# Residential Distribution System Harmonic Mitigation Using PV Interfacing Inverter

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**Abstract:** — In this study, electricity quality was improved in residential areas by adopting distributed generating systems. In the distribution network, active and passive filters are utilised to counteract a harmonic resonance in residential areas. The harmonics were corrected to enhance distribution generation (DG) using a photovoltaic interface inverter. For utility providers, the rising non-linear demands in the typical home of today constitute a significant worry. The harmonic resonance generated by the installation of capacitor banks in the distribution network might make the issue worse. Passive or active filters are frequently employed to reduce harmonic distortions. Harmonic distortions caused by an increase in the use of electronic gadgets in households are a significant problem for utility providers. In addition to the deteriorating power quality, the harmonic current flow may disrupt the nearby phone lines. Because home loads are distributed, it is challenging to measure harmonics in a residential system. The possibility of employing photovoltaic (PV) interface inverters to correct the harmonics in home systems is investigated in this study. First, a system model including the residential load and DG is created. Then, using the virtual harmonic damping impedance idea, several compensation systems are thoroughly analysed and compared. Studies are also done on the system's capacitor banks' impacts. Through research and simulations, the efficiency of the harmonic compensatory schemes is confirmed under various scenarios.

**Keywords**: Distributed generation (DG), photovoltaic (PV),power quality improvement, harmonic compensation, renewableenergy, residential distribution system.

## I. INTRODUCTION

Renewable energy is produced using replenishable natural resources including wind, wave, sun, biomass, and tidal power. In recent years, the need for renewable energy has increased significantly. The surge in renewable energy production has been ascribed to the rise in the price of fossil fuels and the country's desire for greener energy sources. Governments and companies Due to their potential to create significant amounts of energy without producing greenhouse gases that can contribute to climate change, countries all over the globe are investing extensively in the development of technology to harness the power of clean, renewable energy sources. We are turning back to renewable energy sources as a result of the rise in fossil fuel prices and the environmental issues brought on by the usage of conventional fuels in recent years.

Renewable energy sources are limitless, clean, and have the potential for decentralised usage (they can be used in the same place as theyare produced). Additionally, they have the benefit of complementing one another, resulting in a positive integration. On electricity distribution networks all throughout the world, distributed generation (DG) units are becoming more and more prevalent. As more distributed energy resource-based distributed generation (DG) units are connected to the grid, the energy business is going through fundamental changes as a result of growing concerns about the cost of conventional energy, energy security, and greenhouse gas emissions. Electricity businesses are focusing increasingly on distributed generation systems in order to enhance power quality.

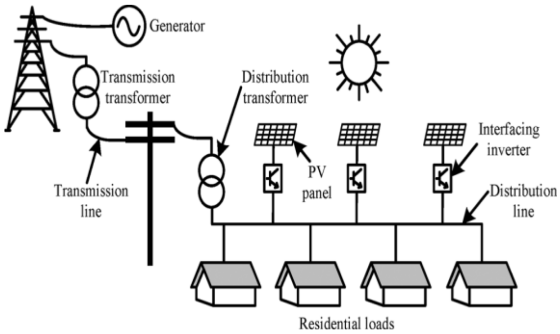



**Fig.1. Residential system with PV installations**

The telecommunications industry is particularly concerned about the harmonic current flow, which might interfere with nearby phone lines, in addition to the declining power quality. Due to the distributed nature of residential loads, harmonic compensation in residential systems is challenging. As a result, lump sum payments are only sometimes effective. Finding a practical method to offset scattered load harmonics and enhance the power quality of the home distribution system is thus a crucial issue.

The power business is undergoing a paradigm transition as more distributed generation (DG) systems powered by renewable energy are connected to the power distribution network, in addition to having growing worries about power quality. These PV systems, which are linked to the grid as indicated in Fig. 1, do so using DG-grid interfacing inverters, which are primarily used to convert the voltage from the energy source to a voltage that can be easily connected to the grid and to send any additional power to the grid. If correctly managed, these DG-gridinterfacing converters may perform a variety of ancillary functions in addition to their principal actual power injection function, including power factor adjustment, voltage support, flicker avoidance, system harmonic compensation, and imbalance voltage compensation.

