International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 02 Issue: 06 | Sep-2015 www.irjet.net p-ISSN: 2395-0072

Mitigation of Harmonics in Dispersed Load System By Using Hybrid Compensation Methods

Peddireddy M.S Reddy[1],D.Vamsi[2]

[1]PG Student, Department of EEE, JNTUA, Ananthapuramu, Andhra Pradesh, India.
[2]PG Student, Department of EEE, JNTUA, Ananthapuramu, Andhra Pradesh, India.

---***---

Abstract-*The nonlinear loads in residential area is increasing day by day. Due to this nonlinear loads, harmonics are generated and this further complicated by the installation of capacitor banks connected to the distribution system. The harmonic resonance will be introduced by this capacitor banks in distribution system and the harmonics are compensated by using active or passive filters. However, distributed generation (DG) system such as photovoltaic (PV), wind and fuel cells with the DG grid interfaced converters are controlled properly to improve the power quality of the system. This paper mainly discuses on the residential system harmonic mitigation through PV grid interfacing inverters. 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. Fuzzy based controller is designed to mitigate the harmonics and improve the harmonic performance and also reduces the harmonic distortion. This paper mainly discuss the effectiveness of harmonic compensation methods under different conditions.*

***Key Words:**Residential distribution system, Distributed generation (DG), Photo voltaic (PV), power quality improvement, harmonic compensation.*

I.INTRODUCTION

The utilization of power electronics devices are rising concern. Due to this power electronics devices operation, harmonics are generated. This will be further complicated by some system components such as power factor correction (PFC) capacitors connected to the residential distribution system. The harmonic currents are flow to the nearby system dispersed nature of the residential loads. The bulge compensation provided to this dispersed load is not effective. So that this topic is very important to compensate the dispersed load harmonics and improve the power quality of the residential system.

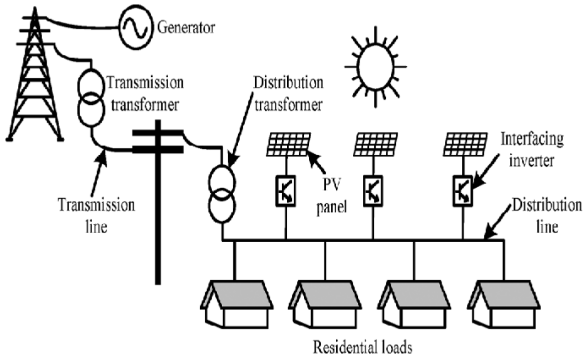


Fig.1.Residential load system with PV interfaced inverters

With the growing concerns on renewable energy cost, energy security and greenhouse gas emissions, the power industry is experiencing fundamental changes as more distributed energy resource based DG systems are being connected to the grid. The installation of rooftop photovoltaic (PV) system is increased day by day. This PV systems are connected to the grid through DG-grid interfacing inverter is shown in fig,1.This interfacing inverters are controlled properly to give some ancillary services such as flicker mitigation, power factor compensation, voltage support, imbalance voltage compensation, system harmonic compensation in addition to the primary function of real power injection. Then the additional power rating is achievable due to the interfacing inverters. The concept of harmonic compensation using DG-grid interfacing PV inverters has been described in [7] and [8]. In the previous paper, considered system is usually very simple e.g., the system is again comprised of some lines and loads to give realistic results. In the previous paper, the effects of the harmonic resonance with some system components such as capacitors are not sufficiently considered. Additionally, a system with distributed loads and distributed generation system specifies the importance of harmonic compensation to provide best compensation results is an important topic but it not be addressed in the literature.

This paper addresses the effects of the harmonic resonance. As a first step, an existing residential distribution system with distribution transformers, line impedances, and typical home loads is modeled. The home load models are developed by the load characteristics of residentialappliances for the analysis of the effects of the harmonics in the

residential system and is used to investigate the effects of nonlinear loads on the power quality of the modeled residential distribution system. This distribution system models are connected to the PV interfacing inverters are controlled to improve the power quality of the system by harmonics damping virtual impedance. The PV locations on harmonic compensation has some effects such as end-of-line [2] and distributed compensation [11], [12] are investigated.

II. DG-GRID INTERFACING INVERTER VIRTUAL HARMONIC IMPEDANCE CONTROL

At high frequencies, the residential system harmonics are compensated by controlling the PV inverters operation by using virtual harmonic impedance. The virtual impedance is implemented by the voltage or current reference or the PWM signal modification through digital control of the inverters. Virtual impedance can be either at the harmonic frequencies or at fundamental frequency. The fundamental frequency virtual impedance is mainly used to promote DG power flow control and grid disturbance ride through. The virtual harmonic impedance is mainly used for active damping and harmonic compensation of the distribution system. The virtual harmonic impedance has two components: 1) Virtual harmonic inductor and 2) Virtual harmonic resistance.

A.VIRTUAL HARMONIC INDUCTOR

The voltage controlled DG units [14]are compensate the harmonics, where the DG units is represented as controlled voltage source (V_{DG}) with output series impedance ($Z_{DG\text{-}h}$). Then the Harmonic components of the controlled voltage source $V_{DG\text{-}h}$ are compensated at the point of common coupling (PCC), $V_{PCC\text{-}h}$ with a feedback gain G. So, that$V_{DG\text{-}h} = -G \times V_{PCC-h}$. Therefore, the equivalent harmonic impedance of DG unit becomes $Z_{DG\text{-}h}/(1+G)$ and G attains value of -1 to ∞. Therefore, this virtual harmonic inductor method is very attractive for micro-grid.

