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An Efficient Residential Distribution System Harmonic Compensation Using PV Interfacing Inverter

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Abstract: ***In this paper using distributed generation system in residential areas power quality is improved. To compensate harmonic resonance in residential areas, active and passive filters are used in distribution network. In the distribution generation (DG) system using photovoltaic interface inverter the harmonics were compensated. In general, increasing utilization of electronic devices in homes is a growing concern for utility companies due to harmonic distortions. The harmonic problem could be further complicated by the harmonic resonance introduced by other system components, such as the power factor correction (PFC) capacitors. Besides the degrading power quality, the harmonic current flow may interfere with the adjacent telephone lines. Compensating the harmonics in a residential system is difficult because of the dispersed nature of the residential loads. So, in this paper the power quality was improved reducing the load harmonics in residential distribution system. Due to installation of capacitor banks in the distribution network the harmonics resonance was worsen. So in order to reduce the harmonics distortion, active or passive filter are used.***

Index Terms**—Distributed generation (DG), photovoltaic (PV), power quality improvement, harmonic compensation, renewable energy, residential distribution system.**

I. INTRODUCTION

The increasing utilization of electronic devices in today's homes is a growing concern for utility companies due to harmonic distortions. The harmonic problem could be further complicated by the harmonic resonance introduced by other system components, such as the power factor correction (PFC) capacitors. Besides the degrading power quality, the harmonic current flow is also a concern for the telecommunication industry as this harmonic current flow may interfere with the adjacent telephone lines. Compensating the harmonics in a residential system is difficult because of the dispersed nature of the residential loads. Therefore, lump compensation at a few locations is not every effective. As a result, finding an effective way to compensate the dispersed load harmonics and improve the residential distribution system power quality is an important.

In addition to having increasing concerns about power quality, the power industry is experiencing a paradigm shift as more renewable energy based distributed generation (DG) systems are being connected to the power distribution network. A typical example is the increasing installation of rooftop photovoltaic (PV) systems in residential areas. As shown in Fig, these PV systems are connected to the grid through DG-grid interfacing inverters, which are used mainly to convert the voltage from the energy source to the voltage that can be readily connected to the grid, and to transfer the real power to the grid. If controlled properly, these DG-grid interfacing converters are able to provide a number of ancillary functions such as power factor compensation, voltage support, flicker mitigation, system harmonic compensation, and unbalance voltage compensation in addition to the primary function of real power injection.

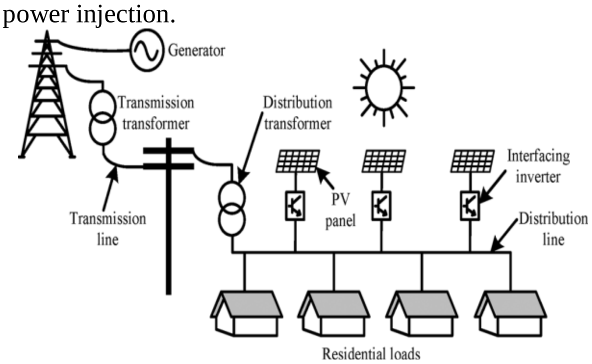

Fig 1.Residential system with PV installations

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This potential for ancillary services can be realized by properly utilizing the available apparent power rating from the interfacing inverters. Doing so is feasible as most of the time these inverters are not running at their maximum power due to the intermittent nature of renewable energy (such as PV). The concept of system harmonic compensation using grid interfacing PV inverter. However, the system considered in the previous work is usually too simple (e.g., the system is often comprised of only a few lines and loads) to provide realistic results.
Also, the effects of harmonic resonance with other power system components, such as capacitors, are not sufficiently considered in the previous work. Additionally, for a system with distributed loads and DG systems, assigning the harmonic compensation priority to different DG systems to achieve the best compensation, due to this above mentioned issues.

