Comprehensive Assessment and Mitigation of Harmonic Resonance in Smart Distribution Grid with Solar Photovoltaic

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Abstract- The paper explores the occurrence of resonance between the grid connected solar photovoltaic system and distribution grid components. In order to alleviate the harmonics, the LC or LCL filters are invariably employed at the output of interfacing inverter. Additionally, the transformers, capacitor banks, and cables are customarily used in power system. These inductive and capacitive elements can invoke the harmonic resonance by reacting with grid impedance. The objective of present paper is to analyse the harmonic resonance when a solar PV system is penetrated into the distribution grid under varying network conditions. The paper investigates the effect of inverter output filter, weak/strong grid, cable length, and capacitor sizing on the harmonic resonance. The end goal is to examine the harmonic resonance by varying the system parameters and its harmful outcome, such as dangerous over voltage at the various buses. Finally a control scheme is suggested to mitigate the effect of harmonic resonance. It is expected that the future smart power grid will witness more share of solar PV, therefore, the harmonic resonance between grid elements and inverters will be a great issue of concern. In order to the meet the goals of such grid, the delayed recognition of harmonics and resonance may lead to high cost solution.

Keywords Total harmonic distortion (THD); resonance; smart grid penetrated solar PV; C-type passive filter.

1. Introduction

The power quality issues are untraceable during the developing and integrating stages of solar PV plants and therefore, often overlooked. Power electronic inverter is a crucial facilitator which enables the integration of solar PV into the grid [1-5]. Harmonics are introduced in the system due to the widespread use of inverter-based solar PV interface and extensive use of nonlinear loads [6-8]. The output of solar PV inverter is connected to LC or LCL filter to alleviate the harmonics but such filters are prone to frequency shifting and impedance variation problems [9-12]. Moreover, the power system components such as transformers, capacitors, connecting cables are widely used in the process of integration. These inductive and capacitive elements, at certain harmonic frequency excite an unintentional phenomenon called harmonic resonance [13-18]. There are documented incidents available about the harmonic resonance and its ruinous effects such as component failures, destabilization, and plant shut downs in references[19-23].The aim of this paper is to manifest the occurrence of harmonic resonance due to solar PV inverter and associated distribution grid components. The end goal is to examine the harmonic resonance by varying the system parameters and its harmful outcome, such as dangerous over voltage at the various buses. Such analysis is quite useful to develop suitable control strategies to supply the clean power to all stockholders and fulfil the smart distribution grid objective. The paper is structured as follows: The modelling of various power grid components is presented in Section II. Harmonic resonance due to PV inverter filter is discussed in Section III. Modelling of smart distribution grid with solar PV is given in Section IV. Section V presents the Investigation on harmonic resonance and results discussion.

Finally, Section VI presents the conclusion on the research findings.

2. Modelling of Power System Components for Harmonic Resonance Studies

2.1. Grid Inverter Modelling

The model of the grid connected inverter for resonance studies is presented in Fig. 1 [24-26]. Where, I_p and Z_p are the inverter current and impedance respectively. While V_g and Z_g are the grid voltage and impedance respectively. If the grid has low fault level, the integration of solar PV inverters may incite harmonic resonance with the grid impedance [27]. The frequency of resonance depends on the inverter and grid impedance characteristics.

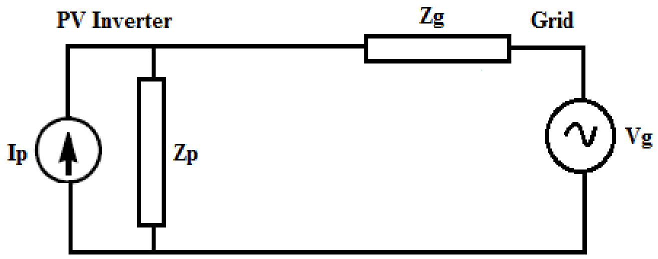

Fig.1. Grid inverter model

2.2. Cable Modelling

The capacitance of cable is about 20 times higher than overhead lines of the same length. Effect of this capacitance is small for power frequency applications, but it has profound effect at higher harmonic frequencies. For harmonic resonance studies cables are considered as distributed transmission lines as shown in Fig. 2 [27-29].

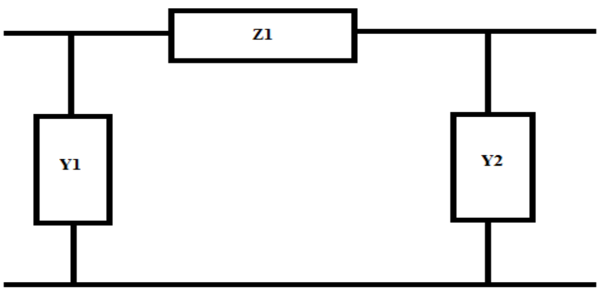

Fig.2. Equivalent pi model of cable

The series impedance and parallel admittances are given in (1).

$$Z_1 = \left(R_0 + jnX_0\right)L \qquad Y_1 = Y_2 = jnB_0L \;/\, 2 \tag{1}$$

R_0, X_0, and B_0 are the unit-length resistance, reactance and susceptance, L is the length of cable, and n is the harmonic order.