B.VIRTUAL HARMONIC RESISTANCE

In this method, the DG operates like a shunt active power filter (APF) and the harmonic current produced by the non-linear loads are absorbed. Current controlled grid interfacing inverter is used for improving the distribution system harmonic. So that total harmonic distortion of PCC voltage is decreased and source current will be harmonic free. However, for improving this function of DG system behaves like a Resistive-APF (R-APF). The harmonic components ofthe grid side voltage ($V_{Grid\text{-}h}$) are extracted and the reference current of the DG system is produced by the $I_{DG}^{*}=V_{Grid\text{-}h}/R_h$. This method is suitable for the residential rooftop PV inverters when the current is controlled

C. PV INVERTER CONTROL BY VIRTUAL HARMONIC RESISTANCE

The PV inverter work as an R-APF with virtual harmonic resistance control. The PV system used in this work is a two stage conversion system as shown in fig.2. First the DC-DC converter that step up the output of PV to level of DC link voltage by using MPPT (maximum power point tracking) method and then transfers this dc into ac by providing suitable inverter that connects the system to the grid. The PV output current reference (I_{DG}^{*}) has two components, fundamental component (I_f^{*}) and harmonic component (I_h^{*}).The reference harmonic current was obtained by $I_h^{*}= V_{G\text{-}h}/R_h$. Then the grid reference current is produced by combining the fundamental current (I_f^{*}) and the reference harmonic current (I_h^{*}). The PV system output current has two control loops, inner (LC) filter inductor current control loop and output DG current (I_{DG}) control loop. For the harmonic current control and fundamental current tracking, P + Resonant controller are used (1).

$$G_c = K_P + \sum_{h=1,5,7...} \frac{2K_{ih}\omega_{ch} s}{s^2 + 2\omega_{ch} s + \omega_h^2} \qquad (1)$$

Where, K_P is the proportional control gain at all frequencies, K_{ih} is the integral gain at each frequency, ω_{ch} is the cut-off bandwidth at each frequency and ω_h is the system fundamental harmonic frequency. To improve the dynamic response and stability of the control loop, a proportional controller is used for the inner (LC) filter inductor current feedback loop.

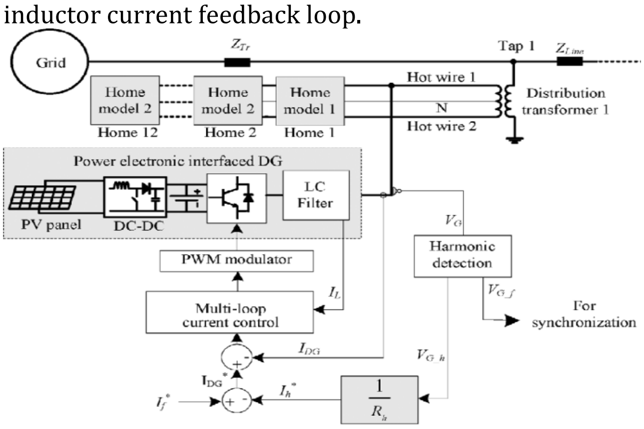


Fig.2. Harmonic damping with R-APF based DG

III. MODELING OF DISTRIBUTION SYSTEM

In this model, consider the residential house load, distribution system model with PFC capacitors and PV inverters (with virtual harmonic impedance) are first developed.

A.RESIDENTIAL LOAD MODELING

The home models are designed for different home appliances as a harmonic current source (i_{Lh}) connected in parallel with the fundamental impedance (Z_f) as shown in fig.3.
Where,

$$I_{Lh} = \sum_{h=3,5,7...} i_h \quad (2)$$

To obtain the home model, first generate the individual home appliances models, including TV, refrigerator, compact fluorescent light (CFL), personal computer (PC), adjustable speed drive (ASD) fridge, dryer and washer. The appliance harmonic load current data are measured practically, where the data are collected from [9] and [15]. To construct the home model, these home appliances are connected to hotwire 1, 2 and neutral N as shown in fig.4. Then, the constructed home models are connected to the distribution system model (fig.5) [10]. All the home appliances are connected between hotwire 1 and neutral N (except dryer) for home model 1 and for home model 2, the appliance models are connected between neutral N and hotwire 2. Finally, the dryer model is connected between hotwire 1 and 2 for both home models (1 and 2). In this paper, the system parameters are used to model the distribution system are listed in table 2 [10].

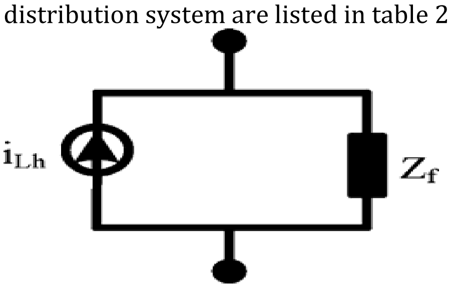


Fig.3. Home load model with harmonic current source in parallel with fundamental impedance (Z_f).

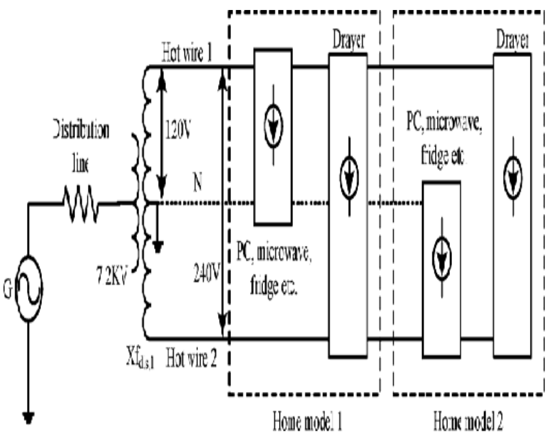


Fig.4. Connection configuration of home model 1.

The distribution system is connected to the 12.47 KV distribution feeder through a 34.4 KV transmission line, transmission transformer (Xf_{tr}) and distribution transformer (Xf_{dis}). The 3-phase distribution transformer has 11 nodes and each node has 12 home groups and these loads are connected to the distribution feeder. This distribution feeder connected to the DG to compensate the harmonics produced by the load.