A residential distribution system with line impedances, distribution transformers and typical house loads is modeled first. The house load model is created from the aggregated load characteristics of typical residential appliances. This house load model is used to investigate the effect of non-linear residential loads on the power quality of the modeled distribution system. Then the PV grid-interfacing inverters are connected to the distribution system model and are controlled to improve the power quality by acting as harmonics-damping virtual impedance. The effects of the PV locations on harmonic compensation such as end-of-line and distributed compensation. An in-depth analysis and explanation of the performance differences are also carried out to provide a guide for properly assigning the harmonics compensation priorities to PV inverters at different locations of the distribution system.

II. LITERATURE SURVEY

The concept and operation of distributed generation is clearly explained by N.Jenkins in [2]. Distributed generation generates electricity from several small energy sources. Distributed generation plants have excellent economies of scale. It allows collection of energy from several sources and can give lower environmental impacts and improved security of supply. In general terms, Distributed Generation (DG) is any type of electrical generator or static inverter, it is producing alternating current that (a) has capability of parallel operation with the utility distribution system, or (b) is designed to operate separately from the utility system and can feed the load that can also fed by the utility electrical system. A distributed generator is sometimes referred to simply as "generator".

The Distributed generation (DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaic's, and wind turbines.

The concept of photo voltaic system was introduced by the French physicist, Edmund Becquerel He found that certain materials have property to produce small amounts of electric current when exposed to sunlight. In 1905, Albert Einstein described the nature of light and the photoelectric effect which has become the basic principle for photovoltaic technology. The first photovoltaic module was built by Bell Laboratories in 1954[M]

PV cell are basically semiconductor diode. This semiconductor diode has got a p-n junction which is exposed to light. When illuminated by sunlight it generates electric power. PV cell are made up of various semiconductor materials. But mono-crystalline silicon and poly-crystalline silicon are mainly used for commercial use.

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment."

All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

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The harmonic is "a sinusoidal component of a periodic wave or quantity is having a frequency that is an integral multiple of the fundamental frequency." .Some references refer to "clean" or "pure" power as those without any harmonics. But such clean waveforms typically only exist in a laboratory.

Harmonics have been around for a long time and will continue to do so. In fact, musicians have been aware of such since the invention of the first string or woodwind instrument.

III. PROBLEM FORMULATION

The increasing utilization of electronic devices in today's homes is a growing concern for utility companies due to harmonic distortions. The harmonic problem could be further complicated by the harmonic resonance introduced by other system components, such as the power factor correction (PFC) capacitors. Besides the degrading power quality, the harmonic current flow is also a concern for the telecommunication industry as this harmonic current flow may interfere with the adjacent telephone lines. Compensating the harmonics in a residential system is difficult because of the dispersed nature of the residential loads. Therefore, lump compensation at a few locations is not every effective. As a result, finding an effective way to compensate the dispersed load harmonics and improve the residential distribution system power quality.

IV. OBJECTIVE

The main objective is to reduce the residential harmonics using dg grid interfacing inverters in residential areas to improve power quality. Reduction of harmonics results in the improvement of power quality.

A. DISTRIBUTED GENERATION

INTRODUCTION

Distributed generation (DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaic's, and wind turbines.

B. Applications of Distributed Generating Systems

There are many reasons a customer may choose to install a distributed generator. DG can be used to generate a customer's entire electricity supply; for peak shaving (generating a portion of a customer's electricity onsite to reduce the amount of electricity purchased during peak price periods); for standby or emergency generation (as a backup to Wires Owner's power supply); as a green power source (using renewable technology); or for increased reliability. In some remote locations, DG can be less costly as it eliminates the need for expensive construction of distribution and/or transmission lines.

Benefits of Distributed Generating Systems

- Has a lower capital cost because of the small size of the DG (although the investment cost per KVA of a DG can be much higher than that of a large power plant).
- May reduce the need for large infrastructure construction or upgrades because the DG can be constructed at the load location.
- If the DG provides power for local use, it may reduce pressure on distribution and transmission lines.
- With some technologies, produces zero or near-zero pollutant emissions over its useful life (not taking into consideration pollutant emissions over the entire product lifecycle i.e. pollution produced during the manufacturing or after decommissioning of the DG system).
- With some technologies such as solar or wind, it is a form of renewable energy.
- Can increase power reliability as back-up or stand-by power to customers.
- Offers customers a choice in meeting their energy needs.

