Power Quality Improvement in Residential System using PV Interfacing Inverter

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Abstract**-- This paper presents the compensation of solar powered residential system harmonics using photovoltaic (PV) interfacing inverters. In this work DG interfacing inverter virtual harmonic impedance control with pulse width modulation technique is used to mitigate the harmonic distortions. The capacitor banks, installed in the distribution network, for harmonic mitigation worsen the situation by introducing the harmonic resonance. In this work, simulated a model of the existing system in a nearby organization containing the residential loads and DG is first developed. An in-depth analysis and comparison of different compensation schemes based on the virtual harmonic damping impedance concept are carried out. The effectiveness of the harmonic compensation strategies under different conditions is verified through analysis and simulations.**

Key words — Distributed generation (DG), photovoltaic (PV), power quality improvement, harmonic compensation, renewable energy, residential distribution system

I INTRODUCTION

The growing utilization of electronic devices in domestic appliances is a rising concern for utility companies due to harmonic distortions. The harmonic problem might be further complicated by the harmonic resonance introduced by other system components, such as the power factor correction (PFC) capacitors. Further, the degraded power quality and the harmonic current flow are also the concern for the telecommunication industry as the harmonic current flow may interfere with the adjacent telephone lines [1]. Compensating the harmonics in a residential system is complicated because of the dispersed nature of residential loads. Therefore, bulge compensation at a few locations is not very effective [2]. As a result, finding an effective way to compensate the dispersed load harmonics and improve the residential system power quality is an important issue.

In addition to having increasing concerns about power quality, the power industry is experiencing a pattern shift, as more renewable energy based distributed generation (DG) systems are being connected to the power distribution network [4,5]. A typical example is the increase in installation of rooftop photovoltaic (PV) systems in residential areas.Distributed generation includes fuel cells, wind generation, photo voltaic generation etc., this DG system contains inverters, and by properly controlling this inverter power quality may be improved [3]. A PV framework utilizes sunlight based cells to change over light into power and it has numerous segments, including cells mechanical and electrical associations and mountings, and also supplies for directing and altering the electrical yield. At rapid market growth, these PV systems are connected to the grid through DG grid interfacing inverters, which are mainly used 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. These DG interfacing inverters are controlled properly they 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 real power injection[4-5].

The idea of crossover recompense plan in scattered era framework introduces a mixture payment framework comprising of a dynamic channel and circulated latent The idea of crossover recompense plan in scattered era framework introduces a mixture payment framework comprising of a dynamic channel and circulated latent filters[5]. In the framework, every individual uninvolved channel is associated with a contortion source and intended to kill fundamental music and supply sensitive force for the bending source, while the dynamic channel is in charge of the revision of the framework unbalance and the wiping out of the remaining sounds filters [5]. In the framework, every individual uninvolved channel is associated with a contortion source and intended to kill fundamental music and supply sensitive force for the bending source, while the dynamic channel is in charge of the revision of the framework unbalance and the wiping out of the remaining sounds. However, the system considered in the previous work is usually too simple (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 result is an important topic that has not been addressed in the literature.

This paper addresses the harmonic resonance problem [1]. As a first step, an existing residential distribution system with line impedances, distribution transformers and typical house loads is modeled. The household burden is model from the amassed burden attributes of average private apparatuses [8, 9]. This house burden model is utilized to research the impact of non-direct private loads on force nature of the dissemination framework. As an issue step PV framework interfacing inverters are joined with the circulation framework model. These are controlled for enhancing the force quality by going about as music damping virtual impedance. The effect of the PV location on harmonic compensation such as end-of-line and distributed compensation are investigated [2.10, 11]. 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. These analysis results are verified by simulations of a sample residential distribution system**.** The results are analyzed and the best locations of PV inverters are identified to reduce the total harmonic distortion.

II DG–GRID INTERFACING INVERTER VIRTUAL HARMONIC IMPEDANCE CONTROL

a. virtual harmonic inductor

The purpose point of common coupling (PCC) consonant remuneration utilizing current controlled matrix joined DG acts as an issue dynamic force channel (APF). In this the DG unit retains consonant momentums of the nonlinear burdens, leaving voltage with lower all out symphonious contortion (THD). To further enhance the frameworks execution, a discrete recurrence tuned dispersed APF is utilized [11, 12]. In this control technique, every DG unit acts as an issue differing conductance yh for diverse symphonious voltages, and the consonant ebbs and flows can be appropriately imparted among DG units by utilizing symphonious conductance and volt ampere hang control[12]A harmonic compensation technique by voltage controlled DG unit is used [3], in these technique DG unit is represented as controlled voltage source(V_{DG}) with output series impedance($Z_{DG\text{-}h}$). The harmonic components of controlled voltage source, $V_{DG\text{-}h}$ are controlled according to the harmonic voltage of the point of common coupling, ($V_{PCC\text{-}h}$), with a positive feedback gain G so that

$$V_{DG-h} = -G \times V_{PCC-h} \quad (1)$$

the equivalent harmonic impedance of DG ($Z_{DG\_h,eq}$) at the installation point can be derived through simple manipulations as

