Harmonic Analysis in Hybrid Power Plant using ETAP Software

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ABSTRACT
Rising demand of electric power coupled with rising use of non-linear loads such as laptops, arc furnace etc., along with rise of renewables energy sources such as solar, wind etc., has revolutionized the human civilization but badly affected the power quality of power system. Harmonics injected by non-linear loads and renewable energy sources have led to issues such as rise in losses, overheating of rotor windings of induction motor, malfunctioning of relays etc. These factors disturb harmonics of electrical waves by making them non-sinusoidal. Harmonic analysis and taking steps to remedy the same therefore has become essential.

In this study, the simulated 250.5 MW Solar PV Plant which is in addition to the existing 1980 MW thermal plant of a large generating station have been analyzedso that the distortion in voltage waveforms and current waveforms due to nonlinear loads, that is, renewable energy sources etc., may be analyzed. Distortions in voltage waveform at various buses of LPGCL buses have been analyzed in this study using ETAP software.

General Terms
Hybrid Power Plant, Renewable energy, PV Solar plant, Inverters, 13-Bus System, Modelling for Harmonic Analysis, Norton equivalent impedance.

Keywords
Voltage harmonics, Current harmonics, Harmonics Analysis, ETAP (Electric Transient Analyzer Program), THD (Total Harmonic Disorder).

1. INTRODUCTION
What is harmonic wave
Harmonics of voltage or current waveform is sinusoidal wave whose frequency is integer multiple of fundamental frequency. These are produced by actions of non-linear loads such as rectifier and saturated electrical machines. In case of PV Solar plant, harmonics are generated through inverters, which is an electronic equipment. Fig. 1 explains harmonics of various orders in a power system.

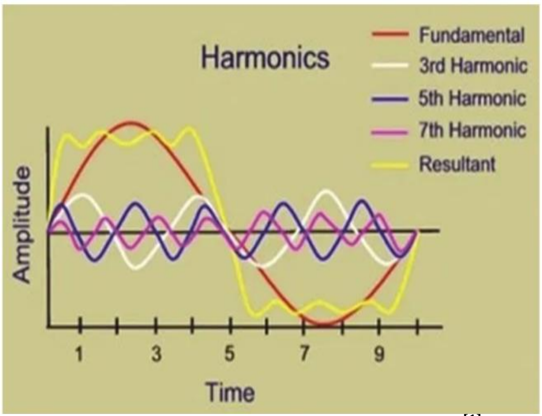

Fig. 1: Harmonics in current or voltage[1]

Harmonics in Solar PV Plant
In a Solar PV Plant, DC output of the PV Arrays are converted to AC through inverters, which is an electronic equipment. These photovoltaic inverters inject harmonics into the electrical installations.

Classification of Harmonics
Harmonics can be classified as

1- Type of signal (voltage or current)
2- Order of harmonic (even,odd,triplen, non-triplen)
3- In three phase they can be further classified according to sequence, that is, positive, negative and zero sequence

Why current harmonics are caused
Current Harmonics are caused due to non-linear loads such as rectifier etc. Voltage harmonics are caused due to current harmonics due to source impedance.

Why it is essential to remove harmonics
It is essential to remove harmonics because harmonics can cause the following issues in the power system which are as follows –

1- Overheating of loads such as non-linearloads, winding of induction motor etc.
2- Electromagnetic interference
3- Insulation failure
4- Reduced power factor
5- Noise
6- Voltage flickering

2. LITERATURE SURVEY
A study by LG Mahiwal and J.G Jamnani “Analysis and Mitigation of Harmonics for Standard IEEE 13 Bus Test

System Using ETAP" [2] focusses on conducting load flow studies, short circuit studies and harmonic studies on IEEE 13 bus system. The paper has further designed filter to limit the harmonic values.

Another study by G.Min,J.Qingren and C.Weidong "Analysis of the Harmonics Influence of Urban Rail Transport Load on Nanning Power Grid based on ETAP"[3] has analyzed the impact of harmonics on Urban Rail Transport on Nanning Power Grid bus on ETAP during normal operation, rush hour and night hour conditions.

X.Chen and G.Zhang, in their study "Harmonic Analysis of AC-DC Hybrid Microgrid Based on ETAP" [4]have presented impact of harmonics on AC-DC microgrid on ETAP due to use of power electronics technology.