2.3. Capacitor Modelling

Power electronics interfaces and the modern loads generate plenty of harmonics and worsen the system power factor. In distribution networks capacitor banks are widely used for voltage enhancement, power-factor improvement, and reactive power compensation. Inappropriate placement and sizing of capacitors at certain harmonic frequency provokes parallel and/or series resonances in the grid [30]. For harmonic resonance studies capacitors can be modeled as Fig. 3. Capacitor C draws current I_c, whereas V_g and Z_g is the grid voltage and impedance respectively. The output of capacitor varies with the square of the voltage (2).

$$K\,\mathrm{var}_2 = K\,\mathrm{var}_1 \left|\frac{V_2}{V_1}\right|^2 \tag{2}$$

Where, $K\,\mathrm{var}_1$ is the capacitor output at voltage V_1 and $K\,\mathrm{var}_2$ is the capacitor output at voltage V_2.

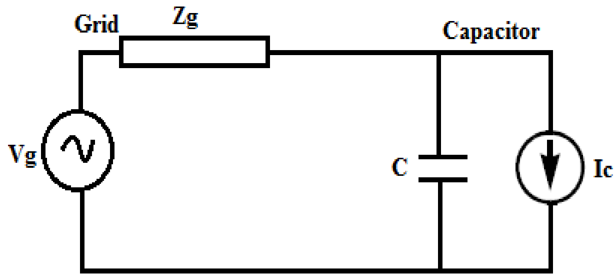

Fig. 3 Model of capacitor

2.4. Load Modelling

Linear loads provide the damping at high frequencies and affect the resonance conditions in the network [31]. The linear loads are modelled as conventional PV and PQ buses at fundamental frequency and shunt admittances are also included in harmonic frequencies modelling [32]. The h^{th} harmonic frequency admittance of a linear load connected to bus y is presented in (3).

$$y_y^{(h)} = \left(\frac{P_y^{(1)} - j\dfrac{Q_y^{(1)}}{h}}{\left|V_y^{(1)}\right|^2} \right) \tag{3}$$

At any bus y, the harmonic current will be function of its fundamental and harmonic voltages as expressed in (4).

$$I^{(h)} = f_y^h\left(V_y^{(1)}, V_y^{(5)}, V_y^{(7)}, V_y^{(9)}, \ldots. V_y^{(L)}, \alpha_y, \beta_y\right) \tag{4}$$

Where, L is Maximum harmonic order and α_k, β_k are the nonlinear load control parameters.

3. Modelling of Smart Distribution Grid with Solar Photovoltaic

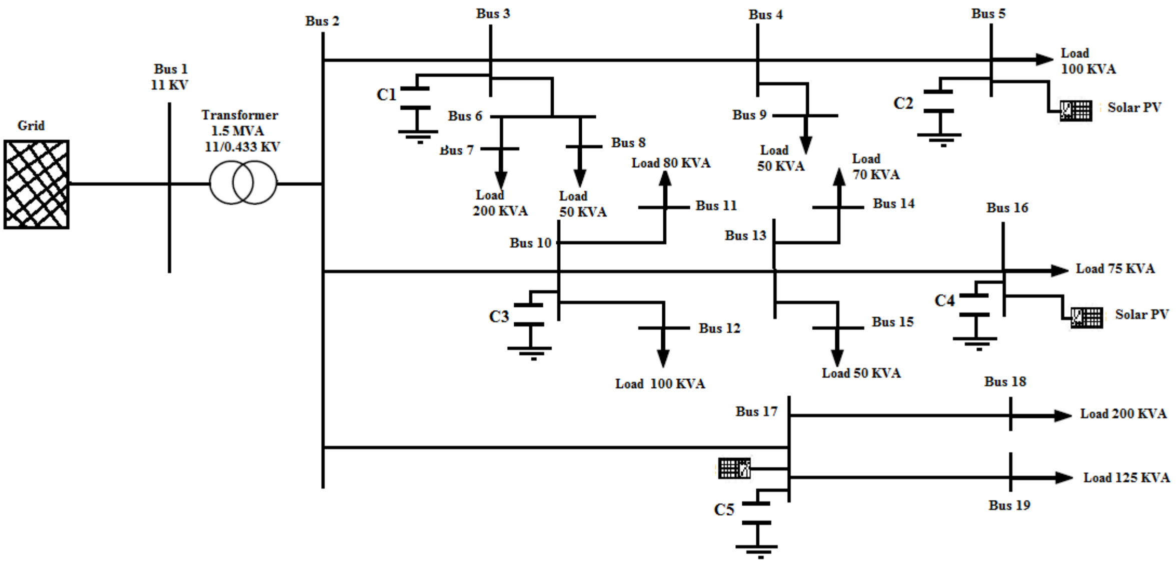

Fig.4. Smart rural distribution grid with solar photovoltaic

The model of 11 kV rural smart distribution grid with solar photovoltaic is shown in Fig. 4. A transformer of capacity 1.5 MVA, 11/0.433 kV is employed to feed the loads. Loads of varying natures in the connected area are fed through laterals. Capacitors at various locations are used for power factor improvement and reactive power compensation. Table 1 shows the rating details of capacitors. Solar PVs are connected at the buses 5, 16 and 17. Their rating details are given in Table 2.