By effectively leveraging the available apparent power rating from the interface inverters, this potential for supplementary services may be achieved. This is possible since these inverters are typically not operating at full power due to the intermittent nature of renewable energy (such as PV). The idea of grid-interfacing PV inverters for system harmonic correction has been mentioned in the literature. However, the system that was previously studied is typically too simplistic (it frequently just consists of a few lines and loads) to produce accurate findings.

## II. SYSTEM MODELING

In this study, the harmonics of the home system are compensated for by controlling the PV inverters as virtual harmonic impedance at the harmonic frequencies. Therefore, the virtual impedance control idea is introduced in this part before the residential system model and harmonic compensation performances are explored. Without requiring the system to be connected to any physical components, virtual impedance simulates the effects of physical impedance.

When controlling DG inverters digitally, the virtual impedance is implemented by changing the voltage or current reference or the PWM signal. Either the fundamental frequency or the harmonic frequencies might have virtual impedance. The primary purposes of the basic frequency virtual impedance are DG power flow regulation and grid disturbance ride through. Active damping and harmonic correction for distribution systems are the two major uses of the harmonic virtual impedance. The virtual harmonic impedance and its management techniques are covered in more detail in the next subsections because the main focus of this work is on the system harmonics correction utilising PV inverters.

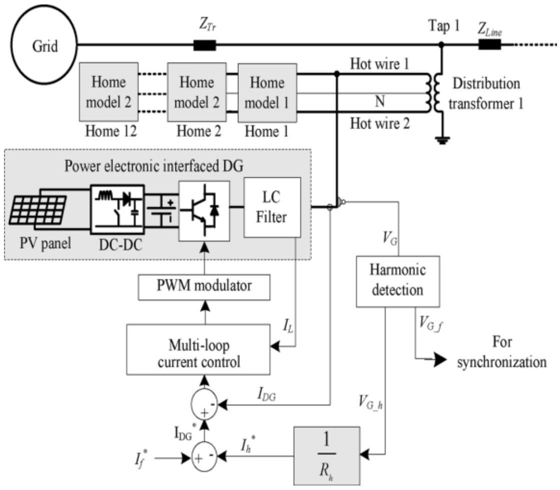



**Fig.2. Harmonic damping with R-APF based DG.**

The PV inverters act as R-APFs and regulate virtual harmonic resistance. Figure 2 displays a block schematic of the system harmonic damping control. The PV system in this illustration is a two-stage conversion system that consists of an inverter to connect the system to the grid and a DC-DC converter to boost the PV output to the DC link voltage level with MPPT management.

The output current reference of the PV system has two components: I the fundamental component, which results from the power factor and DC link voltage control loops (which are not shown in Fig. 2 because the focus is on harmonics compensation), and (ii) the harmonic components, which are used for harmonic compensation.

$$G_c = K_p + \sum_{h=1,5,7\ldots} \frac{2K_{ih}\omega_{ch}s}{s^2 + 2\omega_{ch}s + \omega_h^2}$$

The distribution system is modelled in the part that follows, and the previously described PV inverter system is then connected to the created distribution system model to examine the performance of harmonic correction.

$$i_{Lh} = \sum_{h=3,5,7\ldots} i_h$$

In the remaining sections of this work, regulated current sources at the required harmonic frequencies are utilised to model the PV inverter with virtual impedance control in order to prevent the impacts of various current control approaches on the PV inverter. This part develops the system model that includes the residential home load, PFC capacitor-equipped distribution systems, and PV inverters (with virtual harmonic impedance management). The remaining sections of the study employ the established models to analyse harmonic distortions and compensation performances using various strategies. The end-of-line compensation technique can be used in a distribution system with several PV systems by giving the PV inverters linked at the feeder's end harmonic compensation precedence.

These appliances are then linked to hot wires 1, 2, and neutral to build the home model, as illustrated in Fig. 3. As illustrated in Fig. 4, the built-in house models are integrated to a distribution system model. For the house model 1, all appliance models—aside from the dryer—are linked between hot wire 1 and the neutral, while for the home model 2, appliance models are connected between the neutral and hot wire 2. For both the home model 1 and the home model 2, the dryer model is linked to hot wires 1 and 2.