C. Challenges associated with Distributed Generating Systems

- There are no uniform national interconnection standards addressing safety, power quality and reliability for small distributed generation systems.
- The current process for interconnection is not standardized among provinces.
- Interconnection may involve communication with several different organizations

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- The environmental regulations and permit process that have been developed for larger distributed generation projects make some DG projects uneconomical.
- Contractual barriers exist such as liability insurance requirements, fees and charges, and extensive paperwork.

D. Deregulated Power

The restructuring of the electricity industry in Alberta has split the industry into three components: electricity generation, which is now deregulated; Transmission and Distribution of electricity, which is still regulated; and electricity retail, which is now deregulated In order to connect a distributed generation system to the grid, the customer must apply to the utility (or a utility) that owns the wires in their area (now called a Wires Owner). See the map below for a general idea of which Wires Owner to contact in your region. The DG owner must also register with the Power Pool of Alberta and apply to the Alberta Energy and Utilities Board for approval.

E. Safety Issues

Several issues relating to the safety of DG systems are a concern.

1. Islanding

Islanding occurs when a DG system is still generating power to the distribution system when the main breaker from the Wires Owner is open. In this case, the DG system would be the sole supplier of electricity to the distribution system. This is a concern for several reasons.

i. Safety concern for system maintenance If the Wires Owner's line workers are not aware that the DG system is still running, they may be electrocuted working on the line or other equipment connected to the line.

ii. Equipment damage to other Wires Owners customers If the DG is still generating while the main breaker from the wire owner is open, the voltage and the waveform from the DG may fluctuate and may not meet the acceptable standard. Existing customers who are connected to the distribution line are then fed by very poor quality of power from the DG. As a result, their light fixtures, motors and other electric equipment may be damaged or its life may be shortened. If the situation persists unnoticed for an unacceptably long time, a fire hazard may exist.

i. Damage to the DG owner's generator If the DG is still generating while the main breaker from the wires owner is open, the DG equipment may be damaged when the wires owner’s main breaker is closed due to closing out of synchronism.

ii.To ensure the safety of a DG system, EPCOR recommends contracting with an experienced professional engineer registered with APEGGA (Association of Professional Engineers, Geologists and Geophysicists of Alberta) for the design and installation of the system. They will ensure the system is in compliance with provincial and national guidelines and the interconnection guidelines provided by the wires owner.

2. Power Quality

Power quality is important because many electric devices and appliances are designed to function at a specific voltage and frequency. In North America, AC (alternating current) power is delivered at 120 and 240 Volts and 60 Hz (cycles per second). If power is not delivered properly, it may result in appliance malfunction or damage. In the worst situation, fire hazard is a possibility.

E. SUMMARY

In this section we discussed about distribution generator applications, challenges associated with it, deregulated power and also its safety measures.