Table 1. Rating details of capacitor banks

Capacitor	Rating of Capacitor Bank
C1	3 × 50 kVAR, 0.433 kV
C2	1 × 50 kVAR, 0.433 kV
C3	2 × 50 kVAR, 0.433 kV
C4	1 × 50 kVAR, 0.433 kV
C5	3 × 50 kVAR, 0.433 kV

Table 2. Solar PV parameters

S. No.	Component / Parameter	Rating
1	PV panel (Watt/panel)	280
2	PV panels in series	11
3	PV panels in parallel	161
4	Total no. of panels	1771
5	Volts (dc)	400
6	kW(dc)	500
7	Amp (dc)	1240
8	Inverter (kVA)	600
9	Inverter (Amp)	800
10	Inverter (output voltage) (volts)	433

4. Algorithm for Resonance Identification

The analytical steps for harmonic resonance analyses and resonance damping are presented here;

The aim of harmonic resonance analysis is to get the frequency at which the resonance occurs. The harmonic resonance is investigated by implementing following analytical steps [34].

(1) An admittance matrix is formed by considering the models of solar PV, transformer, cables, and other components of distribution system at fundamental frequency. The voltage-current relationship for such matrix can be expressed as (5)

$$\begin{bmatrix} I_1 \\ I_i \\ I_j \\ I_n \end{bmatrix} = \begin{bmatrix} y_{11} & -y_{1i} & -y_{1j} & -y_{1n} \\ -y_{i1} & y_{ii} & -y_{ij} & -y_{in} \\ -y_{j1} & -y_{ji} & y_{jj} & -y_{jn} \\ -y_{n1} & -y_{ni} & -y_{nj} & y_{nn} \end{bmatrix} \begin{bmatrix} v_1 \\ v_i \\ v_j \\ v_n \end{bmatrix} \quad (5)$$

Where, v_1, I_1, v_i, I_i are the input voltages and currents at bus 1 to i and I_n, I_j, v_j, v_n are output currents and voltages at bus n to j. The complex admittances can be determined by (6):

$$y_{ij} = \left. \frac{I_i}{v_j} \right|_{I_k=0} \quad k = 1...n, k \neq i \quad (6)$$

Where the off-diagonal elements, that is, y_{ij} is the transfer admittance and y_{ii} is the self-admittance.

(2) The admittance matrix is modified for various harmonic frequencies and the equation (6) is repeatedly iterated in order to get the various operating points. The curve between the impedance versus frequency gives the points at which the harmonic resonance occurs.

4. Harmonic Resonance Results and Discussion

This section presents the generation of voltage and current harmonics by the solar PV inverters, their interaction with network components and resulting occurrence of harmonic resonance in the system. The section also presents the finding about the variation in harmonic resonance due to varying network conditions.

4.1. Voltage and Current Harmonics due to Solar PV Inverters

PV inverters are the main contributor of harmonics in the network. The nature of voltage and current harmonics generated by solar PV inverters are presented in Figs. (4-5). such harmonics can invoke the harmonic resonance in the network as presented in next sections.

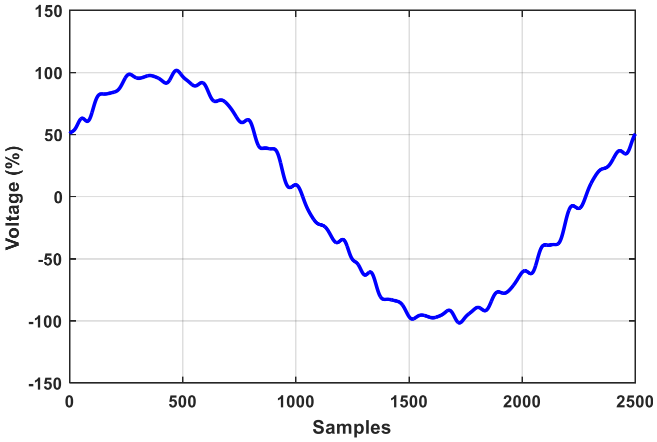

Fig.4(a). Voltage harmonics waveform at bus 5

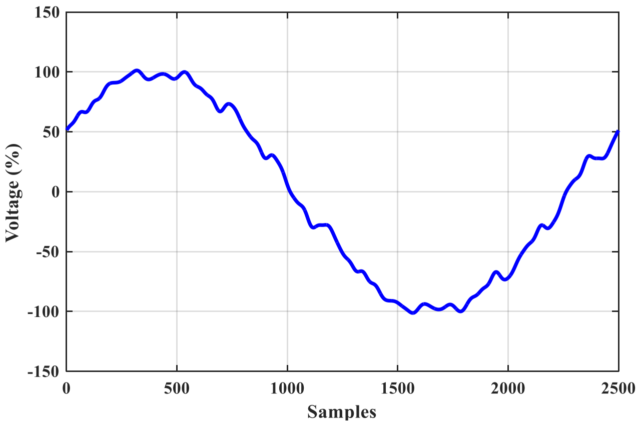

Fig.4(b). Voltage harmonics waveform at bus 16

4.2. Impact of Frequency on Harmonic Impedance

The voltage and current of various frequencies exist in the system, which affects the operation of system. The parameter harmonic impedance portrays the behaviour of the system due to the presence of changing frequencies [33]. Harmonic impedance is a time varying quantity and depends on the state of the power system and variation in connected load. Harmonic impedance is used for various purposes [34-36] such as;