M.E Farrag,A.Haggag,H.Farooq and Waqas Ali, in their paper "Analysis and Mitigation of Harmonics Caused by Air Conditioners in a Distribution System" [5] conducted analysis and mitigation of harmonics of 1.5-ton 2KW Air conditioner and thereby have given solutions to mitigate the harmonics caused by using power conditioners.

A.Olatoke and M.Darwish, in their study "Relay coordination and harmonic analysis in distribution network with over 20 percent renewable sources" [6] have talked about problems arising due to penetration of more than 20 percent of distribution energy of which renewable energy sources are a part. The Paper states that problems such as malfunctioning of relays, stability issues,distribution control problem, etc., arise due to harmonics issue.

Y.Pang and Y.Xu, in their study "Analysis and Treatment of Harmonic in Power Network with Railway based on ETAP Software" [7] have analyzed the impact of harmonics on power system of railway system and thus compared measurement of the harmonics using field test data using PQView and using simulation data by conducting harmonic studies in ETAP.

Y.Sun,V.Cuk,E.C de Jong and J.F.G Cobben in their study "Ultrafast charging station harmonic resonance analysis in Dutch MV grid: application of power converter harmonic model" [8] created a viable model for conducting harmonics analysis.

3. MODELLING FOR HARMONIC ANALYSIS

In this study harmonic analysis has been carried in order to access the impact of harmonics on integrating 250.5 MW (83.5x3 MW) solar PV system with 1980 MW (660x3 MW) Lalitpur thermal plant. Suggestions have also been incorporated for mitigating the harmonics. This study also discusses harmful effects of harmonics. In his study, solar PV system has been integrated with generating switchyard.

Modelling of harmonic-generation devices consists of a current source model as shown Fig. 2. It can be seen in this figure that the Harmonic current source, which is the inverter in case of Solar PV System, supplies harmonics to the grid, which needs to be filtered out.

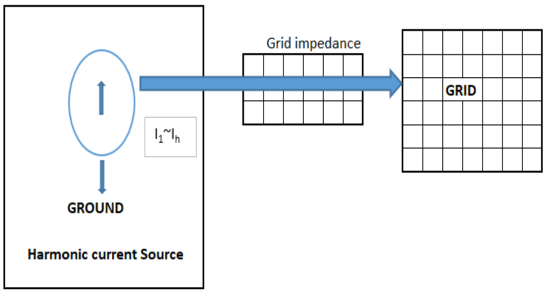

Fig. 2:Harmonic current flow illustration

In Fig. 2, an illustration of harmonic current flow has been shown. The Harmonic current source arises in inverters in a Solar PV Plant. It passes through the Inverter transformer and finally goes to the grid. However, before that, it may affect the inverter transformer also since harmonics will create excessive flux density in the core of the inverter transformer.

Model for resolving harmonics

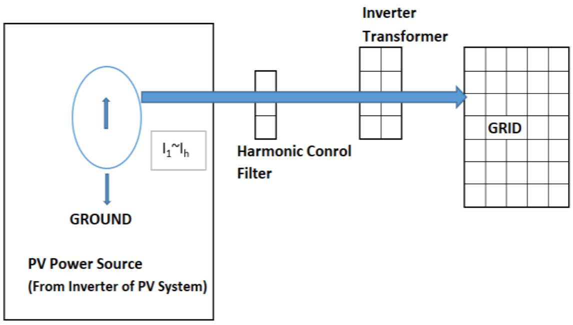

Fig. 3: Model for resolving harmonics

Fig. 3 shows a typical model for resolving harmonics in a power system. The harmonics generated form PV Power source, which is the inverter of a PV System is required to be passed through a filter, which filters out the harmonics in the current and voltage, both and transfers the clean current/ voltage to the inverter transformer and finally to the grid.

4. IMPLEMENTATION METHODOLOGY

The Hybrid Power Plant:

The power plant chosen for the purpose of this analysis is a 3x660 MW Super-Critical thermal power plant situated in Central India. The said plant has been supplemented with a simulated 250.5 MW Solar PV System. The said PV plant uses 134,914 PV Modules of 2450 wp and 167inverters, finally generating 250.5 MW output, which are connected to the three thermal Generator Transformers.