$$I_{DG\_h} = \left(V_{DG\_h} - V_{PCC\_h}\right) / Z_{DG\_h}$$

$$= -(1+G) V_{PCC\_h} / Z_{DG\_h} \quad (2)$$

$$Z_{DG\_heq} = V_{PCC\_h} / I_{DG\_h} \quad (3)$$

where I_{DG_h} is the DG harmonic current and Z_{DG_h} is the DG harmonic impedance. By legitimately controlling the DG consonant voltage with a positive criticism addition of G, the DG symphonious impedance will be scaled around an element of (1 + G). Consequently, the consonant impedance at the DG side can be considerably lower than that at the framework side. As an issue, the majority of the nonlinear burden current will be retained by the DG unit, leaving an enhanced lattice current and PCC voltage. Clearly, a higher G quality will further lessen the PCC voltage music. With G = 0, the framework will be a standard voltage-controlled DG unit without any dynamic recompense. The consonant current can be imparted consequently as indicated by the DG- and network side symphonious impedances. This is as opposed to the current-controlled strategy, where the DG current will be sinusoidal if the dynamic force sifting capacity is not empowered. Besides, it is well realized that the center of the V –f droop control of parallel DG frameworks is the principal force stream, and in this way, the DG current is inclined to have symphonious issues. On the off chance that wanted, this proposed technique can likewise be utilized to control the DG present with lower sounds and better THD to meet the present framework association prerequisite [2]. This is possible by utilizing a negative criticism pick up ($-1 < G < 0$) so that the DG identical impedance is expanded at the symphonious frequencies. As an issue, the PCC consonant voltage will be enhanced contrasted with the routine V –f hang control. Surely, if the DG consonant current can be legitimately lessened with a negative G, the execution will be the same as that of the traditional current-control.

As a result the equivalent harmonic impedance of the DG becomes

$$Z_{DG-h} / (1+G) \quad (4)$$

Here G can be in the range of -1 to ∞. A virtual inductive equivalent impedance is introduced in this technique to compensate the system harmonics, since the impedance is primarily inductive at harmonic frequencies , it is quite attractive for use in micro grid, where the voltage- controlled DG is significant for providing the micro grid voltage and frequency control

b. virtual harmonic resistance

Distribution system harmonic compensation using current controlled grid interfacing inverter operates like a shunt active power filter (APF) and absorbs the harmonic current generated by the nonlinear load, then the source current becomes harmonic free and at the PCC the total harmonic distortion will be reduced. This is achieved by operating the DG as resistive-APF(R-APF).

The controlling is done as the harmonic components of grid side voltage, $V_{Grid\text{-}h}$, are extracted and reference harmonic current of DG is produced as

$$I_{DG}^{*} = V_{Grid-h} / R_h \qquad (5)$$

c.Analysis of proposed control stategy

The data used for the simulink model is in table.1

Parameter	value
Distribution feeder voltage	7200V(line to neutral)
Distribution transformer	7200V/120V, 0.015+0.03j p.u
Distribution line impedance	43Ω/Km, 150μH/Km
Number of distribution nodes	11
House load in each node	12
PFC capacitor	4μF to 12μF

For fundamental current tracking and harmonic current control, P+ Resonant controllers are used

$$G_C = K_P + \sum_{h=1,5,7...} \frac{2K_{ih}\omega_{ch} s}{s^2 + 2\omega_{ch} s + \omega_h^2} \qquad (6)$$

Where G_C controller gain

K_p proportional gain constant for all frequencies

K_{ih} integral gain constant for individual frequency

ω_h harmonic frequency

ω_{ch} harmonic cutoff frequency

For the inner filter inductor current feedback loop a proportional controller is adopted to improve the dynamic response and stability of the control loop, [22]the distribution system model having 11nodes and 12 homes in each node is shown in fig 1

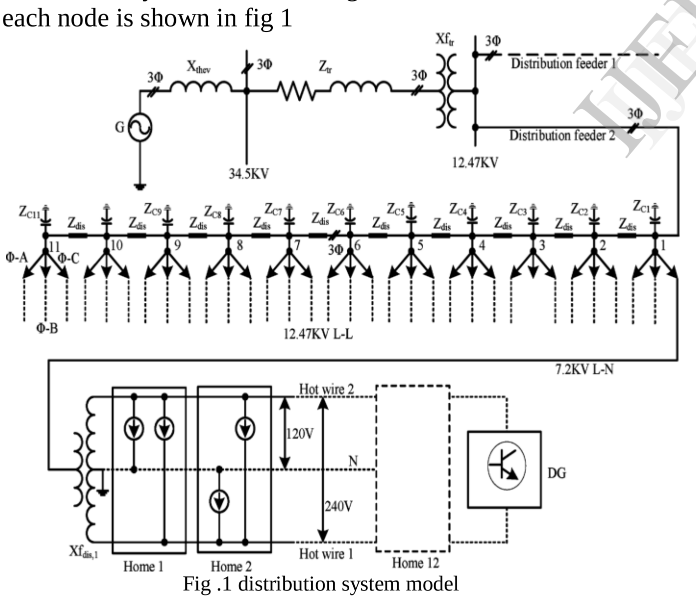


Fig .1 distribution system model

the Equivalent circuit of a single DG–grid system with VCM is shown in fig

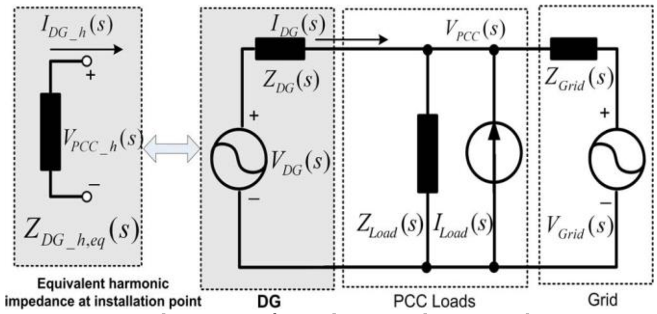


Fig 2 Equivalent circuit of a single DG–grid system with VCM.