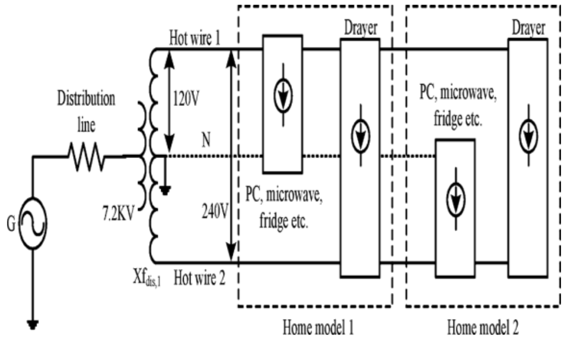



**Fig. 3.Connection configuration of home model 1.**

Locations of residential PV systems are typically unpredictable because they rely on which home has been installed. To get the optimum harmonic compensation outcome, an appropriate compensation approach should be established. However, coordinated management of the PV inverters in a system is achievable. The end-of-distribution-feeder (or end of line) compensation and distributed compensation are the two methods for harmonic compensation when utilising DG connecting inverters.

These capacitors could result in harmonic resonances and compromise the effectiveness of the harmonic correction. The analysis in the preceding sections is expanded in this part to take PFC capacitor effects into account. The position of the capacitor and the reactance value of the capacitor both affect the voltage profile along the distribution line with a capacitor. By enhancing power transfer capability, voltage control, and power factor, a capacitor linked to the end of a distribution network often offers the optimum performance for enhancing the voltage profile down the distribution line.

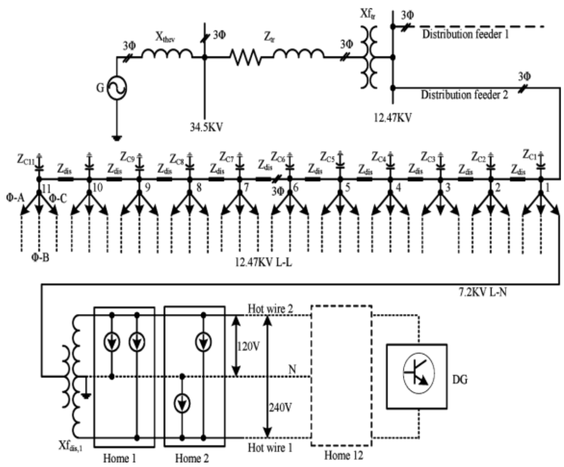



**Fig. 4.Distribution system model.**

On the other hand, the distributed compensationapproach can be implemented by operating all PV invertersin the harmonic compensation mode with equal priority.Capacitors are often installed in distribution systems forvoltage regulation and reactive power compensation. However, the most efficient capacitor placement also dependson the load, load power factor, line parameters of the distributionnetwork, and reactance value.Fig. 5 shows the simplified distribution feeder of the distribution system shown in Fig. 4 with DG connected at the secondaryside of the distribution transformer.

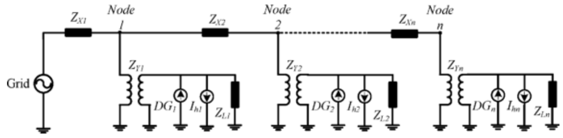



**Fig. 5.Typical distribution feeder with DG.**

Referring the system to the primary side of the transformer,the equivalent circuit of such a system is shown in Fig. 6 (notethat the same symbols as in Fig. 5 are used in Fig. 6 to representthe system. Also, as the analysis here focuses on harmonic frequencies,the source is shorted in Fig. 6).