TABLE 1: HARMONIC LOAD CURRENT DATA FOF HOME APPLIANCES

Harmonic Load current data	Appliance model of			
	CFL		PC	
	Mag	Ang	Mag	Ang
1st	15	21.2	83	50
3rd	13	53.9	65	1.6
5th	09	105.5	41	3.6
7th	07	169.4	16	8.6
9th	07	-	10	58.1
11th	06	134.8	12	168.7
13th	039	-84.2	12	178.0
		-21.8		

TABLE2: SYSTEM PARAMETER

Parameters	Value
Distribution feeder voltage	7200 V (L-N)
Distribution line impedance	43Ω/km, 150µH/km
Distribution transformer	7200V/1200V, 0.015+0.03j p.u.
PFC capacitor	4µF to 12µF
Number of distribution node	11
House load in each node	12

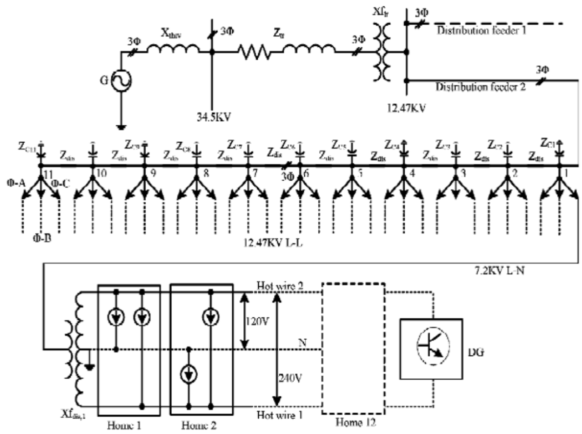


Fig.5.Distribution system model

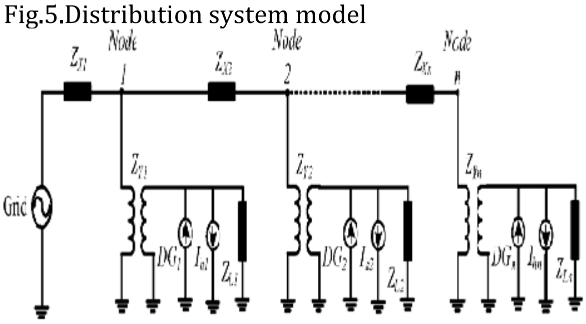


Fig.6. Typical distribution feeder with DG

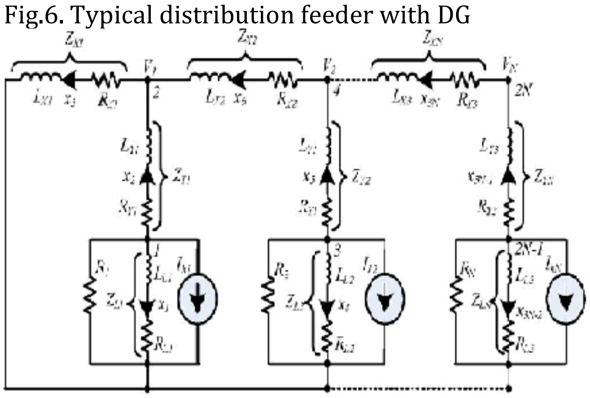


Fig.7. Equivalent circuit of an N node distribution feeder

B.DISTRIBUTIOM SYSTEM MODELING WITHOUT CAPACITOR BANK

In this model, simplified distribution feeder of the distribution system with DG connect to the secondary side of the distribution transformer as shown in fig.5. Here n represents the no. of nodes in the distribution feeder (n=1,2,3,…N). Z_{Xn} (R_{Xn} + jωL_{Xn}), Z_{Yn} (R_{Yn} + jωL_{Yn}) and Z_{Ln} (R_{Ln} + jωL_{Ln}) represents the distribution line, distribution transformer and fundamental load impedance at the n^{th} node. DG_n and I_{hn} represents the DG current and harmonic current of the non linear load at the n^{th} node. Referring to system to the primary side of the transformer, an equivalent circuit of the N node distribution feeder is shown in fig.7. The voltage at the n^{th} node is V_n. and x_1, x_4….x_{3N-2} are current flow through the impedances Z_{L1}, Z_{L2}…. Z_{Ln}. To modeling the distribution system without capacitor, x_1 ,x_2, x_{3N}… are taken as state variables, I_{hn} is the input variable and V_n is taken as the output variable of the state space model of the system. The 1-N, N+1 to 2N and 2N+1 to 3N equations given below (3) to (5),

$$\bigcup_{n=1}^{N} n \rightarrow I_{h,n} = x_{3,n-2} + x_{3,n-1} + \frac{x_{3n-2}R_{L,n} + \dot{x}_{3n-2}L_{L,n}}{R_n} \quad (3)$$

$$\bigcup_{n=1}^{N} N+n \rightarrow \sum_{n=1}^{N}(x_{3,n}R_{X,n} + \dot{x}_{3,n}L_{X,n}) - x_{3n-1}R_{Y,n} - \dot{x}_{3n-1}L_{Y,n} = x$$

$$\bigcup_{n=1}^{N} 2N+n \rightarrow x_{3n-1} + x_{3n+3} = x_{3n} \quad (5)$$

The A_N and B_N matrices of state space model can be obtained by solving equations (3) to (5) and the equation (6) of the system output gives the C_N and D_N matrices of the state space model.

$$\bigcup_{n=1}^{N} v_n = v_{n-1} + x_{3n}R_{Xn} + \dot{x}_{3n}L_{Xn} \quad (6)$$

The state space model of the system is obtained from the following equations (7), (8)

$$\dot{x} = A_N \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{4N} \end{bmatrix} + B_N \begin{bmatrix} I_{h1} \\ I_{h2} \\ \cdot \\ \cdot \\ \cdot \\ I_{hN} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} v_1 \\ v_2 \\ \cdot \\ \cdot \\ \cdot \\ v_N \end{bmatrix} = C_N \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{4N} \end{bmatrix} + D_N \begin{bmatrix} I_{h1} \\ I_{h2} \\ \cdot \\ \cdot \\ \cdot \\ I_{hN} \end{bmatrix} \quad (8)$$

By solving this state space model, the transfer function of the system is find out easily using (9)

$$\frac{v_n(s)}{I_{hn}(s)} = C_N \oint B_N + D_N \quad (9)$$

Where, $\oint$= $(sI-A_N)^{-1}$, I is an 4N$\times 4N$ identity matrix and n=1, 2, 3…..N.