From the equivalent circuit in Fig.1

$$I_{Load} + \frac{V_{DG}}{Z_{DG}} + \frac{V_{Grid}}{Z_{Grid}} + \frac{V_{PCC}}{Z_{Parallel}} = 0 \qquad (7)$$

$$\frac{1}{Z_{Parallel}} = \frac{1}{Z_{DG}} + \frac{1}{Z_{Grid}} + \frac{1}{Z_{Load}} \qquad (8)$$

Considering that ZLoad(s) is much higher than ZGrid(s) and

ZDG(s) and that VGrid(s) ≈ 0 at the harmonic frequencies, when the DG harmonic voltage is actively controlled (harmonic compensation/rejection mode), then the PCC harmonic voltage and DG harmonic current attenuation ratios compared to the uncontrolled mode can be obtained as shown in

$$\frac{V_{PCC,Active}}{V_{PCC,\mathrm{Uncontrolled}}} \approx \frac{Z_{DG} + Z_{Grid}}{Z_{DG} + (1+\mathrm{G}).Z_{\mathrm{Grid}}} \qquad (9)$$

$$\frac{I_{\mathrm{DG},Active}}{I_{\mathrm{DG,Uncontrolled}}} \approx \frac{(Z_{DG} + Z_{Grid})(1+\mathrm{G})}{Z_{DG} + (1+\mathrm{G}).Z_{\mathrm{Grid}}} \qquad (10)$$

Where I_{Load} load current

V_{DG} DG voltage

Z_{DG} DG impedance

Z_{Grid} grid impedance

III CONTROL OF PV INVERTERS WITH VIRTUAL HARMONIC RESISTANCE

By virtual harmonic resistance control the PV inverters work as R-APF.The PV system has two stage conversion system, which includes a DC-DC converter that steps up the PV output to the DC link voltage level with maximum power point tracking (MPPT) control, and an inverter that connects the system to the grid. The PV system output current reference has two components (i) the fundamental component (I_f^*) which is produced from the DC link voltage control and (ii) the harmonic components (I_h^*) which are used for harmonic compensation.

For virtual resistance control the reference harmonic current of the PV system is realized by using

$$I_h^* = {V_{G-h}} / {R_h} \qquad (11)$$

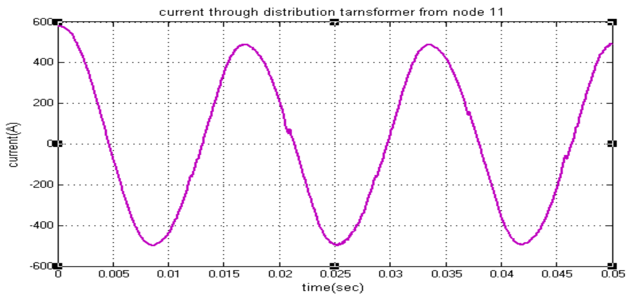
Then the current reference of DG is obtained by combining the fundamental reference and the harmonic current reference (I_f^*). Finally the PV system output current is controlled with double control loops, containing outer output current (I_{DG}) control loop and an inner (LC) filter inductor current control loop.

IV DISTRIBUTED COMPENSATION IN A SOLAR POWERED RESIDENTIAL SYSTEM

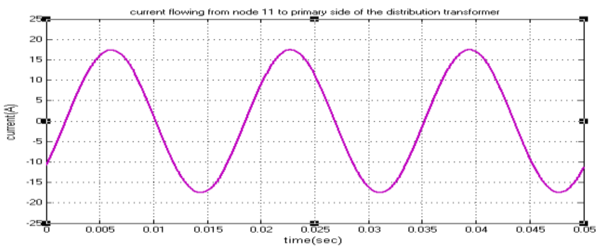
Capacitors are often installed in distribution systems for voltage regulation and reactive power compensation. These capacitors may cause harmonic resonances and affect the harmonic compensation performance. This section extends the analysis in the previous sections to include the effects of PFC capacitors.

The voltage profile along the distribution line with a capacitor is influenced by the capacitor location and the capacitor's reactance value. Generally, a capacitor connected at the end of a distribution network provides the best performance for improving the voltage profile along the distribution line by improving the power transfer capability, voltage regulation, and power factor [13]. However, the most efficient capacitor placement also depends on the load, load power factor, line parameters of the distribution network, and reactance value [14].

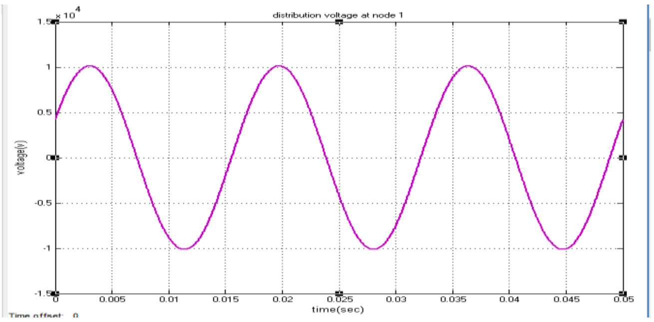
The simulation results for a solar powered residential system having 12 nodes are as below, by observing the results of simulink model the total harmonic distortions at the first node is better than the last node i.e, the THD is goes on increasing from the first node. Distribution system model of a 11 node system .