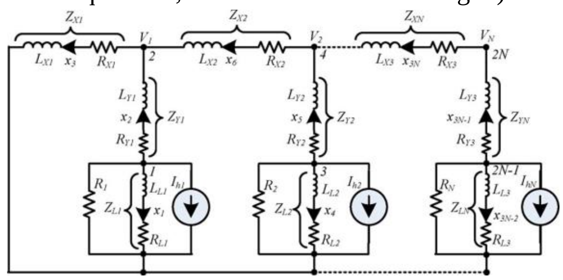


**Fig. 6.Equivalent circuit of an N node distribution feeder.**

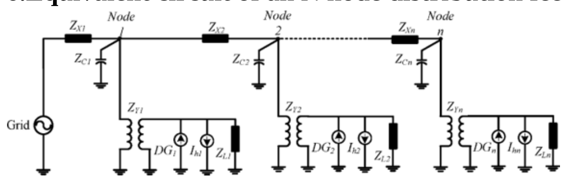



**Fig. 7.Typical distribution feeder with DG and PFC capacitors.**

The installation of the power factor correction (PFC) capacitorin the distribution system makes the harmonic issues complex,and some harmonics can be amplified. Although installingan active power filter may mitigate the harmonics at thepoint of installation in such a situation, the harmonics may beamplified on the other busses due to the whack and mole effects. To investigate the effectiveness of different harmoniccompensation schemes in such a situation, a distributionbus with capacitors connected has to be modeled. Fig. 7 showsthe equivalent distribution feeder of the distribution system withPFC capacitors. It also includes DG systems connected at thesecondary side of the distribution transformer.

## III. SIMULATION RESULTS

Matlab/Simulink was also used to do time domain simulations of an 11-node system in order to validate the results of the research presented above. The problem will include the relatively low frequency range since the house model contains harmonics up to the thirteenth in the time domain simulations. Different compensation systems' harmonic current and voltage contents along the distribution line are displayed, demonstrating how end-of-line compensation results in decreased low-order harmonics along the whole distribution line.

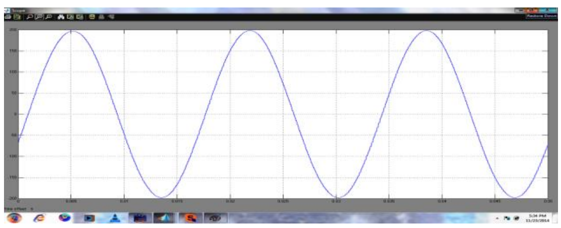


**Fig.8. Current through distribution line**

**Fig.9. current flowing from node 11 to primary side of distribution transformer 11**

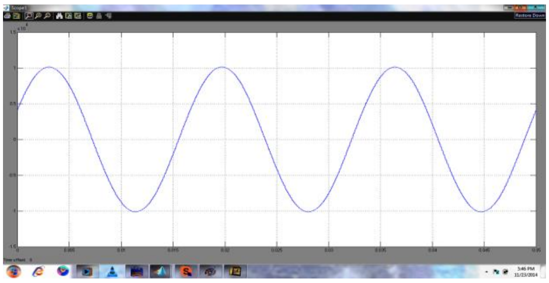


**Fig.10. Distribution voltages at node 1**

It shows the Distribution voltages at node 1 in distribution system by using the PV interfacing inverter and shows the improvement of the power quality.It shows the Voltage at node 11 in the distribution system using PV interfacing inverter and shows the improvement of the power quality.

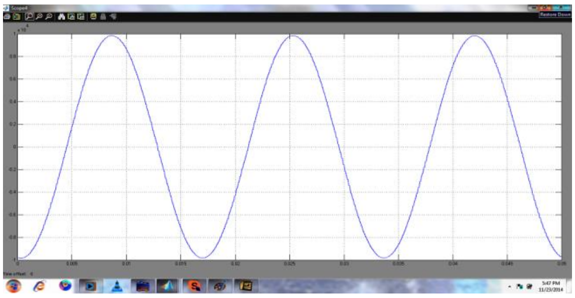


**Fig.11. Voltage at node 11**

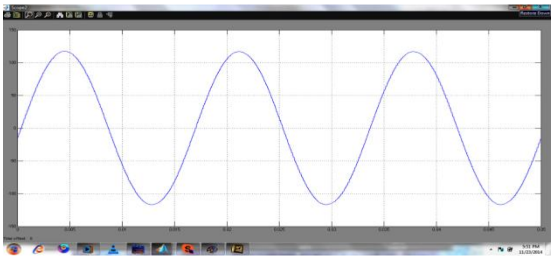


**Fig.12. hot wires 1 to neutral voltage of distribution transformer 11**

It shows the hot wires 1 to neutral voltage of distribution transformer 11 in the distribution generation system using the PV interfacing inverter and also shows the reduction of the harmonics. It shows the hot wires 1 to neutral voltage of distribution transformer 11 in the distribution system by using the PV interfacing inverter and shows the reduction of the harmonics.