C.DISTRIBUTION SYSTEM MODELING WITH PFC CAPACITOR

The installation of the PFC capacitor in the distribution system makes the harmonic issues more complex and can be amplified. Although, implementation of an active power filter (APF) mitigates the harmonics and it will creates the whack and mole effect [2]. To study the different harmonic compensation schemes in the situation where the capacitors are connected to the distribution bus. The DG system connected to the secondary side of the distribution transformer with power factor correction (PFC) capacitors.Fig.8 shows the typical distribution feeder with DG and PFC capacitors. Referring the system to the primary side of the distribution transformer, the equivalent circuit of an N node distribution feeder with PFC capacitors is shown in fig.9. Z_{C1}, Z_{C2}....Z_{CN} represents the impedances of the capacitors (C_{C1},C_{C2},......C_{CN}) at the n^{th} node and x_1,x_2....x_{4n} are taken as state variables. There are 4N state equations for a N-node system. The 1-N, N+1 to 2N, 2N+1 to 3N and 3N+1 to 4N equations are given below,

$$\bigcup_{n=1}^{N} n \rightarrow I_{h.n} = x_{4n-3}x_{4n-2} + \frac{x_{4n-3}R_{L.n} + \dot{x}_{4n-3}L_{L.n}}{R_n} \quad (10)$$

$$\bigcup_{n=1}^{N} N+n \rightarrow \sum_{n=1}^{N}(x_{4.n-1}R_{X.n} + \dot{x}_{4.n-1}L_{X.n}) - x_{4n-2}R_{Yn} - \dot{x}_{4.n-1}L_{X.n} = x_{4n-2}R_{L.n} + \dot{x}_{4n-2}L_{L.n} \quad (11)$$

$$\bigcup_{n=1}^{N} 2N+n \rightarrow x_{4n-2} + x_{4n+3} = x_{4n-1} + \dot{x}_{4n}C_{Cn} \quad (12)$$

$$\bigcup_{n=1}^{N} 3N+n \rightarrow \sum_{n=1}^{N}(x_{4.n-1}R_{X.n} + \dot{x}_{4.n-1}L_{X.n} = x_{4n} \quad (13)$$

The A_N and B_N matrices of the state space model can be obtained by solving the equations (10) to (13). The equation (14) of the system output gives the C_N and D_N matrices of the state space model.

$$\bigcup_{n=1}^{N} v_n = v_{n-1} + x_{4n-1}R_{Xn} + \dot{x}_{4n-1}L_{Xn} \quad (14)$$

The state space model of the system is obtained from the following equation (15) and (16).

$$\dot{x} = A_N \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{4N} \end{bmatrix} + B_N \begin{bmatrix} I_{h1} \\ I_{h2} \\ \cdot \\ \cdot \\ \cdot \\ I_{hN} \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} v_1 \\ v_2 \\ \cdot \\ \cdot \\ \cdot \\ v_N \end{bmatrix} = C_N \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{4N} \end{bmatrix} + D_N \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ \cdot \\ \cdot \\ I_{hN} \end{bmatrix} \quad (16)$$

By solving this state space model, the transfer function of the system can be find out easily using (17).

$$\frac{v_n(s)}{I_{hn}(s)} = C_N \oint B_N + D_N \quad (17)$$

Where, $\oint = (sI - A_N)^{-1}$, I is a 4N×4N identity matrix and n=1, 2,3……N.

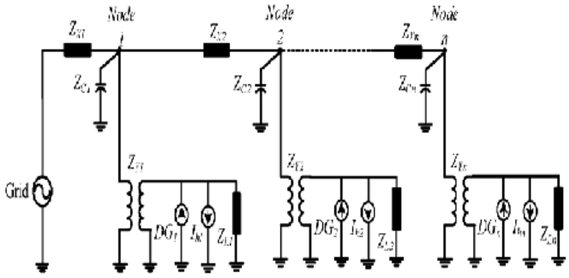


Fig.8. Typical distribution feeder with DG and PFC capacitor

IV.DISTRIBUTION SYSTEM HARMONIC COMPENSATION USING DG

The effects of harmonic compensation using photovoltaic (PV) inverters will be discussed in this section. Let us consider, a simple two node system for initial implementation. The locations of residential PV systems are usually not controlled properly as they depend on the installed residential system. The compensation methods are used for obtaining the good harmonic compensation performance and controlling the PV inverters in the system is possible. Two compensation strategies are used for the harmonic compensation using DG interfacing inverters are;

1) The END OF LINE COMPENSATION is executed by allocating the harmonic compensation priority to the PV inverters connected at the end of the distribution feeder.

2) The DISTRIBUTED COMPENSATION is executed by operating all PV inverters with equal priority in the harmonic compensation scheme.

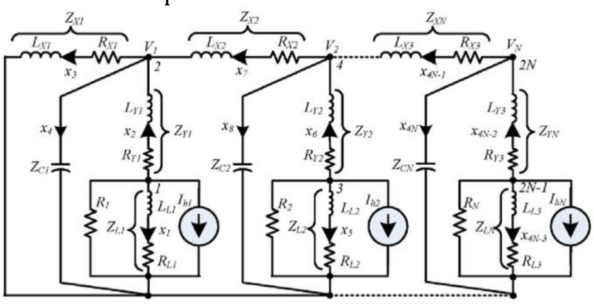


Fig.9. Equivalent circuit of an N node distribution feeder with PFC capacitors.