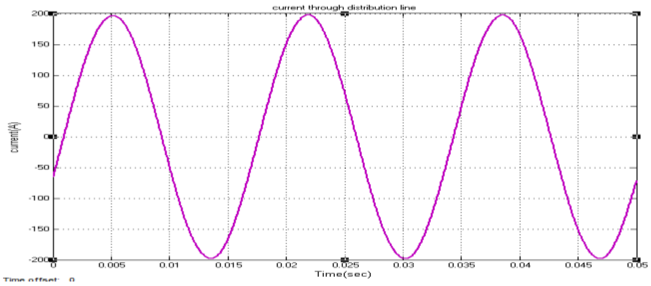
(a) Current through distribution line



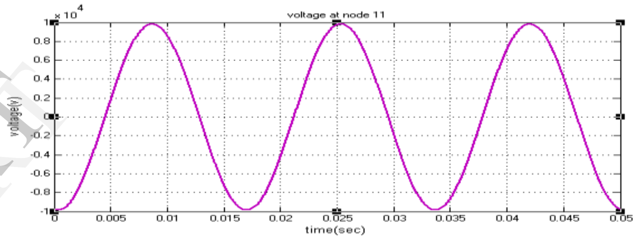
(b) Current flowing from node 11



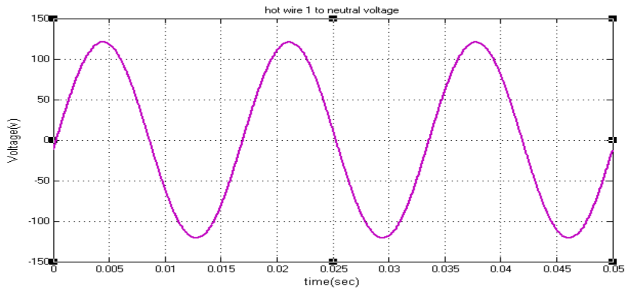
(c) Distribution voltage at node 1



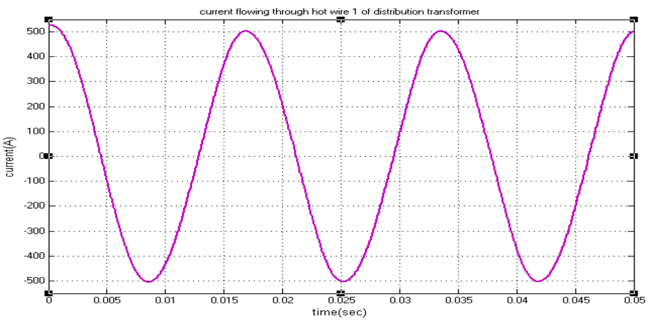
(d) Current flowing from node1 to primary side of the distribution transformer



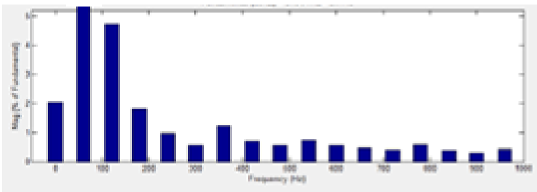
(e) Voltage at node 11



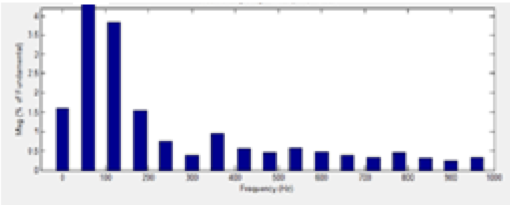
(f) hot wire1 to neutral voltage



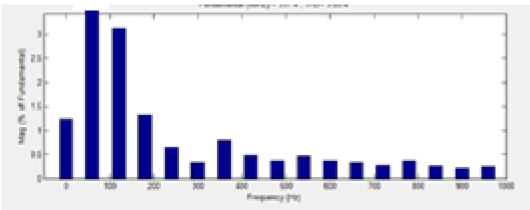
(g) Current through hotwire1 of distribution transformer



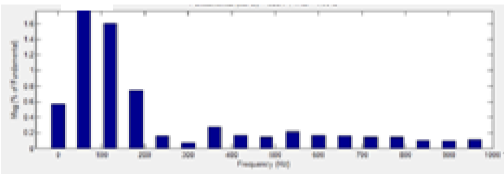
(h) THD at 11th node



(i) THD at 8th node



(j) THD at 4th node



(k) THD at 1st node

V DISTRIBUTED COMPENSATION RESIDENTIAL DISTRIBUTION SYSTEM USING HYSTERESIS CONTROLLER

a *Hysteresis controller*

The hysteresis controller has breaking point groups are on either side of a sign speaking to the wanted yield waveform, the inverter switches are worked as the created flag inside limits[4]. The sine reference sign wave of fancied size and recurrence is created by the control circuit, and this sign is contrasted and the genuine sign. In the event that the sign surpasses a recommended hysteresis band, the upper switch in the half-scaffold is turned OFF and the lower switch is turned ON else the sign crosses as far as possible, the lower switch is turned OFF and the upper switch is turned ON.

The real flag wave is in this manner compelled to track the sine reference wave inside the hysteresis band limits. A controlled current inverter is obliged to create this remunerating current. Hysteresis current control is a strategy for controlling a voltage source inverter with the goal that a yield current is produced which takes after a reference current waveform. This strategy controls the switches in an inverter non concurrently to incline the present through an inductor all over with the goal that it tracks a reference current sign. Hysteresis current control is the simplest control technique to execute.