V. RESULTS AND ANANLYSIS

Simulation studies

Existing Model

ISSN: 2319-5967
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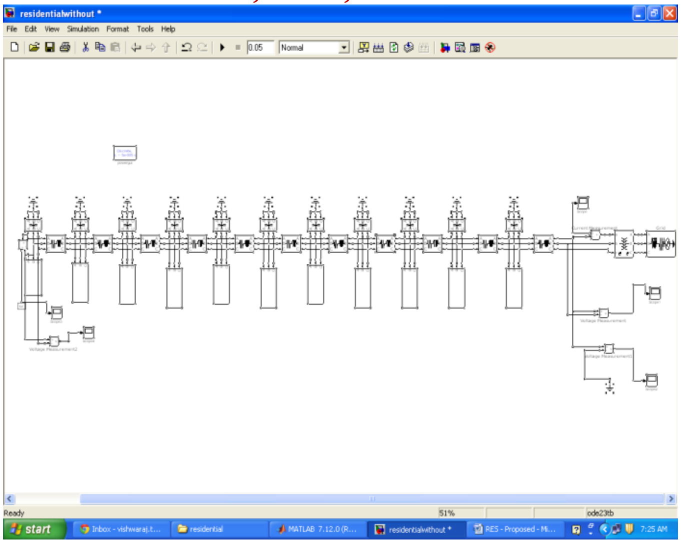
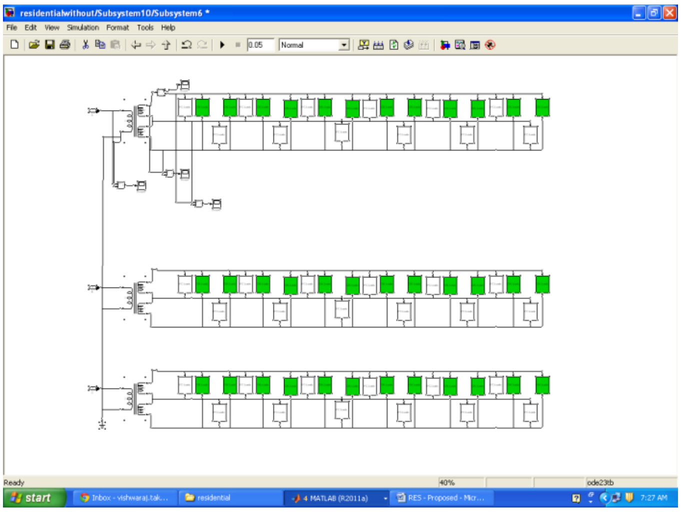
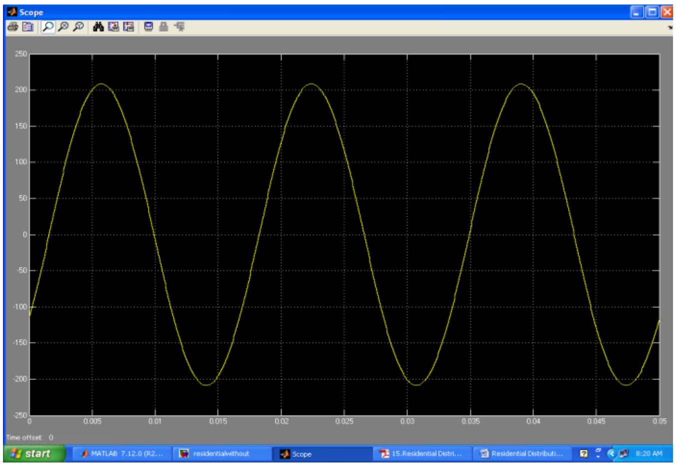
Volume 4, Issue 6, November 2015





At 11th node sub-system– With PFC and Without PV- interfacing.

With PFC:



(a) Current through distribution line

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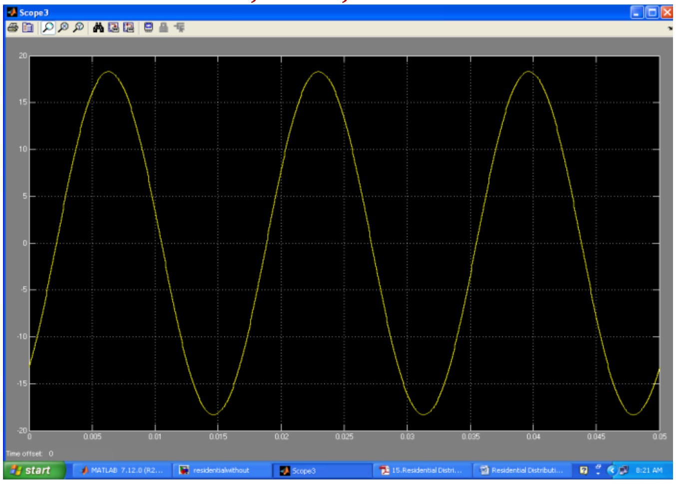
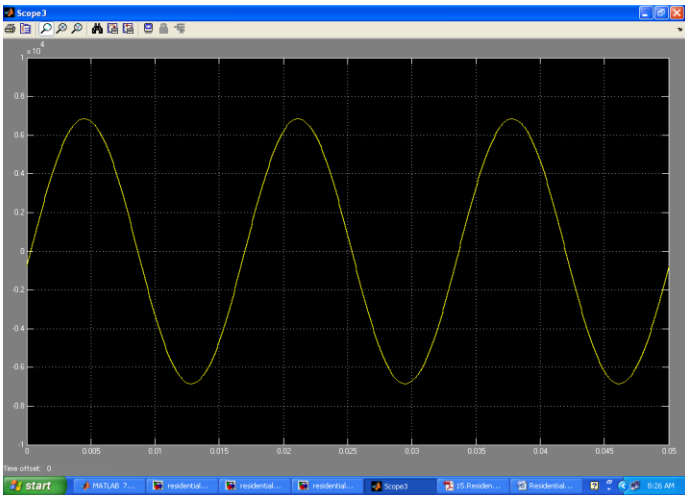
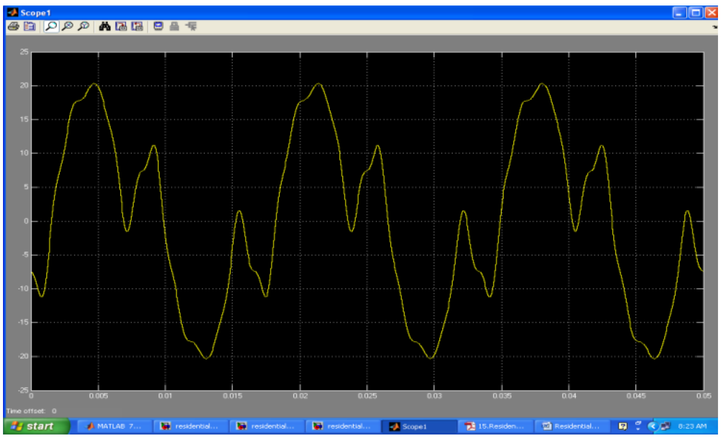


(b) Current flowing from node 11 to primary side of distribution transformer 11



(c)Current flowing through hot wire 1 of distribution transformer 11



(d) DG harmonic current at 11th node

Proposed Model:

At 11th node sub-system– With PV- interfacing

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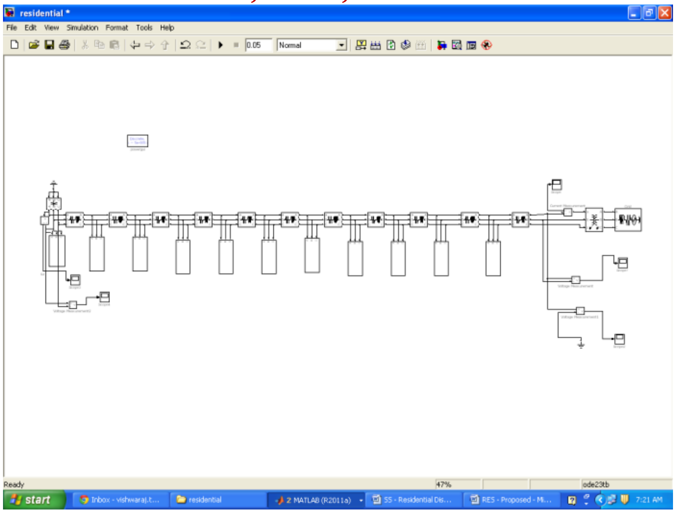
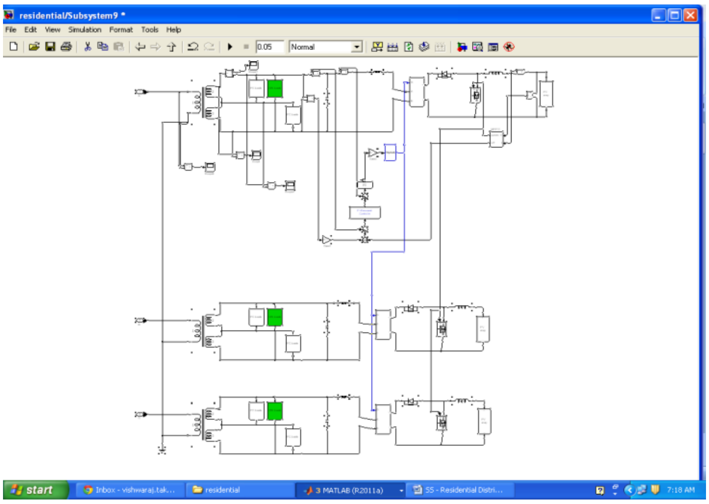
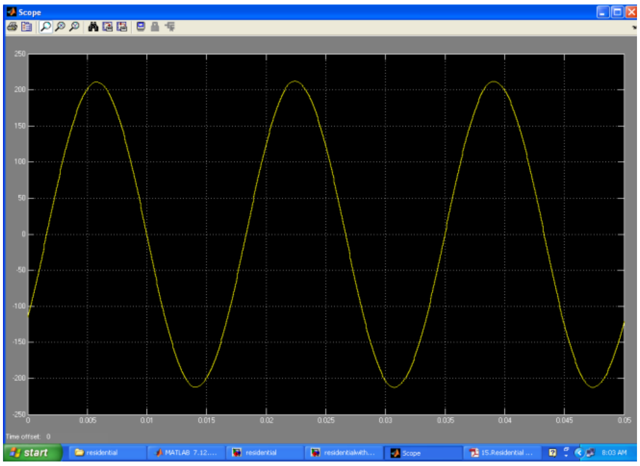




With PV



(a) Current through distribution line.

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ISO 9001:2008 Certified
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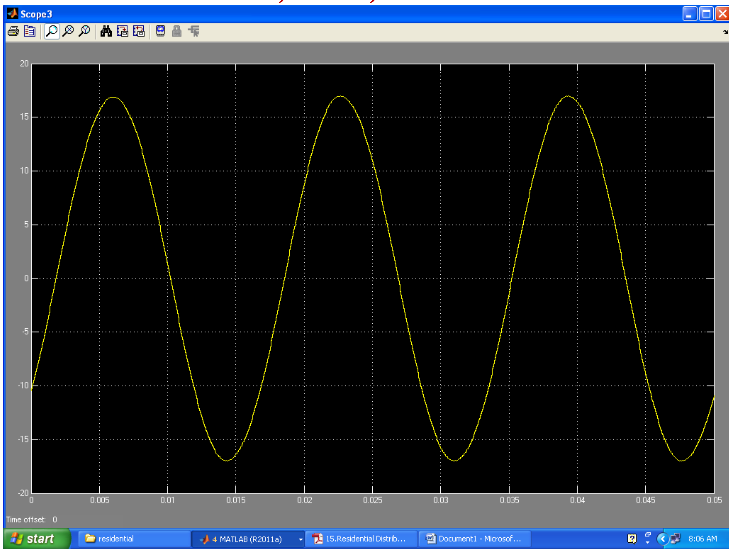
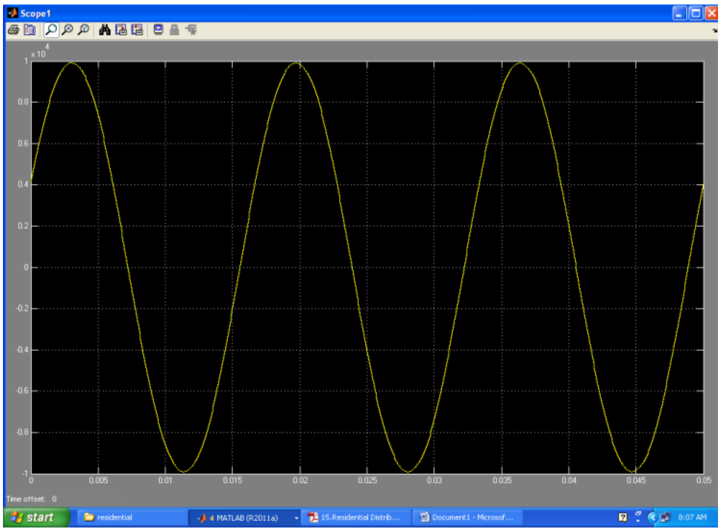
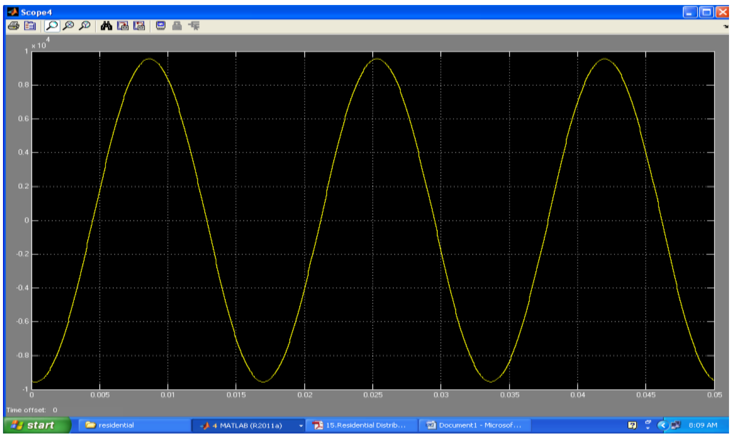
Volume 4, Issue 6, November 2015