For example, a two node system is used in this section, for studying the effects of different compensation techniques as shown in fig.6. The equivalent circuit of an N node distribution feeder system is shown in fig.7 with N=2. Solving this analysis, assumed that both nodes 1 and 2 have identical loads ($i=I_{h1}=I_{h2}$, $Z_{L1}=Z_{L2}$), same transformer ($Z_X=Z_{Xf,1}=Z_{Xf,2}$) and same line parameters ($Z_Y=Z_{line,1}=Z_{line,2}$). In this situation, x_1,x_2,x_3,x_4 and x_5 are taken as state variables, i is taken as input variable and V_1 and V_2 are taken as output variables of state space model of the system. The frequency related performance of different compensation techniques can be explained by an equivalent circuit is shown in fig.10.The impedances ZX, ZY and Zf are much higher than the ZVR1 and ZVR2 at high frequency region. The most of the adjacent harmonic load current flowing through the inverter harmonic virtual impedances (ZVR1 and ZVR2) when, this impedances are connected. In case of DG at node 1as shown in fig.10.(a), most of the harmonic current (Ih1) will be absorbed by ZVR1 but Ih2 flows through node 1 and 2. So, that VTHD is high at both nodes 1 and 2. In case of DG at node 2 as shown in fig.10.(b) , Ih2 is absorbed by ZVR2, most of Ih1 flows through ZY and the harmonic current flowing through V_2 is less. However, in case of DG at node 1 and node 2 as shown in fig.11.(c), most of harmonic currents (I_{h1} and I_{h2}) will be absorbed by virtual harmonic impedances (Z_{VR1} and Z_{VR2}) respectively and the voltage at both nodes 1 and 2 will be less. When, the harmonic frequency increases, Z_X and Z_Y also increases but the Z_{VR1} and Z_{VR2} remains same resulting the constant level of damping to the harmonics in case of DG at both nodes 1 and 2. In any case of DG location (node 1 or 2), the harmonic current flowing through node 1 is same in both cases ($Z_Y<<Z_X$). At low frequency range, Z_{VR1} and Z_{VR2} of DG's are comparable to Z_X for the compensation. Therefore, most of the harmonic current flows to source through the distributed feeders resulting higher harmonic voltages in the system. The performance difference of single DG and distributed compensation is commonly related to the system impedance at low frequency region. An examined earlier with $Z_Y<<Z_X$ we can assume $Z_X \approx Z_Y+Z_X$. If the virtual impedances of all DG's are same, so the impedances at I_{h1} and I_{h2} will be same in case of distributed compensation. But the impedances at I_{h1} and I_{h2} will be different, in case of a single DG at node 1 or 2. Therefore current flowing to the source will be $|I_{Zx1}|+|I_{Zx2}|$ for distribution compensation and $|I_{Zx1}+|I_{Zx2}|$ for single DG compensation. At high frequency, I_{Zx1} or I_{Zx2} will be very small when the compensation at node 1 or 2 is used due to the small damping resistance from the DG for single compensation. As a result, $|I_{Grid}| \approx |I_{Zx1}| + |I_{Zx2}|$ due to I_{Zx1} and I_{Zx2} have different phases. The damping resistance of the DG equals to Z_X at low frequency and for single DG compensation node 1 or 2 will lead to $|I_{Grid}|<|I_{Zx1}|+|I_{Zx2}|$ due to phase difference. Therefore, the current I_{Zx1} or I_{Zx2} of single DG compensation will be higher compared with distributed compensation. The total current flowing to the source will be lower and provide the best performance with single DG compensation is important in the low frequency region. Therefore, the end-of-line compensation is the best option for single DG compensation as it resulted in the lowest feeder harmonic feeder voltage drops.

V. HARMONIC COMPENSATION IN AN 11 NODE DISTRIBUTION SYSTEM

In this section, different harmonic compensation performance under an 11 node residential distribution system without PFC capacitors is discussed. In this method, provides clear similarities of different harmonic compensation strategies and the criterion that the total harmonic RMS current from all the DG's in the system is

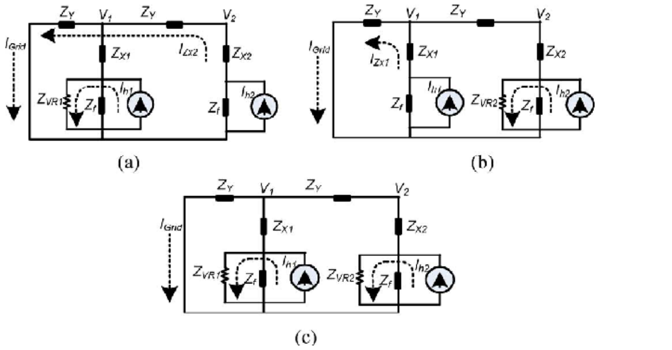
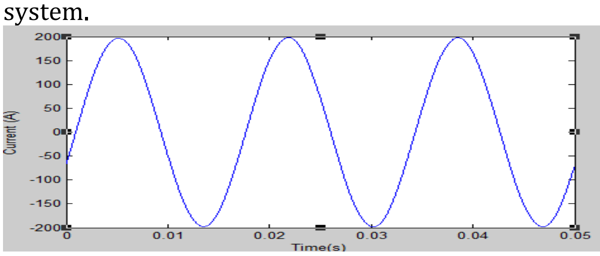
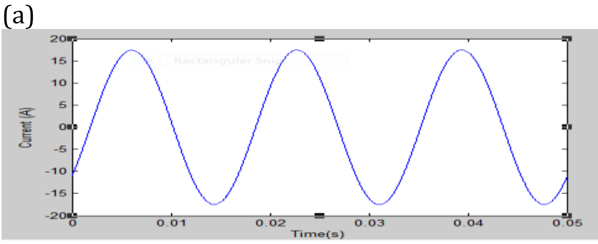