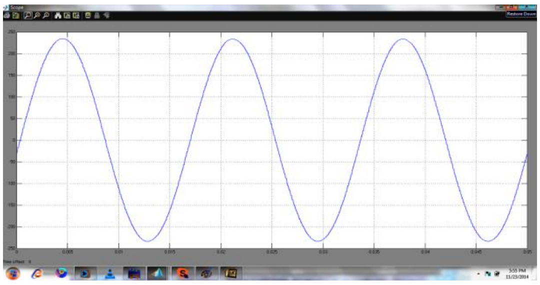


**Fig.13. hot wire 1 to hot wire 2 voltage of distribution transformer 11**

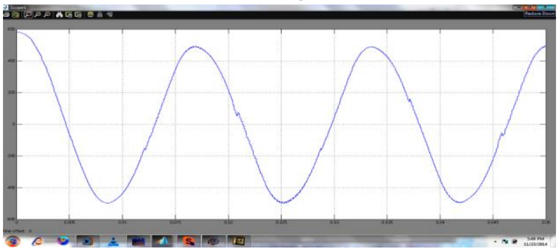


**Fig.14. current flowing through hot wire 1 of distribution transformer 11**

The current flowing through hot wire 1 of distribution transformer 11 in the distribution system by using the PV interfacing inverter and shows the harmonic compensation with the increasing of the power quality. It shows the distribution generation system harmonic current at 11th node in the distribution system using the PV interfacing inverter and shows the improvement of the power quality.

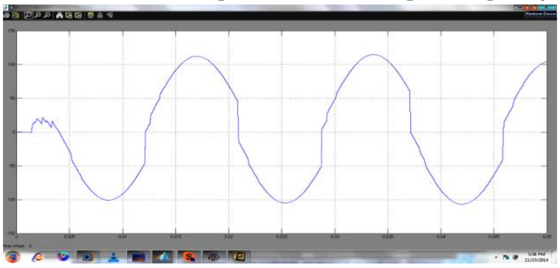


**Fig.15. DG harmonic current at 11th node**

Capacitors are often installed in distribution systems forvoltage regulation and reactive power compensation. Thesecapacitors may cause harmonic resonances and affect theharmonic compensation performance. This section extends theanalysis in the previous sections to include the effects of PFCcapacitors. It shows the Current through distribution line in the distribution generation system using the PFC capacitor and it is shows the less power quality improvement than the PV interfacing inverter.

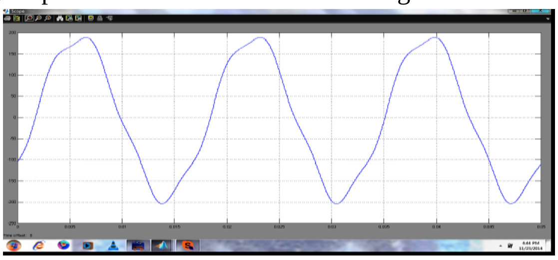


**Fig.16. Current through distribution line**

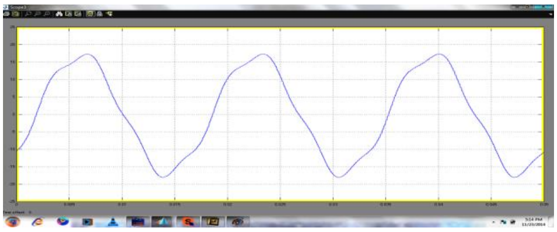


**Fig.17. current flowing from node 11 to primary side of distribution transformer 1**

The current flowing from node 11 to primary side of distribution transformer 1 in the distribution generation system using the PFC capacitor and it is shows the less power quality improvement than the PV interfacing inverter.The current flowing through hot wire 1 of distribution transformer 11 in the distribution generation system using the PFC capacitor and it is shows the less power quality improvement than the PV interfacing inverter.

