at the nodes 1 and 3. When only virtual resistor regulation using (8) is applied to both DG units, it can be seen from the second column of Fig. 14 that harmonic voltage distortions are mitigated. Finally, DG unit 2 is further controlled with a nonlinear virtual capacitor to compensate the effects of its *LCL* filter grid side inductor; the associated voltage waveform is shown in the third column of Fig. 14.

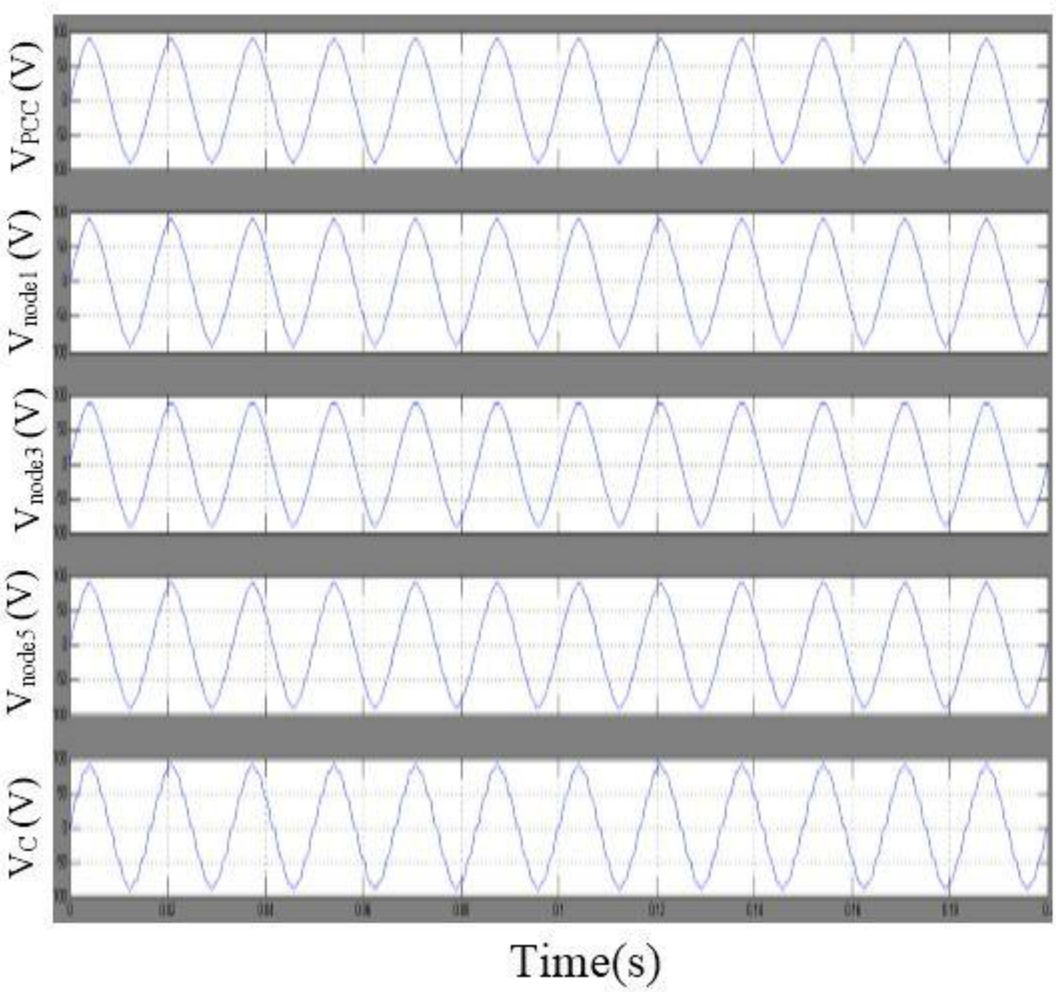
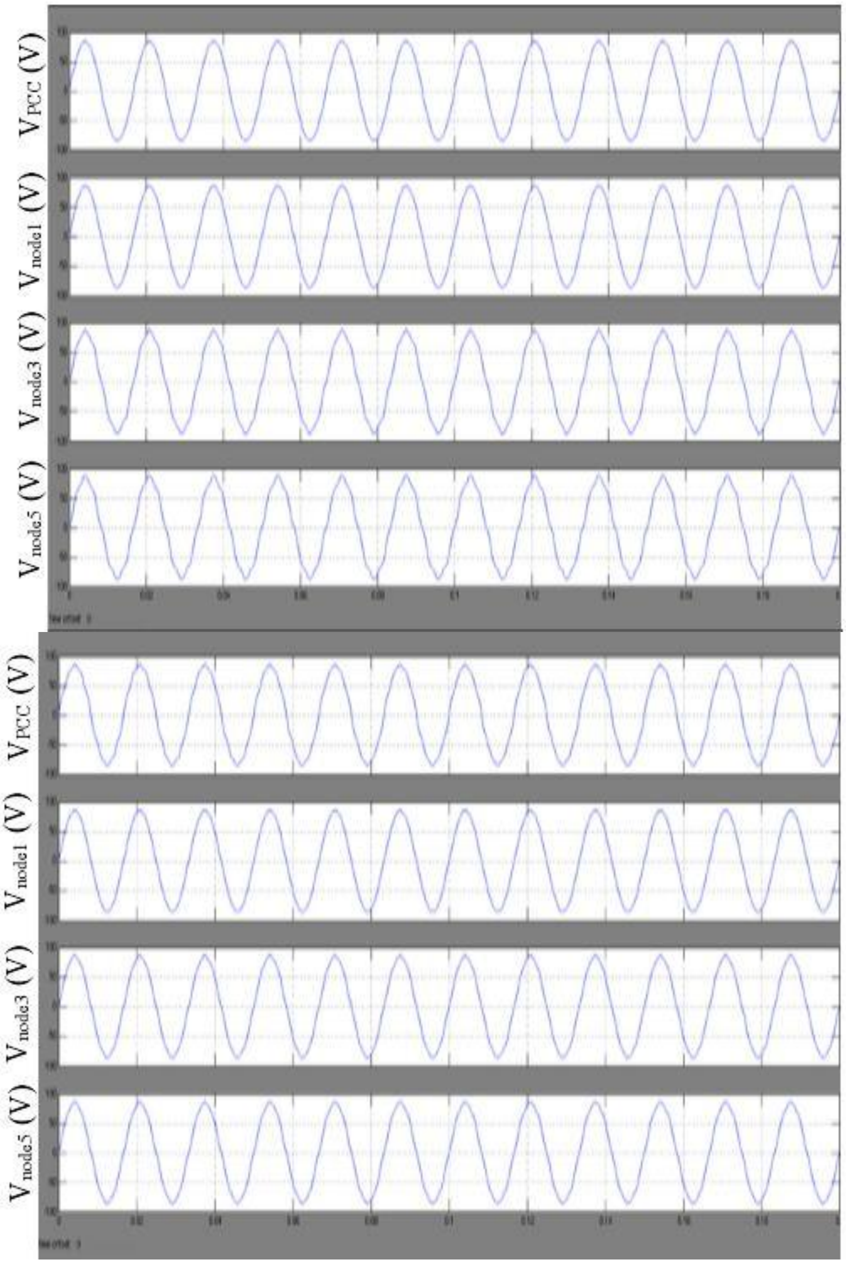


Fig.13. Harmonic voltage amplification during a single DG unit islanding operation (with virtual nonlinear capacitor and resistor based active damping) [from upper to lower: (a) PCC voltage (THD = 6.1%); (b) node 1 voltage (THD = 6.0%); (c) node 3 voltage (THD = 5.2%); (d) node 5 voltage (THD = 5.3%); and (e) DG unit filter capacitor voltage (THD = 7.1%)].