(b) Current flowing from node 11 to primary side of distribution transformer 11.



(c) Distribution voltage at node 1



(d) Voltage at node 11

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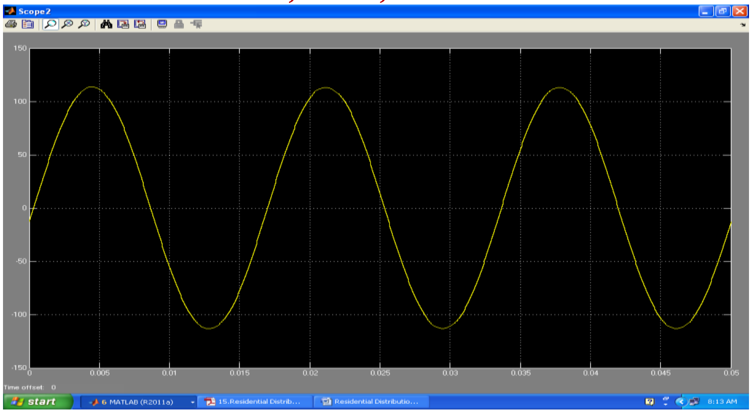
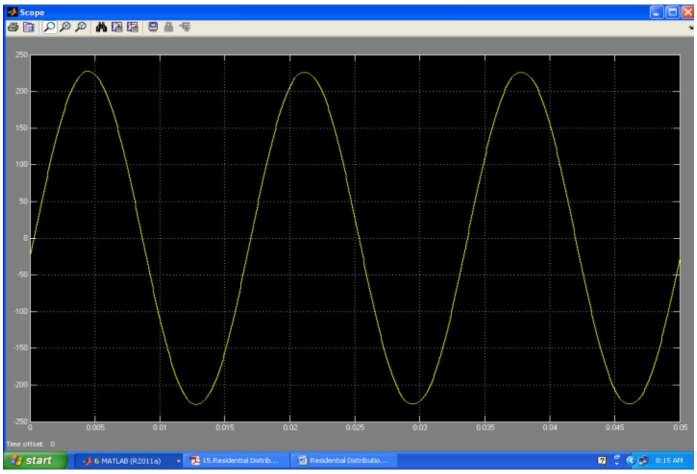
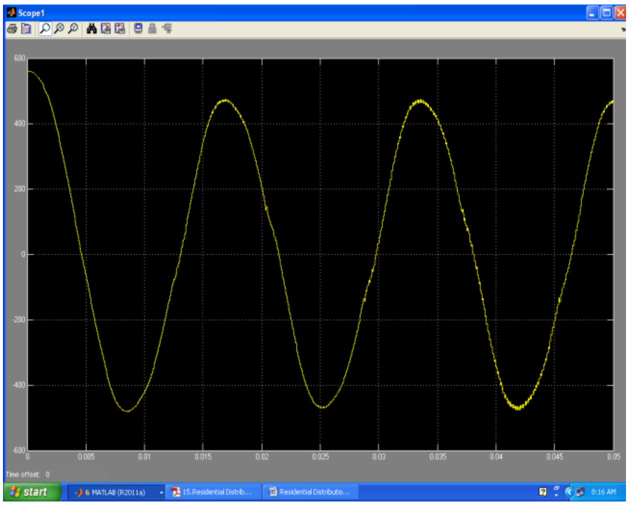