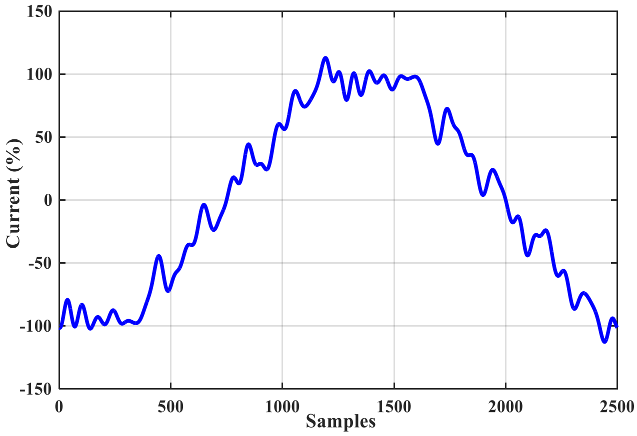

Fig. 5(a). Current harmonics waveform between bus 4 &5

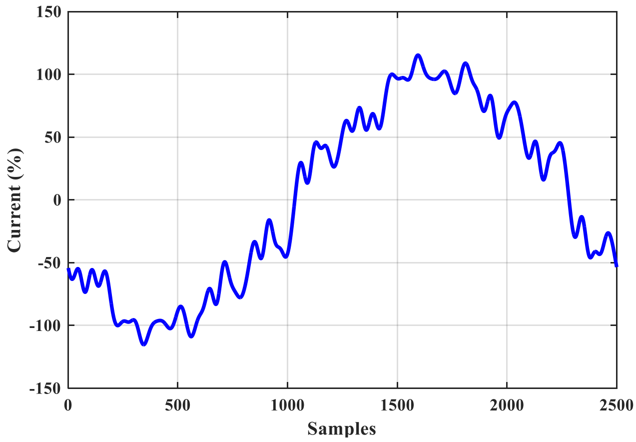

Fig. 5(b). Current harmonics waveform between bus 13 & 16

- Assessing the level of harmonics propagated by the harmonic source and harmonic resonance in the distribution system.
- To design the active and passive harmonic filters.
- For the expansion of the system with the addition of new harmonic generating loads. Harmonic impedance is given by (7) [32].

$$Z_h = \frac{\Delta V_h}{\Delta I_h} \tag{7}$$

Where, ΔV_h and ΔI_h are the change in harmonic voltage and current, due to change in power system state. Fig. 6 presents the variation in resistance and reactance with different frequencies at bus 5. Such system can have different impedance characteristics at various frequencies. The variation in impedance characteristics depends on system state and the availability of component in service. Therefore the resonating frequency also varies with the variation in impedance characteristics of the system. This is a challenging task for the filter designer.

Fig.7 presents the variation in impedance magnitude versus frequency. The parallel resonances occur at crest points, which give the maximum impedance and the series resonances at the lowest points of the impedance plot. The level of harmonics in the power system significantly changes due to the presence of nonlinear and time-varying elements. The order of harmonics at various buses, and the total harmonic distortion is presented in Table 3. Table 4 presents the evaluated harmonic impedances along with phase shift, which gives the clear view about the harmonic frequency and its value for the particular bus. It is also observed that harmonic resonance creates the overvoltage situation at various buses. The magnitude of overvoltage at the time of resonance rises to 133 % at bus 5. Such momentary overvoltage is dangerous for the connected equipment. From Table 3 and 4, it can be observed that, the harmonic resonant frequency differs from the available harmonic orders. For the given smart distribution system, THD is more than the IEEE standards of less than 5% level. In such harmonic-rich environment, both series and parallel resonance will occur. At peak points voltage gets magnified and overvoltage occurs in the system. The value of parallel resonant frequency is smaller than its series resonant frequency due to the source inductance contribution.

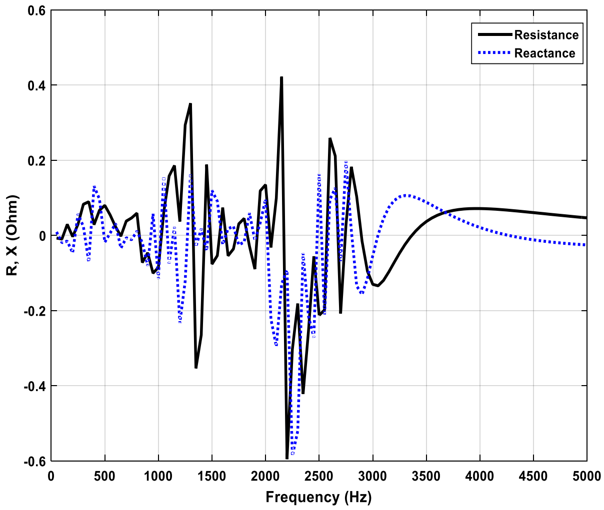

Fig.6. Variation in resistance and reactance with frequency at bus 5

4.3. Effect of Weak and Strong Grid

The impedance of weak grid varies significantly with variation in operating conditions, the value of short-circuit ratio (SCR) for a weak grid is less than 3 [37]. Harmonic resonance can also be examined in weak and strong grids in Fig.8. It is observed that, by changing the grid strength, harmonic resonance shifts towards lower frequency levels, while at higher frequencies no considerable change is observed. The shifting of resonance towards low frequency side is harmful for the distribution system components.