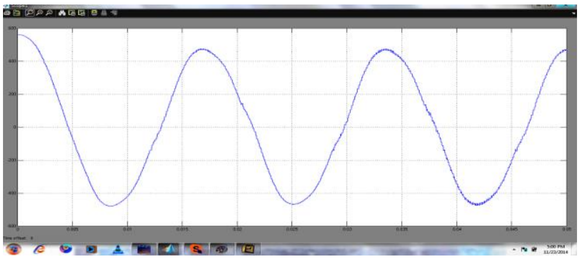


**Fig.18. current flowing through hot wire 1 of distribution transformer 11**

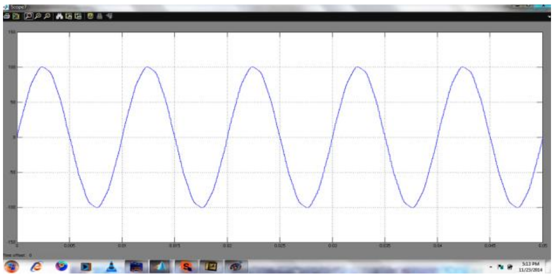
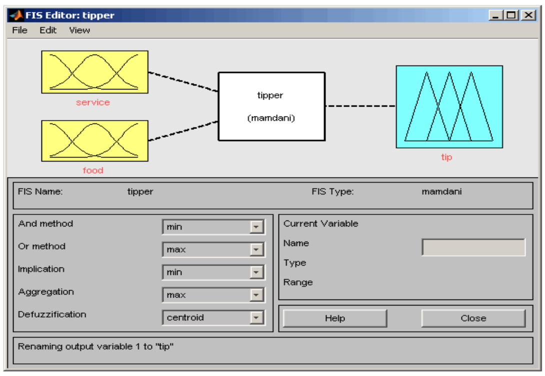


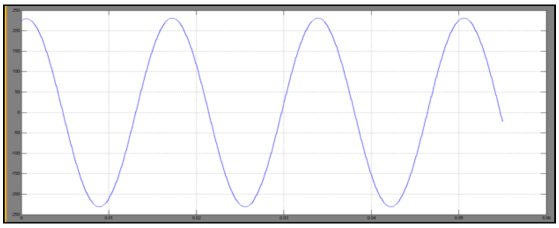
**Fig.19. DG harmonic current at 11$^{th}$ node**

Fuzzification is the process where the input crisp quantities are converted into fuzzy sets and also converts numeric (non fuzzy) input variables to linguistic (fuzzy) variables. The membership function is defined as errors and changes in error as Positive Small (PS), Positive Medium (PM), Positive Big (PB), Negative Small (NS), Negative Medium (NM) and Negative Big(NB).



The FIS Editor GUI tool allows you to edit the highest level features of the fuzzy inference system, such as the number of input and output variables, the defuzzification method used, and so on. Refer to The FIS Editor for more information about how to use the GUIs associated with fuzzy.The FIS Editor is the high-level display for any fuzzy logic inference system. It allows you to call the various other editors to operate on the FIS. This interface allows convenient access to all other editors with an emphasis on maximum flexibility for interaction with the fuzzy system.

Fuzzy based controller is designed to mitigate the harmonics and improve the harmonic performance and also reduces the harmonic distortion.In this work, a system model containing the DG and residential loads are first developed. Simulation results using MATLAB program shows the effectiveness of harmonic compensation strategies under different conditions. As in depth analysis and comparison of different compensation methods and effects of the capacitor banks in the system are also studied. This paper mainly discusses the effectiveness of harmonic compensation methods under different conditions.