Because the Solar PV Plant has been designed to supplement the thermal generation, that is to say, the thermal power plant will adjust its generation so that maximum output of the Solar PV Plant is transmitted to the system, the combination of the thermal unit and the solar power plant has been termed as "Hybrid Power Plant" in this study.

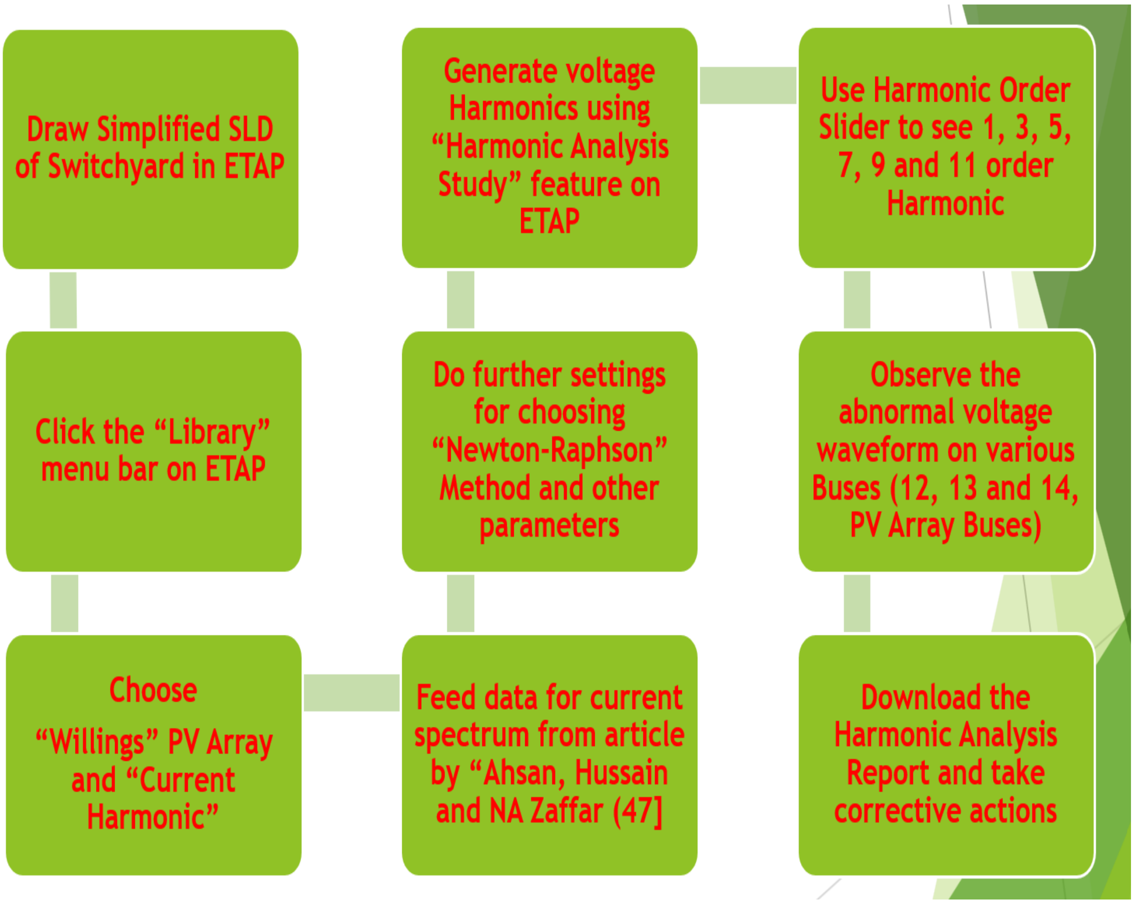

Fig. 4: Implementation Methodology

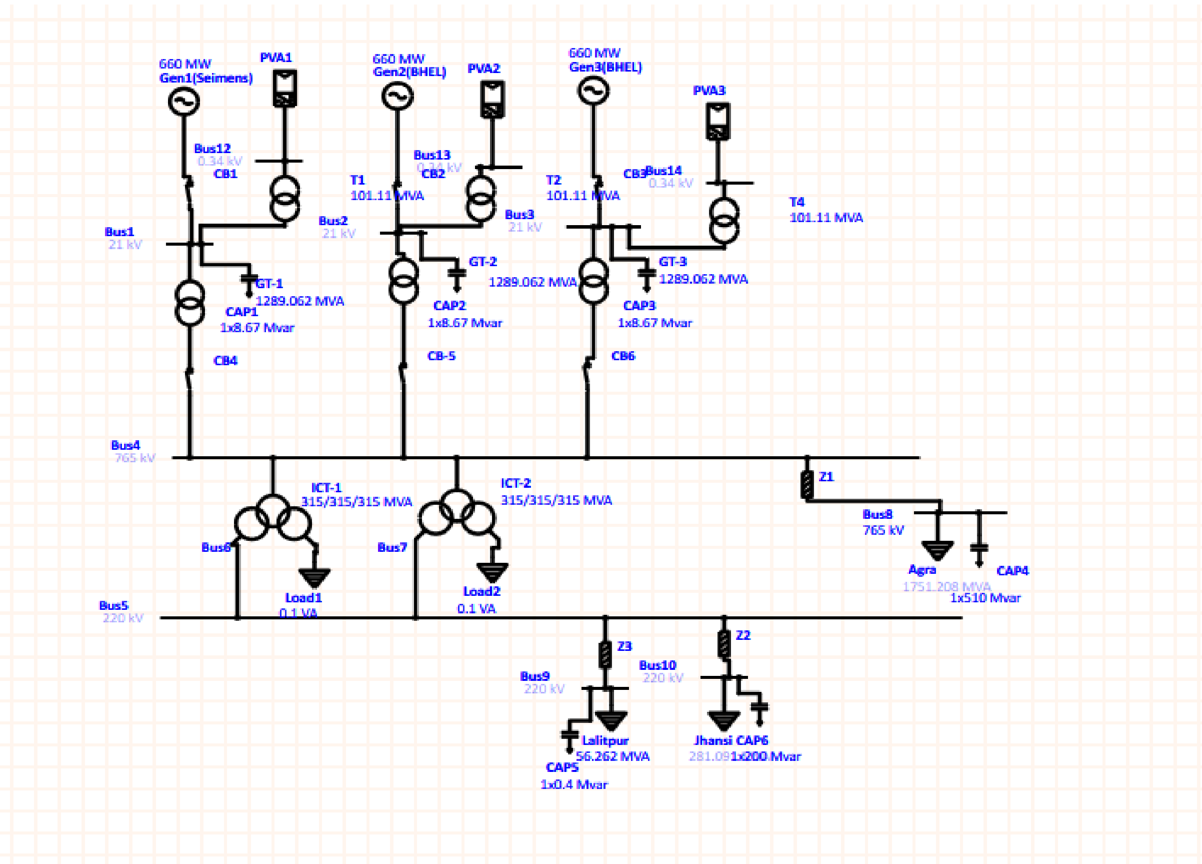

Fig. 5: Simplified 13-Bus 765 kV Switchyard

Simplification of Switchyard

Elimination of non-participating buses and description of 13 buses.

The 38-bus system of the Switchyard of the chosen model, that is 1980 MW Thermal and additional 250.5 MW Solar PV Plant has been simplified to 13 bus system by eliminating buses which do not form part of the load flow system. The simplified network now has 3 GT buses (bus 1,2 and 3), 3 Solar PV Power Buses (Bus 12,13 and 14), one 765 kV common bus (bus 4), one 765 kVto 220 kV bus (Bus 5), two 220 kV buses for loads to Lalitpur and Jhansi (Bus 6 and 7), one 765 kV load bus to Agra from bus 4 (Bus 8). In addition, 2 buses (Bus 6 and Bus 7) represent the delta connection of three phase, three winding transformers. The simplified switchyard with 13 buses has been shown in Fig. 5.