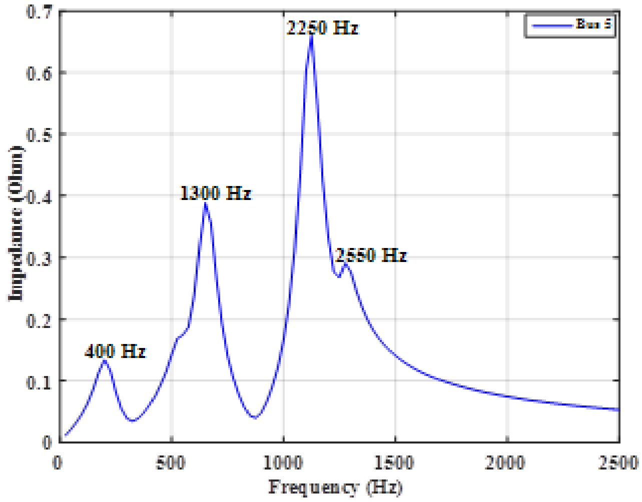

Fig. 7. Harmonic resonance at bus 5

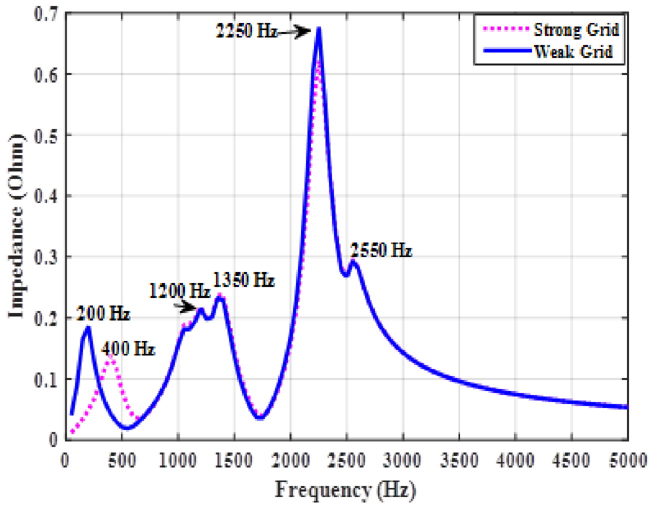

Fig.8. Harmonic resonance at bus 5 due to weak and strong grid

4.4. Effect of Inverter Output Filter

Power electronics interface is the heart of such system which assists the integration of solar PV in the distribution grid. LC and LCL filters are widely used to mitigate the harmonics generated by PV inverters. These filters may excite harmonic resonance by interacting with grid impedance. Fig. 9 presents the comparative analysis of occurrence of harmonic resonance with and without LCL filter. It is observed that the filters damp the resonance and shifts it towards higher frequency level.

4.5. Effect of Capacitor Sizing

Fig. 10 presents the shift in resonance frequency, towards the lower frequency range, with the increase in size of capacitors at bus 5. For 20 % capacitors, the resonance peak occurs at 2250 Hz. For 60% capacitors, the peak occurs at 900 Hz. For 100% capacitors, the peak occurs at 300 Hz. The resonant point shifts towards the lower frequency range and resonant impedance reduces with the increase in size of capacitors. These lower frequency peaks are more dangerous for the PV integrated distribution system. Moreover, if the power factor is controlled by switching the capacitors in sequence, shifting of frequency will cause multiple resonance points. Such parallel harmonic resonance is sufficient to damage the system components including capacitors and difficult to control. Hence capacitors require more attention in terms of sizing and optimal location to avoid the poor power factor and resonant threat to the system.