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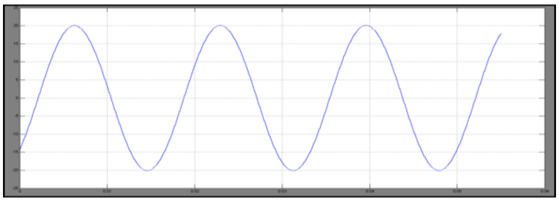

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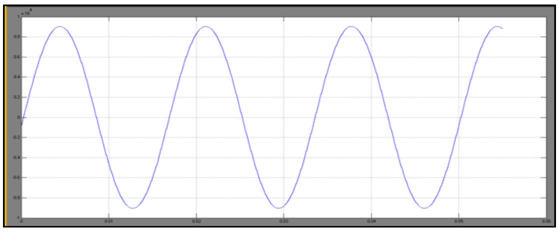

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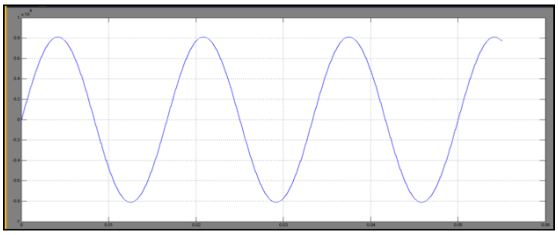

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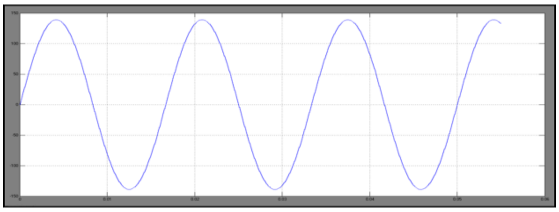

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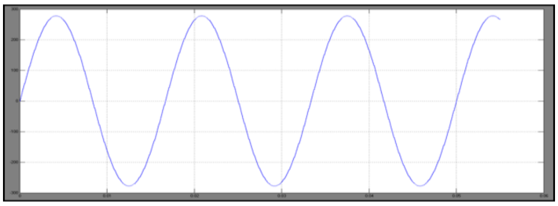

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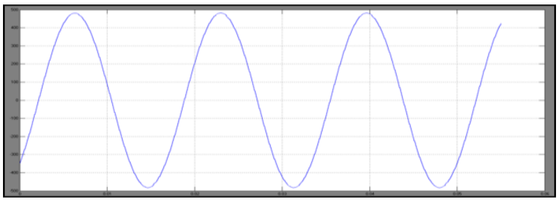

**(g)**

**Fig.20. (a) Current through distribution line, (b) Current flowing from node11 to primary side of distribution transformer 11, (c) Distribution voltage atnode 1, (d) Voltage at node 11, (e) Hot wire 1 to neutral voltage of distributiontransformer 11, (f) Hot wire 1 to hot wire 2 voltage of distribution transformer11, (g) Current flowing through hot wire 1 of distribution transformer 11.**

## IV. CONCLUSION

In this paper, we explored the idea of using residential system DG-grid interfacing inverters as virtual harmonic resistances todamp the system harmonics and improve the power quality. Anin-depth analysis and comparison of different harmonic compensationschemes were conducted to provide a guide for determiningwhether distributed compensation or end-of-line compensationshould be used. After such a determination has beenmade, proper priorities can be assigned to the inverters in thedistribution system for optimal compensation performance.Specifically, the analysis and simulation results showed thatthe end-of-line compensation provided better damping for loworderharmonics, whereas distributed compensation providedbetter damping for high-order harmonics if the equal equivalentrating of the DG was maintained. In the system without PFCcapacitors, this crossover frequency was quite high, and end-oflinecompensation performed better. However, the presence ofcapacitor in the system could significantly reduce this crossoverfrequency to around the 7th order harmonic, so the decisionabout which compensation strategy to use must be made accordingto the system load characteristics.Moreover, the effectsof capacitor sizes, line impedance, and length on the crossoverfrequency were also analyzed in this paper. With the informationabout a distribution system, the crossover frequency betweenthe two compensation strategies can be determined byusing the model developed in this work, and proper priority canbe assigned to the PV inverters at different locations.In our future work, we will consider a supervisory controlsystem of the DGs with communication in order to control theparticipation from each PV inverter automatically according tothe identified priority. Also, to provide an accurate effectivenessanalysis of the harmonics compensation by using PV invertersthroughout the day/season/year, the use of a statisticalhome model of a residential system and solar irradiance historicdata could also be considered.

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