Fig.10. Equivalent circuit of DG (a) at node 1, (b) at node 2, and (c) at nodes 1 and 2

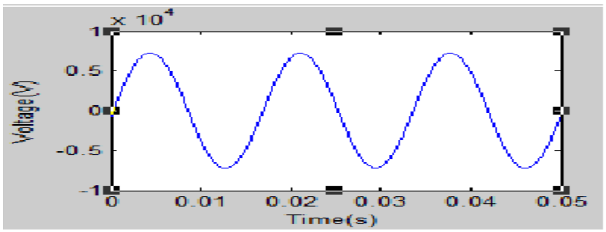
Kept same regardless of the compensation techniques and distribution system configuration is taken for this study. With this criterion in case of the distribution compensation in an 11 node system, the virtual resistance Z_{VR}=1/.58 Ω is selected. This virtual resistance is assumes to a total 76.4 A RMS DG harmonic current and about 2% of the total RMS load current. Fig .11 shows the time domain simulation results of an 11 node distribution system.



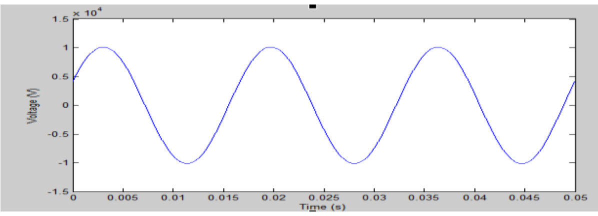
(a)



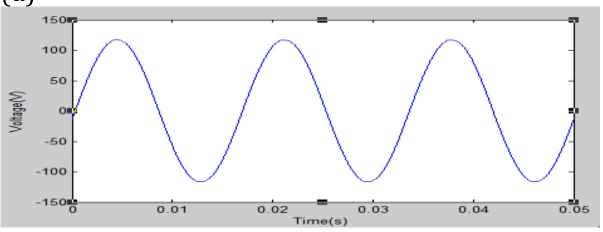
(b)



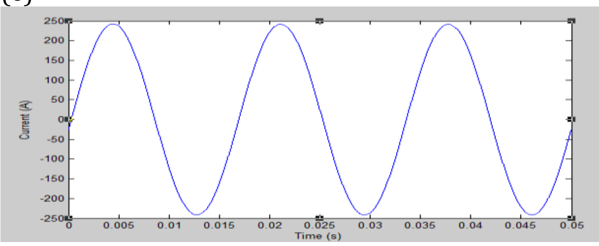
(c)



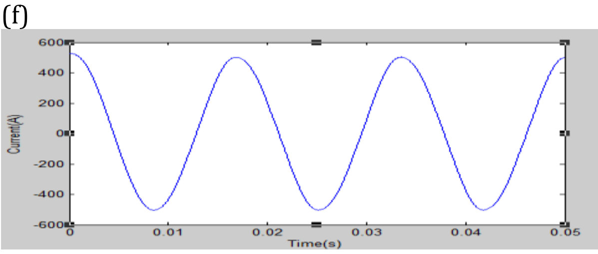
(d)



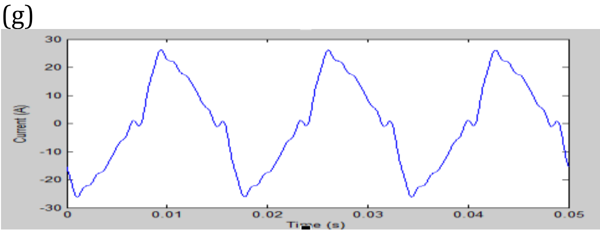
(e)



(f)



(g)

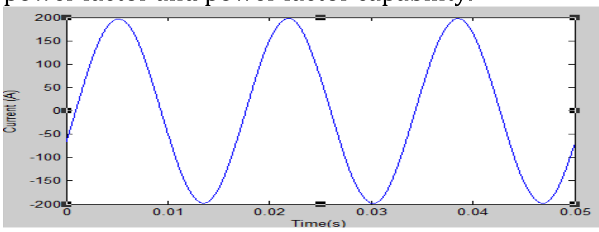


(h)

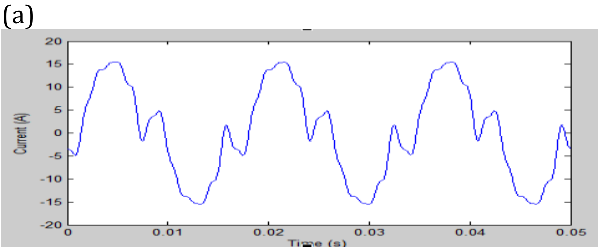
Fig.11 (a) current through distribution line, (b) Current flowing from node 11 to primary side of distribution transformer 11 (c) Distribution voltage at node 1, (d) voltage at node 11, (e) Hot wire 1 to neutral voltage of distribution transformer 11, (f) Hot wire 1 to hot wire 2 voltage of distribution transformer 11, (g) Current flowing through hot wire 1 of distribution transformer 11 and (h) DG harmonic current at 11th node.

VI.HARMONIC COMPENSATION WITH THE PRESENCE OF PFC CAPACITORS

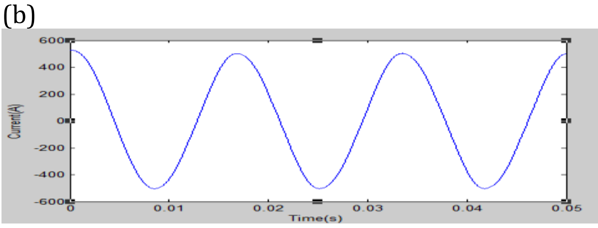
For voltage regulation and reactive power compensation, the PFC capacitors are installed in the distribution system. These PFC capacitors are affects the harmonic compensation performance and may cause harmonic resonances. The voltage profile along the distribution line with PFC capacitors are affected by this capacitor's reactance value and capacitors location. However, the most efficient capacitor placement depends on the line parameter of the distribution system, load power factor, load and reactive value. Generally, the capacitors are installed at the end of the distribution system provides the better performance for improving the voltage regulation, power factor and power factor capability.