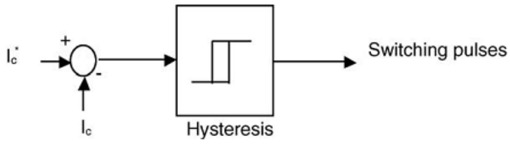


Fig 3 Hysteresis controller

the performance with different harmonic compensation approaches under an 11-node solar powered residential distribution system is investigated. The effects of PFC capacitors and distributed compensation are included in this section. To provide a fair comparison of different harmonic compensation methods, the criterion that the total harmonic RMS current from all the DGs in the system is kept the same irrespective of the compensation scheme and distribution system configuration is adopted for this study. With this criterion, the virtual resistance is $Z_{vr} = {}^{1}\!/_{0.58}\,\Omega$ initially selected in the case of distributed compensation in an 11-node system. This resistance leads to a total 76.4 A RMS DG harmonic current and about 2% of the total load RMS current. The equal equivalent rating for different compensation strategies and different systems is then calculated from this base DG RMS current. it reveals that the end-of-line and distributed compensation has a crossover frequency for a N-node distribution feeder[1]. In the low-frequency region before the crossover frequency end-of-line compensation is better, and in the high-frequency region after the crossover frequency distributed compensation is better. As the feeder node (length) increases, this crossover frequency moves to the lower-frequency region. Time domain simulations of an 11-node system were also conducted by using Matlab/Simulink to verify the above analysis using the developed models. In the time domain simulations, the home model has harmonics up to the 13th, so the situation will involve the relatively low frequency range. Simulink model of 11 node distribution system consisting of 12 home models each is shown in fig.4 and home model in fig.5

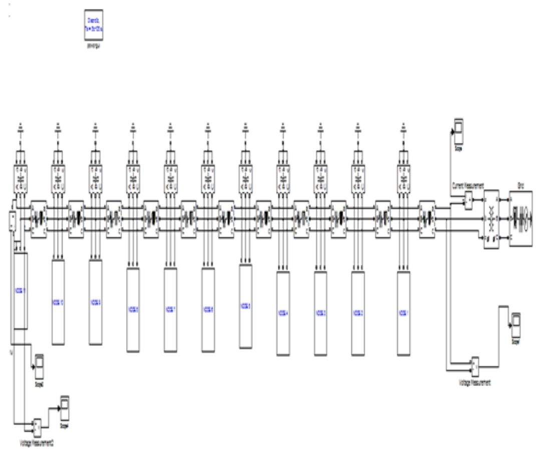


Fig 4 Simulink model of 11 node distribution system

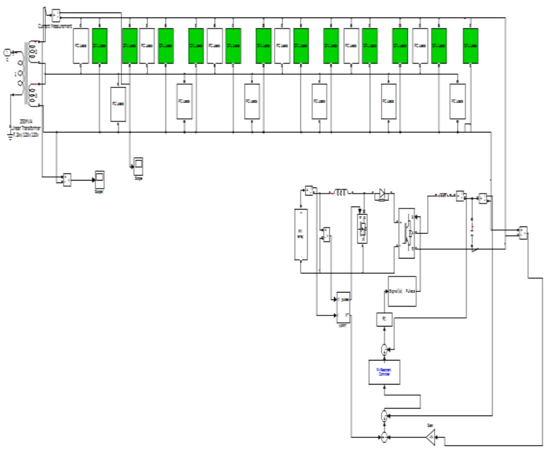


Fig 5 Simulink model of home model

Simulink model of pulse generation using hysteresis controller for the inverter control is shown in fig.6

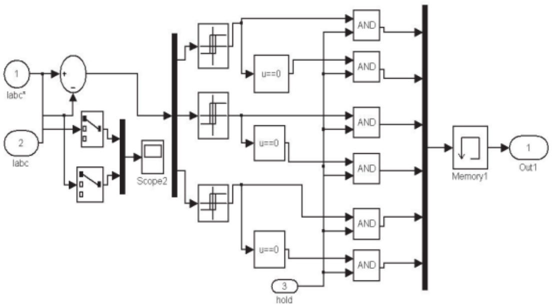
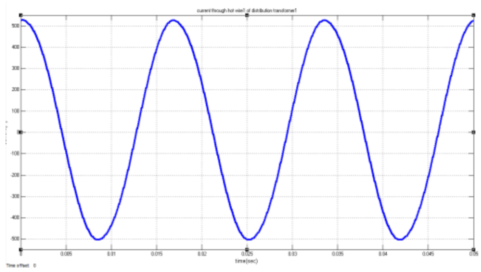


Fig 6 pulse generation using hysteresis controller

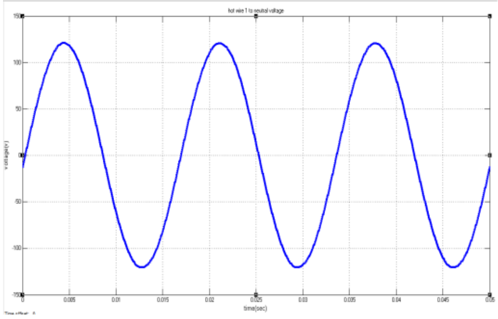
For different compensation strategies the harmonic current and voltage content throughout the distribution line are shown.

Distributed compensation with PFC capacitors provides better results than end of line compensation, which is shown by the following results. In this hysteresis controller is used the results are as follows, and the THD values are decreased i.e.,

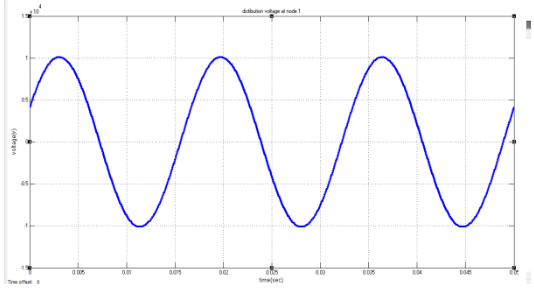
For 11th node 5.77 % to 2.31%
For 8th node 4.65% to 1.79%
For 4th node 3.85% to 1.25%
For 1st node 1.90% to 0.86%