(e) Hot wire 1 to neutral voltage of distribution transformer 11



(f) Hot wire 1 to hot wire 2 voltage of distribution transformer 11



(g) Current flowing through hot wire 1 of distribution transformer 11

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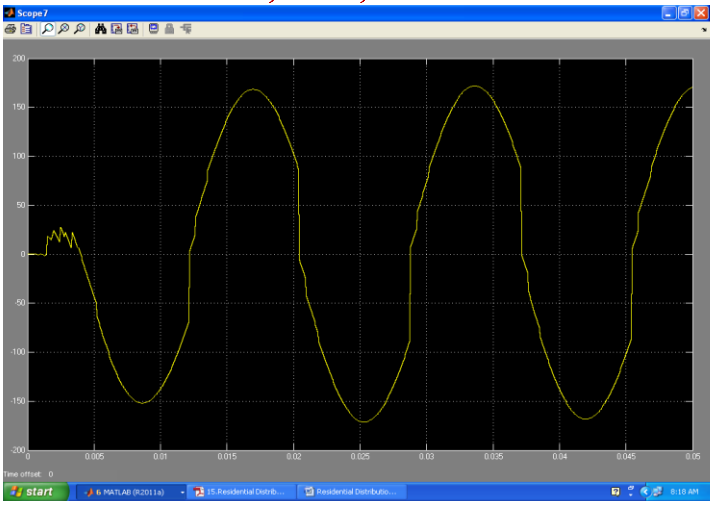
Volume 4, Issue 6, November 2015



(h) DG harmonic current at 11th node.

VI. CONCLUSION

In this we explored the idea of using residential system DG-grid interfacing inverters as virtual harmonic resistances to damp the system harmonics and improve the power quality. An in-depth analysis and comparison of different harmonic compensation schemes were conducted to provide a guide for determining whether distributed compensation or end-of-line compensation should be used. After such a determination has been made, proper priorities can be assigned to the inverters in the distribution system for optimal compensation performance. Specifically, the analysis and simulation results showed that the end-of-line compensation provided better damping for low order harmonics, whereas distributed compensation provided better damping for high-order harmonics if the equal equivalent rating of the DG was maintained.

In the system without PFC capacitors, this crossover frequency was quite high, and end-offline compensation performed better. However, the presence of capacitor in the system could significantly reduce this crossover frequency to around the 7th order harmonic, so the decision about which compensation strategy to use must be made according to the system load characteristics. Moreover, the effects of capacitor sizes, line impedance, and length on the crossover frequency were also analyzed in this paper. With the information about a distribution system, the crossover frequency between the two compensation strategies can be determined by using the model developed in this work, and proper priority can be assigned to the PV inverters at different locations. In our future work, we will consider a supervisory control system of the DGs with communication in order to control the participation from each PV inverter automatically according to the identified priority.

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