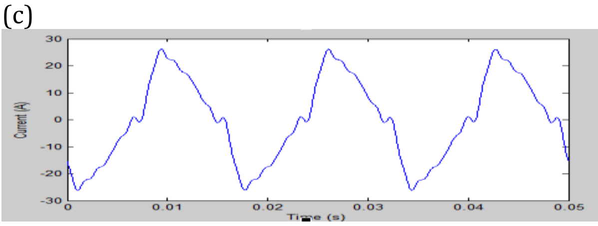
(a)



(b)



(c)



(d)

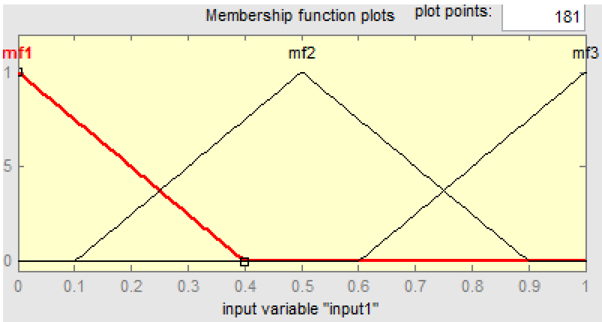
Fig.12 (a) Current through distribution line, (b) Current flowing from node 11 to primary side of distribution transformer, (c) Current flowing through hot wire 1 of distribution transformer 11, and (d) DG harmonic current at the 11 th node

Fig.12 shows the time domain simulation results 11 node system with PFC capacitors. For different compensation methods, the harmonic content throughout the distribution line shows that the low order harmonics are lower throughout the entire line for end-of-line compensation at high frequency. In the case of end-of-line compensation, V_{THD} is lower throughout the distribution feeder, a load model with higher frequency equipment could changes the compensation results. Then, the V_{THD} along the distribution line is decreased by distribution compensation but increased by end-of-line compensation compared with no compensation method.

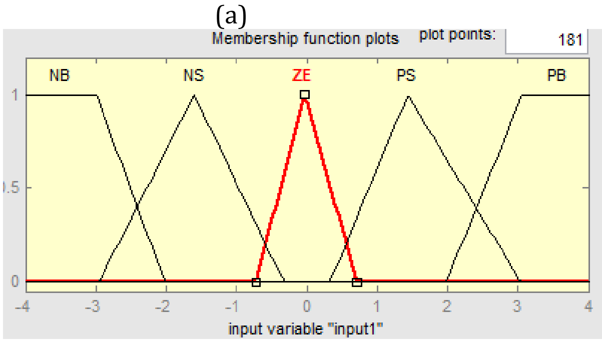
VII. FUZZY LOGIC CONTROLLER

Fuzzy logic controller, approaching the human reasoning that makes use of the tolerance, uncertainty, imprecision and fuzziness in the decision making process and manage to propose a very satisfactory operation, without the need of a detailed mathematical model of the system, just by integrating the experts knowledge into fuzzy rules. In addition, it has essential abilities to deal with noisy date or inaccurate, thus it has able to develop control capability even to those operating conditions where linear control techniques fails i.e., large parameters variations. They consists of an fuzzification block, interference system and defuzzification block.

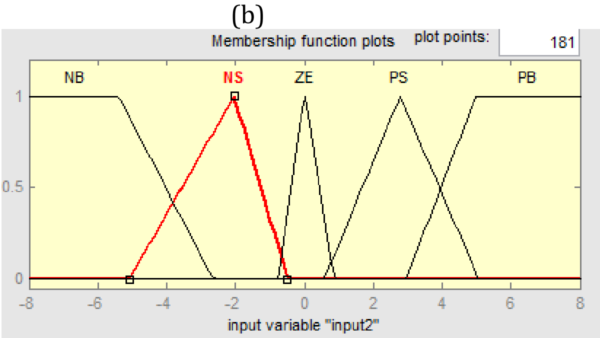
1)**Fuzzifiztion Block**: Fuzzification is the process where the input crisp quantities are converted into fuzzy sets and also converts numeric (non fuzzy) input variables to linguistic (fuzzy) variables. The membership function is defined as errors and changes in error as Positive Small (PS), Positive Medium (PM), Positive Big (PB), Negative Small (NS), Negative Medium (NM) and Negative Big(NB). Fig.13 and 14 shows the input and output membership function.



(a)



(b)



(c)

Fig.13 (a) to (c) the input membership function

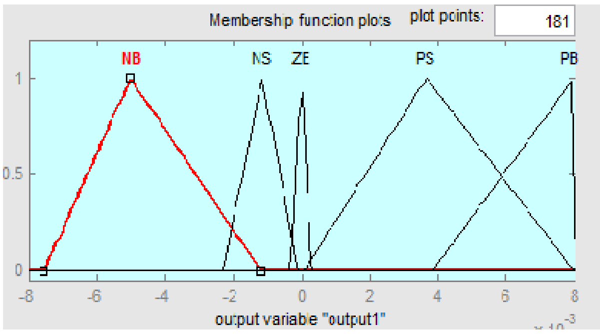


Fig.14. fuzzified output membership function

2) **Rule Base**: It consists of a number of If-Then rules. Then side of rules is called the consequence and If side is called antecedent. These rules are very similar to the human thoughts and then the computer use the linguistic variables. Rule base of FLC is listed in table 4

3) **Inference Mechanism**: It performs the inference procedure on the Min-Max and Max-Dot rules and to provide a reasonable output. The output membership function perform of every rule is given by minimum and most operator.