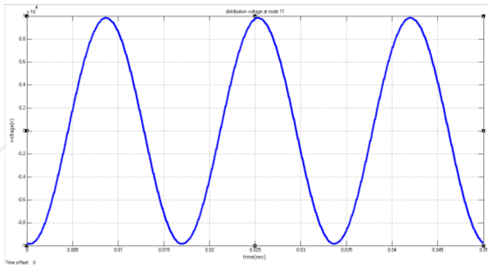
(a) Current through distribution line



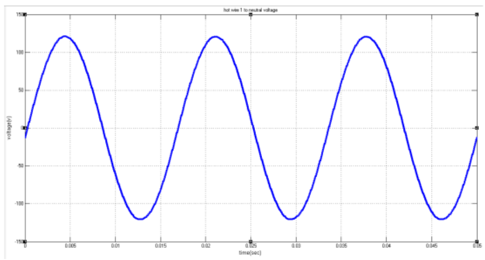
(b)Hot wire1 to neutral voltage



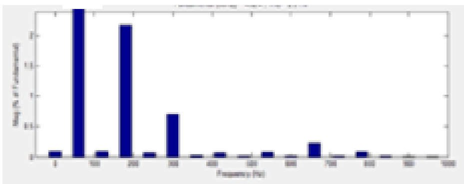
(c)Distribution voltage at node1



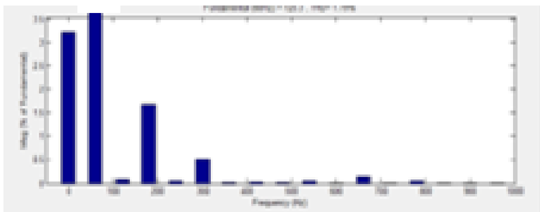
(d)Distribution voltage at node 11



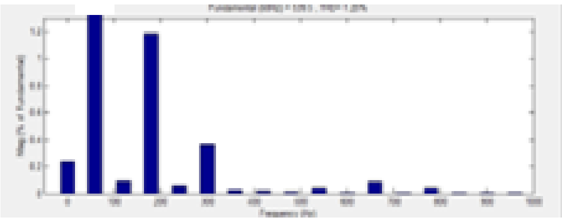
(e)Hot wire 1 to neutral voltage



(f)THD of harmonic current at 11th node



(g)THD of harmonic current at 8th node



(h)THD of harmonic current at 4th node

(i)THD of harmonic current at 1st node

VI CASE STUDY:

To analyze the total system in matlab ,a solar plant used in a near by organisation is taken for case study and plant details are collected for reference,

a. Photo voltaic modules:

The photo voltaic modules used in rishivalley solar plant are jain irrigation systems i.e., **JJ-M660 photovoltaic module**

Specifications of the module:

1. Temperature coefficient of P_{max} : -0.45%/ºk
2. Temperature coefficient of I_{sc} : 0.04%/ºk
3. Temperature coefficient of V_{sc} : -0.35%/ºk
4. NOCT : 45+/-2ºC
5. Safety class : II
6. Maximum series fuse : 15A

b. Controlling technique for 3 phase inverter:

The system of organization consists of three phase inverter; the controlling technique for three phase inverter is different from single phase inverter. Synchronous reference frame control theory is used in three phase for reducing the THD at the point of common coupling. Controlling technique block diagram is shown in fig 6

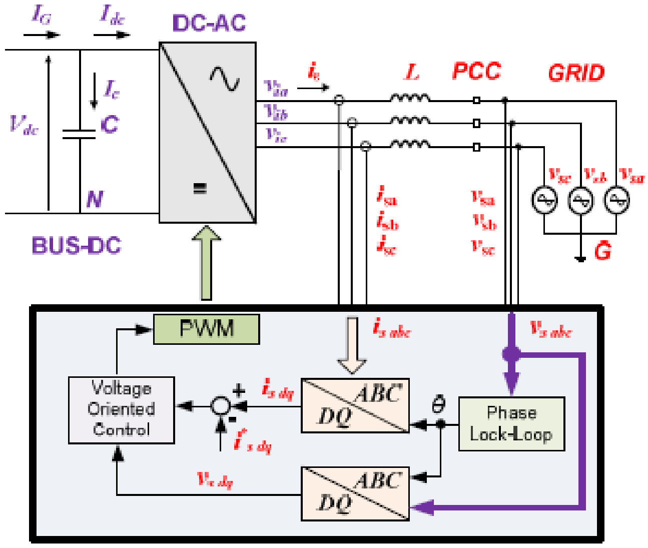


Fig 7 Three phase inverter connected to grid

The voltages and currents are given as

$$v_{ik} = R.i_{sk} + L.\frac{d}{dt} i_{sk} + v_{sk} + v_{NG}, k = a, b.c \qquad (12)$$

Where V_{ik} inverter output voltage

i_{sk} grid current

V_{sk} grid output voltage

V_{NG} voltage between ground and negative of dc bus

In synchronous reference frame with angular velocity ω the equations are

$$v_{idq} = R.i_{sdq} + L\frac{di_{sdq}}{dt} - jL\omega i_{sdq} + v_{sdq} \qquad (13)$$

Where V_{idq} inverter voltage in dq plane

I_{sdq} grid current in dq plane

V_{sdq} grid voltage in dq plane

We could represent this equation in its direct axis "d" and quadrature axis "q"

$$vs\_dq = v_{sd} + jv_{sq}$$

$$v_{sq} = 0 \begin{cases} v_{id} = R.i_{sd} + L\frac{di_{sd}}{dt} + L\omega i_{sq} + v_{sd} \\ v_{iq} = R.i_{sq} + L\frac{di_{sq}}{dt} + L\omega i_{sd} + v_{sq} \end{cases} \qquad (14)$$