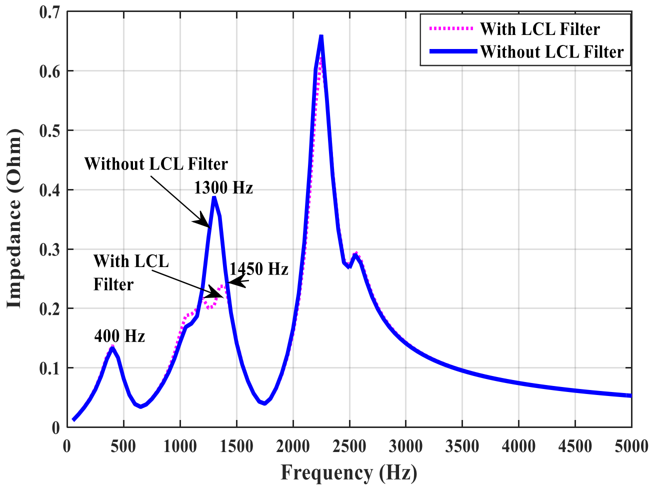

Fig.9. Occurrence of harmonic resonance at bus 5 with and without LCL filter

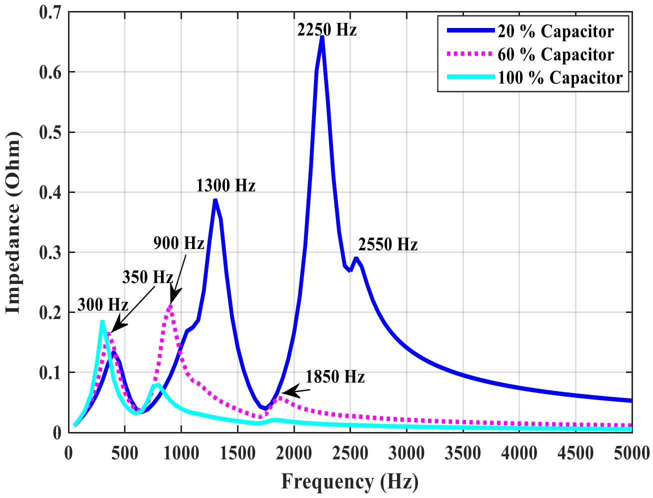

Fig.10. Change in harmonic resonance frequency with variation in capacitor ratings at bus 5

4.6. Effect of Variation in Cable Length

Underground cables are extensively used for distribution purpose in smart distribution system. The capacitance of cables is very high in comparison to overhead conductors. Fig. 11 shows the variation of resonance frequency with cable length. For the cable length of 125 ft. the resonance frequency is 2250 Hz. For the cable length of 500 ft. the resonance frequency is 1000 Hz, and for the cable length of 1000 ft. the resonance frequency is 800 Hz. It shows that, in cables the resonance frequency shifts towards the lower side as the length of cable increases. These lower frequencies are more dangerous for the system components.

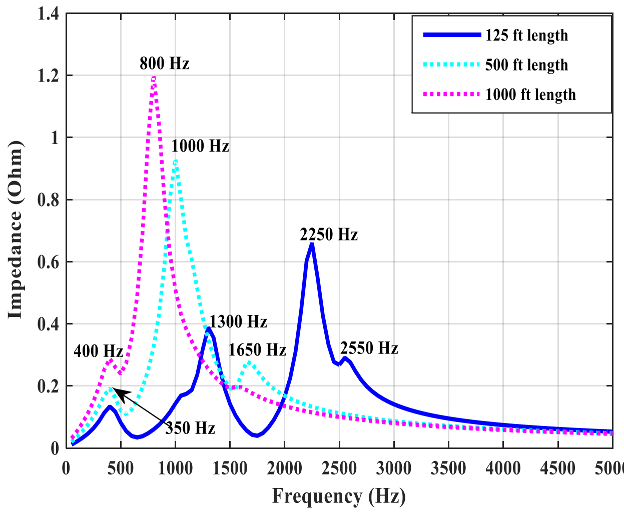

Fig. 11. Change in resonant frequency with cable length

5. Damping the Harmonic Resonances

This section presents the filter planning approach to mitigate the harmonic resonance in the modelled rural distribution grid.

5.1 Filter Modelling

The filtering techniques such as single-tuned and high-pass filters are old but still used to mitigate harmonic distortion in conventional power distribution system and micro grids [38-45]. The efficacy of C-type filters to mitigate the harmonic and resonance is presented in [44-45]. In this paper, the C-type filter (as shown in Fig. 12) is designed, planned and tested for solar PV integrated nonlinear distribution system. The design of C-type filter can be described by equations (8-13).

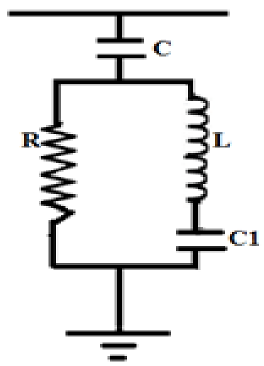

Fig. 12. C-type passive filter

The variation of filter impedance with harmonic order can be written as

$$Zp(h)=\frac{R\left(hX_L-\frac{X_{C1}}{h}\right)^2}{R^2+\left(hX_L-\frac{X_{C1}}{h}\right)^2}+j\left(\frac{R^2\left(hX_L-\frac{X_{C1}}{h}\right)}{R^2+\left(hX_L-\frac{X_{C1}}{h}\right)^2}-\frac{X_C}{h}\right) \quad (8)$$