Although the difference between the second and third columns of Fig. 14 is not very obvious, the harmonic circulating current between parallel DG units can be noticeable.

Moreover, when the nonlinear virtual capacitor control is also applied to DG unit 2, the harmonic voltage drop on its *LCL* filter grid side inductor can be compensated and it also behaves as a virtual harmonic resistor. As a result, the harmonic circulating current among parallel DG units is effectively reduced.



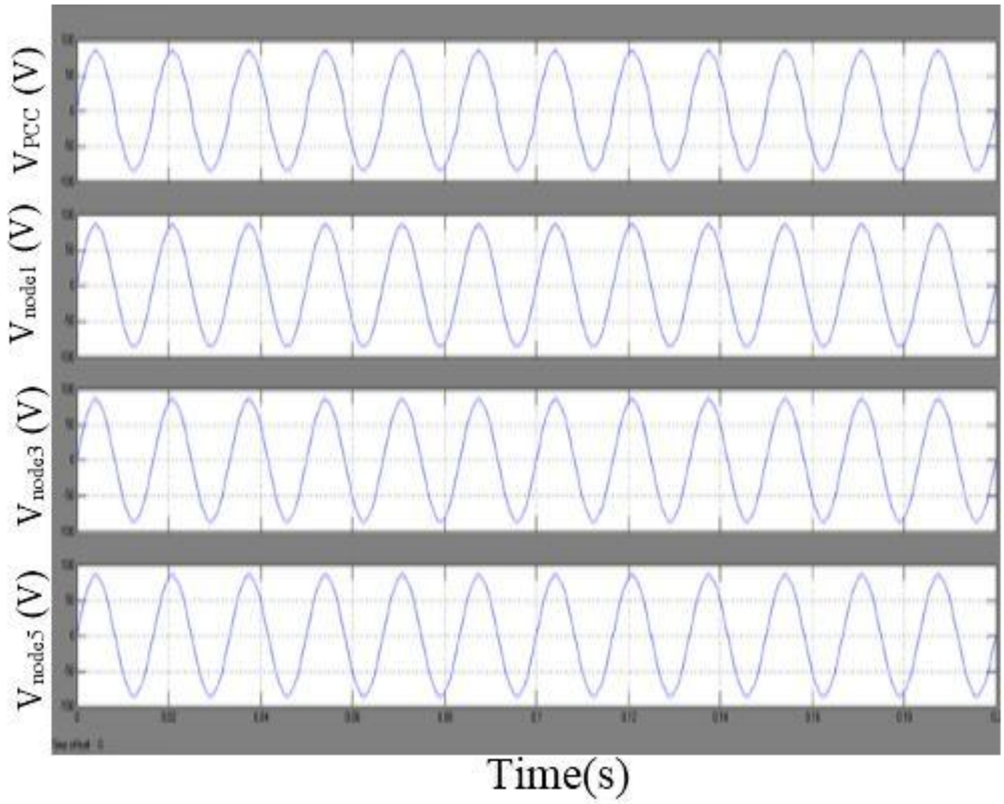


Fig. 14. Harmonic voltage amplification along the feeders (grid-tied operation of two parallel DG units).

CONCLUSION

This paper concludes that a microgrid resonance propagation model is investigated by using fuzzy logic controller and to actively mitigate the resonance using DG units. An enhanced DG unit control scheme that uses the concept of virtual impedance by fuzzy. Here fuzzy controller is used compared to alternative controllers because of its accurate performance. The capacitive component of the proposed nonlinear virtual impedance is especially used to compensate the impact of DG unit LCL filter grid side inductor. The resistive component is responsible for active damping, with properly controlled DG equivalent harmonic impedance at selected harmonic frequencies. The proposed method can also eliminate the harmonic circulating current, comprehensive simulations are conducted to confirm the validity of the proposed method.

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