At the point of common coupling grid voltage doesn't have quadrature component

$$v_{id} = R.i_{sd} + L\frac{di_{sd}}{dt} + L\omega i_{sq} + v_{sd}$$
$$v_{id} = R.i_{sq} + L\frac{di_{sq}}{dt} + v_{couplingd} + v_{sd} \qquad (15)$$

$$v_{iq} = R.i_{sq} + L\frac{di_{sq}}{dt} - L\omega i_{sd}$$
$$v_{iq} = R.i_{sq} + L\frac{di_{sq}}{dt} - v_{couplingq} \qquad (16)$$

Then in a linear and symmetric system the active and reactive components are reduced to direct and quadrature axis components as

$$P = \frac{3}{2}(\mathrm{v_{sd}i_{sd}} + \mathrm{v_{sq}i_{sq}}) \rightarrow \mathrm{P} = \frac{3}{2}(\mathrm{v_{sd}i_{sd}}) \qquad (17)$$

$$Q = \frac{3}{2}(\mathrm{v_{sq}i_{sd}} - \mathrm{v_{sd}i_{sq}}) \rightarrow Q = \frac{3}{2}(\mathrm{v_{sd}i_{sq}}) \qquad (18)$$

c. *Distribution system without compensation*

The distribution system considered is having single feeder, Grid voltage 33KV, Primary distribution transformer 250MVA, 33/11KV' Secondary distribution transformer 100KVA, 11KV/240V, Photovoltaic power generation 150KWP and three phase inverter. The PV with inverter is connected to the secondary of the primary distribution transformer. This system is simulated and it has got THD of 8.54%. As per IEEE standards the permissible THD value is 5%, by using different compensation techniques the accessible limits are reached.the distribution system without compensation is shown in fig 7

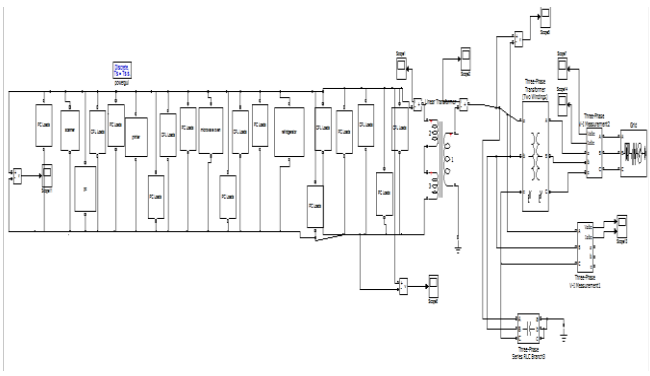


Fig 8 Distribution system without compensation

d. *Harmonic compensation with PFC capacitors:*

The installation of the power factor correction capacitor in the distribution system makes the harmonic issues complex and some harmonics may be amplified. Although installing an active power filter may mitigate the harmonics at point of installation at that instant the harmonics may increased on some buses due to the 'whack a mole' effects. To investigate the effectiveness of different harmonic compensation schemes a distribution system with DG on secondary side of the distribution transformer is modeled. The model consist of different domestic appliances such as fluorescent lamp, personal computer, refrigerator, etc., the simulink model is shown in fig.6 the load data for CFL and PC are in table .1

Table.2 harmonic load data for CFL and PC

Appl model	Data type	Harmonic load current						
		1st	3rd	5th	7th	9th	11th	13th
CFL	Mag	0.15	0.13	0.09	0.07	0.07	0.06	0.039
	Ang	21.2	53.9	105.5	169.4	-134.8	-84.2	-21.8
PC	Mag	0.83	0.65	0.41	0.16	0.10	0.12	0.12
	Ang	0.50	1.6	3.6	8.6	58.1	168.7	178.0

These harmonic loads are modeled as a harmonic current source in parallel with the fundamental impedance

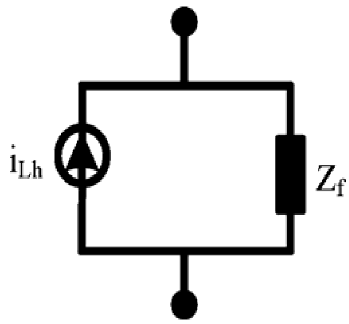


Fig 9 House load model with harmonic current source in parallel with fundamental impedance

$$where, i_{Lh} = \sum_{h=3,5,7....} i_h \qquad (19)$$

To obtain such a home model, individual home appliance models, including personal computer (PC), compact fluorescent light (CFL), adjustable speed drive (ASD) fridge, TV, refrigerator, washer, and dryer are generated first. As an example, the harmonic load current data for the CFL and PC are shown in Table 2. These data are taken from the appliance harmonic load current data are measured practically [14, 29].

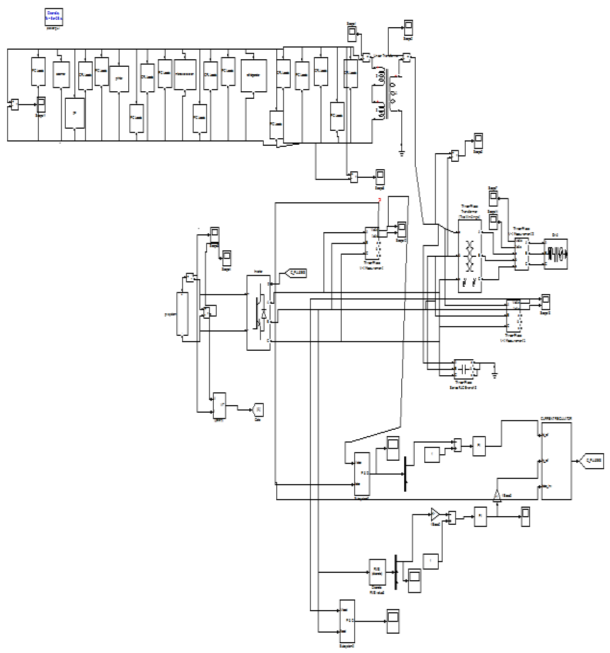


Fig 9.Simulink model of case study

The system with PFC capacitors have low THD i.e.,5.43% and it has reduced about 3% when compared to without compensation.