The behaviour of C-type filter is described by two parameters as

$$h_0=\frac{X_c}{R}=\frac{1}{2\pi f_1 RC} \quad (9)$$

$$m=\frac{h_0 X_L}{R} \quad (10)$$

Where

h_0	Characteristic-harmonic order
m	Damped time constant ratio
h	Order of harmonic $\left(=\frac{f_h}{f_1}\right)$
f_h	Multiple of harmonic frequency
f_1	Fundamental frequency
$\bar{h}$	Normalized harmonic order $\left(=\frac{h}{h_0}\right)$

$$Z_p(h)=R_p(h)+X_p(h) \quad (11)$$

$$R_p(h)=\frac{\left(m\bar{h}-\frac{m}{h_0^2\bar{h}}\right)}{1+\left(m\bar{h}-\frac{m}{h_0^2\bar{h}}\right)^2} \quad (12)$$

$$X_p(h)=\frac{\left(m\bar{h}-\frac{m}{h_0^2\bar{h}}\right)}{1+\left(m\bar{h}-\frac{m}{h_0^2\bar{h}}\right)^2}-\frac{1}{\bar{h}} \quad (13)$$

5.2 Harmonic Power Flow

This analysis is required to assess the individual harmonic contribution of voltage and total harmonic distortion. In this way the ability of filter to mitigate certain amount of harmonic voltages is ascertained. In this work, the fast decoupled harmonic load flow algorithm is preferred for harmonic estimation in solar PV integrated distribution system. The conventional Newton-Raphson load flow algorithm is used to obtain the fundamental component of voltage. At harmonic frequency the harmonic admittance matrix is formulated for the solar PV integrated nonlinear distribution system. The PVs are modelled as a current source which injects harmonic current into the system. The decoupled current sources are used to model the nonlinear loads [46-47]. The harmonic admittance at of various components can be expressed by equations (14-17).

$$y_k^{(h)}=\frac{P_{lk}}{\left|V_k^{(1)}\right|^2}-j\frac{Q_{lk}}{h\left|V_k^{(1)}\right|^2} \quad (14)$$

$$y_{cap,k}^{(h)}=hy_{cap,k}^{(1)} \quad (15)$$

$$y_{k,k+1}^{(h)}=\frac{1}{R_{k,k+1}+jhX_{k,k+1}} \quad (16)$$

$$y_p^{(h)}=\frac{1}{z_p^{(h)}} \quad (17)$$

The current injected by solar PV inverter is given by equations (18-19)

$$I_{sPV,k}^{(1)}=\left[\frac{P_{sPV,k}+jQ_{sPV,k}}{\left|V_k^{(1)}\right|^2}\right]^* \quad (18)$$

$$I_{sPV,k}^{(h)}=R(h)I_{sPV,k}^{(1)} \quad (19)$$

Where

$y_k^{(h)}$	Load admittance at bus k for h^{th} harmonic order
$y_{cap,k}^{(h)}$	Admittance of capacitor at bus k
$y_{k,k+1}^{(h)}$	Feeder admittance between bus k and $k+1$
$y_p^{(h)}$	Admittance of filter p at h^{th} order harmonics
P_{lk}, Q_{lk}	Load active and reactive power at bus k
$y_{cap,k}^{(1)}$	Admittance of capacitor at fundamental frequency at bus k
$R_{k,k+1}$, $X_{k,k+1}$	Branch resistance and reactance between bus k and $k+1$
$R(h)$	Ratio of harmonic current at h^{th} order to its fundamental value

$I_{sPV,k}^{(1)}$	Fundamental current of solar photovoltaic at bus *k*
$P_{sPV,k}$, $Q_{sPV,k}$	Real and reactive power generated by solar PV at bus *k*
$I_{sPV,k}^{(h)}$	Harmonic current of solar photovoltaic at bus *k*

Finally, to obtain the harmonic voltage profile equations as per (20) are solved.

$$Y^{(h)}V^{(h)} = I^{(h)} \quad (20)$$

Step 1) Run the Conventional power flow and obtain the results at fundamental frequency.

Step 2) Calculate the admittance of various components as given in equations (14-17) at h^{th} order harmonic.

Step 3) Calculate the current injection from solar PV using equations (18-19).

Step 4) Solve the set of nodal equations using equation (20) and obtain voltage harmonic distortion.

5.3 Filter Design Steps

The filter design steps are presented below

Step 1) Design the solar PV integrated distribution system with the nonlinear loads.

Step 2) Conduct the normal power flow analysis in order to determine the existing value of voltage, current, and power factor.

Step 3) Carry out the harmonic power flow analysis to determine existing level of individual and total harmonic distortion before installing filter.

Step 4) Design a C-type filter as per the requirement of system. Initially choose a minimum value of capacitors and calculate the filter inductor and resistor to mitigate the desired harmonic frequency and provide the necessary damping in the system.

Step 5) Check the individual harmonic contribution and total harmonic distortion in current/voltage in the concerned branch/ bus and verify if the distortions are within acceptable limits.

Step 6) Check the level of harmonic resonance for the same values of filter components.

Step 7) Check the harmonic distortions and harmonic resonance are not within acceptable limits, go to step 4) and select the filter parameters again. Iterations are required here until the acceptable limits are achieved.

Step 8) stop.