TABLE 3.MEMBRSHIP FUNCTION TABLE

FUZZY RULES	E(n)				
	NB	NS	ZE	PS	PB
NB	ZE	PS	PS	ZE	NS
NS	PB	PS	ZE	ZE	NS
ZE	PB	PS	ZE	NS	NB
PS	PS	ZE	ZE	NS	NB
PB	PS	ZE	NS	NS	ZE

4) **Defuzzification**: It means conversion of fuzzy sets into crisp sets. Generally, a defuzzier is required only when the mamdani fuzzy model is used for designing a controller. Finally, fuzzy outputs are applied to the main control system.

Fuzzy logic controller is used by replacing the PI controller. Better performance can be observed using FLC as shown in fig.15. Table 5 summarizes the harmonic performance using MATLAB/simulink software. The FLC limits the THD to 1.80% of fundamental fundamental value. So, we can see the FLC has ability to improve the harmonic performance and limits the THD below the threshold limit.

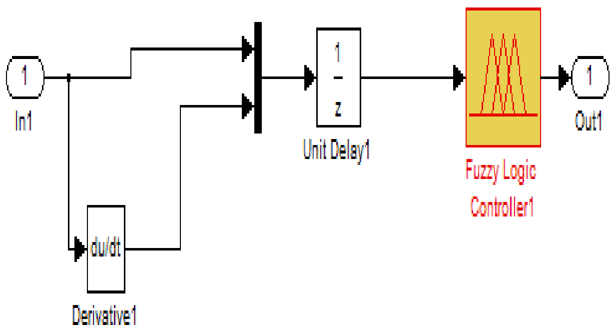


Fig.15. fuzzy logic controller

Table 4: THD performance comparison table

Node Number	Total harmonic distortion (THD)	
	Without Fuzzy	With Fuzzy
I_{h1}	1.90%	0.86%
I_{h2}	3.84%	1.21%
I_{h3}	3.87%	1.23%
I_{h4}	3.85%	1.25%
I_{h5}	3.87%	1.26%
I_{h6}	3.89%	1.27%
I_{h8}	4.65%	1.49%
I_{h11}	5.77%	1.80%

VIII.CONCLUSION

This paper discussed the opportunities of power quality improvement and to mitigate the dispersed load system harmonics using residential system DG interfacing inverters and also using fuzzy controller. Both the end-of-line and distributed compensation method have been considered and their relevant priorities have been investigated and compared. Specifically, the analysis and simulation results shows that the distributed compensation provides better damping for higher order harmonics whereas end-of-line compensation provides better damping for lower order harmonics if the equal equivalent rating of the DG was maintained. In the system with PFC capacitors, the crossover frequency reduces to 7th harmonic, so the decision about which compensation method to use must be made according to the load characteristics of dispersed load system. However, the system without PFC capacitors, the end-of-line compensation performs better when the crossover frequency is higher. In this paper, the effects of capacitor size, length on the crossover frequency and line impedances are also analyzed. By using fuzzy controller, total harmonic distortion is reduced and harmonic performance is improved.

REF ERENCES

[1] J. Arrillaga and N. R. Watson, *Power System Harmonics*, 2nd ed. Hoboken, NJ, USA: Wiley, 2003, pp. 176–180.

[2] K. Wada, H. Fujita, and H. Akagi, "Considerations 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, July/Aug 2002.

[3] European Photovoltaic Industry Association (EPIA) "Annual report 2011", Mar. 2012, pp. 5–7.

[4] Global Wind Energy Council (GWEC) "Global wind report, annual market update 2011", Mar. 2012, pp. 4–7.

[5] Y. W. Li, D. M. Vilathgamuwa, and P. C. Loh, "Microgrid power quality enhancement using a three-phase four- wire grid-interfacing compensator," *IEEE Trans. Ind. Appl.*, vol. 41, pp. 1707–1719, Nov. –Dec. 2005.

[6] A. Capasso,W. Grattieri, R. Lamedica, and A. Prudenzi, "A bottom-up approach to residential load modeling," *IEEE Trans. Power Syst.*, vol. 9, no. 2, pp. 957–964, May 1994.

[7] C. Zhe, F. Blaabjerg, and J. K. Pedersen, "Hybrid compensation arrangement in dispersed generation systems," *IEEE Trans. Power Del.*, vol. 20, no. 2, pp. 1719–1727, Apr. 2005.

[8] M. Prodanovic, K. D. Brabandere, J. V. D. Keybus, T. Green, and J. Driesen, "Harmonic and reactive power compensation as ancillary services in inverter-based distributed generation," *IEE Proc. Gener.Transm. Distrib.*, vol. 1, no. 3, pp. 432–438, May 2007.

[9] A. B. Nassif, J. Yong, and W. Xu, "Measurement-based approach for constructing harmonic models of electronic home appliances," *IEEProc. Gener. Transm. Distrib.*, vol. 4, no. 3, pp. 363–375.

[10] Y. J.Wang, R.M. O'Connell, and G. Brownfield, "Modeling and prediction of distribution system voltage distortion caused by non-linear residential loads," *IEEE Power Eng. Rev.*, vol. 21, no. 7, p. 71, Jul. 2001.

[11] 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.

[12] 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, May 2009.
[13] D. M. Vilathgamuwa, P. C. Loh, and Y. W. Li, "Protection of microgrids during utility voltage sags," *IEEE Trans. Ind. Electron.*, vol. 53, pp. 1427–1436, Oct. 2006.
[14] J. He, Y. Li, and S. Munir, "A flexible harmonic control approachthrough voltage controlled DG-grid interfacing converters," *IEEETrans. Ind. Electron.*, vol. 59, no. 1, pp. 444–455, Jan. 2012.
[15] R. Dwyer, A. K. Khan, M. Mcgranaghan, L. Tang, R. K. Mccluskey,R. Sung, and T. Houy, "Evaluation of harmonic impacts from compact fluorescent lights on distribution systems," *IEEE Trans. Power Syst.*,vol. 10, no. 4, pp. 1772–1779, Nov. 1995.