e. Harmonic compensation with dg

Two control strategies are possible for harmonic compensation using DG 1) End of line compensation and

2)distributed compensation

In end of line compensation priority is given to the pv inverters at the end of the feeder, this method is not effective because THD not improved very much. In distributed compensation all the DGs connected to the feeder are given equal priority and operated in harmonic compensation mode. The THD for distributed compensation is 4.43%.

VII SIMULATION RESULTS AND DISCUSSION:

The 150KW grid connected solar system supplying commercial loads is simulated in MATLAB, the results ,The P-V curve and I-V curve of the case study are as follows

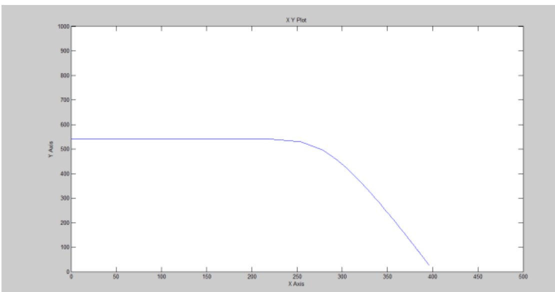


Fig.1 I-V curve

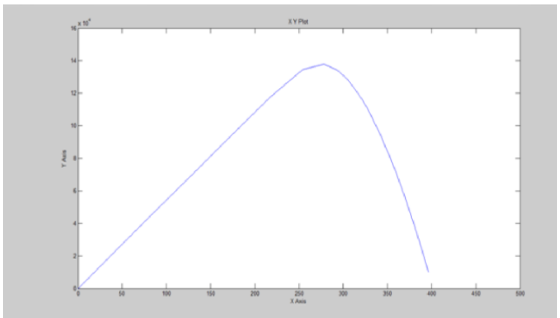
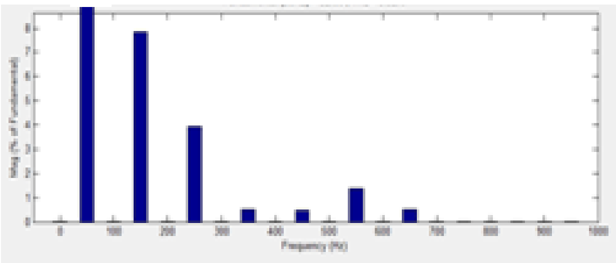
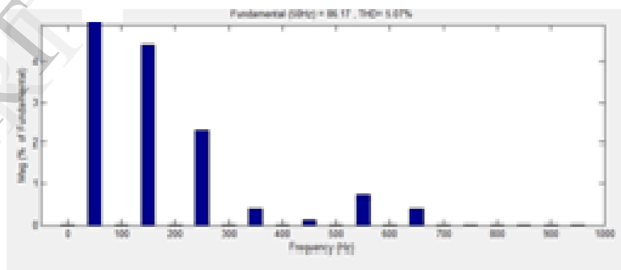


Fig.2 P-V curve

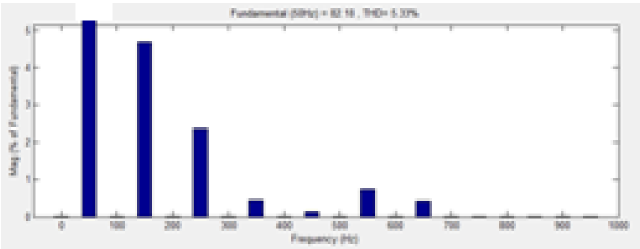
The FFT analysis with controlling and without controlling results are shown in the figure below



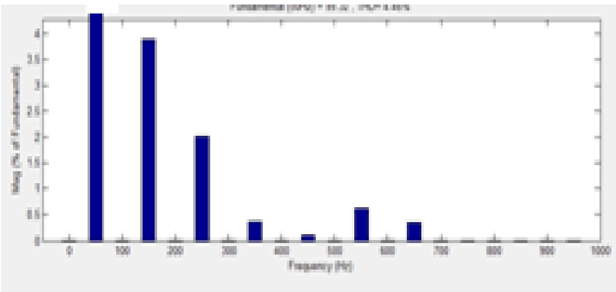
(i)THD of the system without controlling



(ii)With end of line compensation



(iii)With distributed compensation



(iv) THD of the system with both end of line compensation and distributed compensation

CONCLUSION:

In this paper, the thought of utilizing private framework DG-matrix interfacing inverters as virtual consonant resistances to moist the framework music and enhance the force quality is investigated. A top to bottom examination and correlation of distinctive symphonious payment plans were directed to give a manual for figuring out if circulated recompense or end-of-line remuneration ought to be utilized.It is concluded that distributed compensation with PFC capacitors will give better results.

For future work, it will consider a supervisory control arrangement of the DGs with correspondence so as to control the support from every PV inverter naturally as indicated by the recognized need. The use of a statistical home model of a residential system and solar irradiance historic data could also be considered in order to provide accurate analysis of the harmonics compensation by using PV inverters throughout the day/season/year.

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