5.4 Filter Implementation Result and Discussions

Fig. 13 presents damping of harmonic resonance frequency with C-type filter installed at bus 5. The parameters of the designed filter are presented in Table 5. The shift in harmonic resonance frequency due to 5th harmonic C-type filter is shown, It is apparent that impedance magnitude is reduced considerably. Moreover, the resonance shifts towards the higher frequency range which is a definite advantage by installing the C-type passive filter in solar PV integrated distribution system. In addition to reducing harmonic resonance the same filter reduces the total harmonic distortion(THD) in voltage also as presented in Table 7.

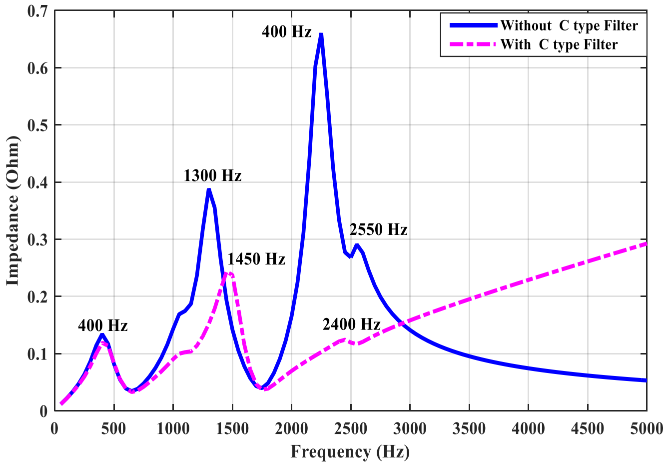

Fig.13. Damping of harmonic resonance frequency with C-type passive filter at bus 5

Table 3. Harmonic order and total harmonic distortion (THD) in voltage at various buses

S. No.	Bus No.	Fundamental Voltage (%)	Order of harmonics	THD %
1	5	100.49	5, 7, 11, 13, 19, 23, 35, 41	9.92
2	6	99.01	5, 7, 11, 13, 37	7.01
3	7	98.8	5, 7, 11, 13, 37	7
4	13	100.02	5, 7, 11, 13	7.12
5	15	99.66	5, 7, 11, 13	7.11
6	16	100.52	5, 7, 11, 13, 37	8.88
7	17	100.14	5, 7, 11, 13, 17	8.98
8	18	99.78	5, 7, 11, 13, 17	9.22
9	19	98.82	5, 7, 11, 13, 17	8.96

Table 4. Overvoltage at various buses due to harmonic resonance

S. No.	Bus No.	|Z| (Ohm)	Z angle (Rad)	Resonance Frequency (Hz)	% Overvoltage
1	5	0.13	0.46	400	133.15
		0.39	0.39	1300	
		0.66	-0.25	2250	
		0.29	-1.03	2550	
2	6	0.13	0.46	400	121.34
		0.11	1.03	1050	
		0.14	0.83	1250	
		0.2	1.01	2150	
		0.15	0.9	2500	
3	7	0.13	0.5	400	121.06
		0.13	1.07	1050	
		0.16	0.9	1250	
		0.25	1.03	2150	
		0.2	0.98	2500	
4	13	0.12	0.37	400	118.22
		0.12	0.55	1050	
		0.19	-0.07	1300	
		0.06	-0.17	2550	
5	15	0.14	0.41	400	117.78
		0.15	0.66	1050	
		0.21	0.11	1300	
		0.12	0.91	2500	
6	16	0.14	0.48	400	127.81
		0.24	0.71	1050	
		0.45	0.03	1300	
		0.24	-0.08	2250	
		0.48	-0.48	2550	
7	17	0.15	0.36	400	122.18
		0.29	-0.36	1100	
		0.04	-1.43	2250	
8	18	0.15	0.43	400	121.97
		0.28	0.24	1050	
9	19	0.18	0.46	400	120.51
		0.3	0.34	1050	

Table 5. C-type filter parameters

Filter parameter	Rating
Resistance (R)	212 Ω
Inductance (L)	140 mH
Capacitance (C1)	12 μF
Capacitance (C)	0.9 μF

Table 6. Voltage THD with and without C-type filter

S. No.	Bus No.	THD (%) Without Filter	Limit as per IEEE Std. 519-1992, 1993 [48]	THD (%) With Filter
1	5	9.92	5.0	4.4
2	6	7.01	5.0	3.0
3	7	7	5.0	2.13
4	13	7.12	5.0	2.55
5	15	7.11	5.0	2.78
6	16	8.88	5.0	3.44
7	17	8.98	5.0	4.1
8	18	9.22	5.0	4.6
9	19	8.96	5.0	3.9

6. Conclusions

This paper presents a comprehensive analysis of harmonic resonance. Harmonic resonance depends on many factors such as nature of load and its variation pattern, strength of grid, system configuration and change in state, modern power electronics control devices etc. it is difficult to provide a uniform solution for all resonance problems. Some recommendations to avoid harmonic resonance in smart grid environment are given here

- Optimal sizing of capacitor and their appropriate location has to be decided at the time of plant commissioning.
- Study the nature of load and variation pattern to choose the proper size of capacitors.
- Automatic switching of the capacitors with the variation in load.
- Consider all states of power system when designing filters to suppress the harmonic resonance.

• All the harmonic generating sources, and order of harmonics generated, have to be considered before designing the control strategy for filter.

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