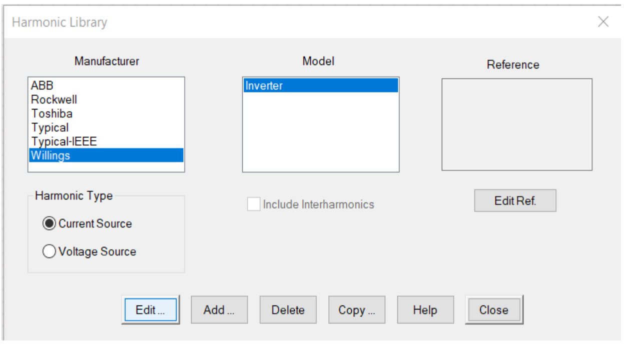

Fig. 6: Harmonic Library in ETAP software

Doing harmonic analysis

Due to the use of inverters, PV system generates current harmonics. Therefore, clicking on library on menu bar of ETAP software and choosing current harmonics and on doing modifications in harmonics tab of PV system on ETAP, harmonic analysis on ETAP has been done

Harmonic Library in ETAP

Fig. 6 displays the screen of Harmonic Library on ETAP Software. Here the PV Array manufactured by Willings has been chosen. Further the source of harmonics as "Current Source" has been chosen because the scope of this study is to analyze current harmonics only.

Fig. 7 displays the harmonic order to be chosen. In the study, 50 Hz has been chosen. Data for current harmonics spectrum has been taken from an Article by S.M Ahsan, A.Husssain and N.A Zaffar "Harmonic analysis of Grid connected solar PV systems with nonlinear household loads in low voltage distribution networks" [7].

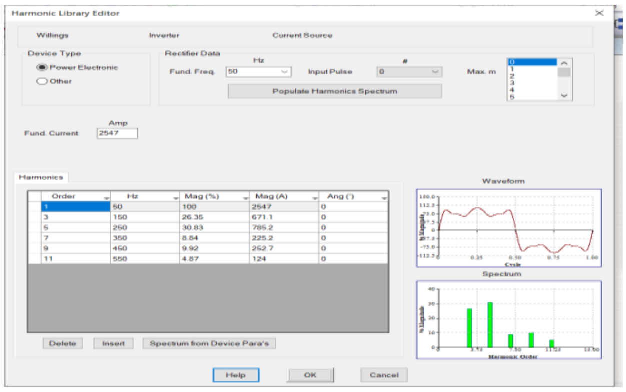

Fig. 7: Current Harmonic spectrum of inverter (Here the data for current harmonics spectrum has been taken from an Article by S.M Ahsan, A.Husssain and N.AZaffar "Harmonic analysis of Grid connected solar PV systems with nonlinear household loads in low voltage distribution networks" [7])

Further settings

Further settings as shown in Fig. 8 have been done with respect to harmonic analysis in ETAP software. Newton Raphson method for Harmonic Load Flow has been chosen.

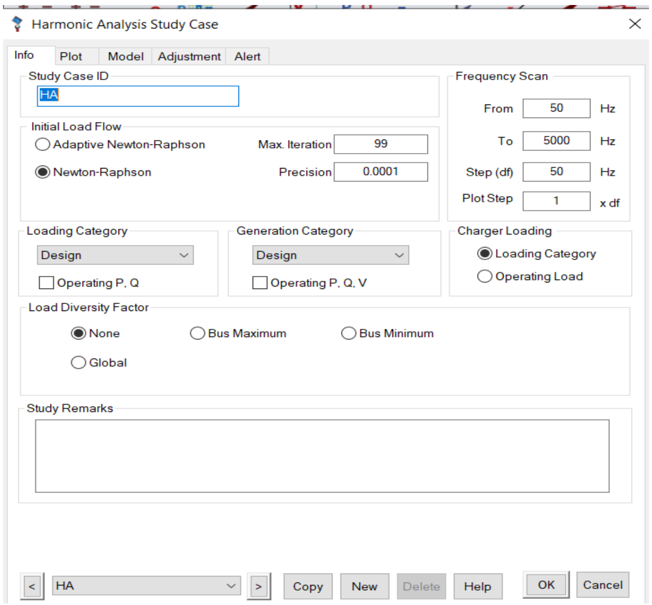

Fig. 8: Further settings for doing harmonic analysis in ETAP Software

5. GENERATION OF VOLTAGE HARMONICS

After the above steps, voltage harmonics arising due to these current harmonics have been generated which have beenanalyzed using ETAP software by using harmonic analysis study. The harmonics have been shown in Fig. 9.

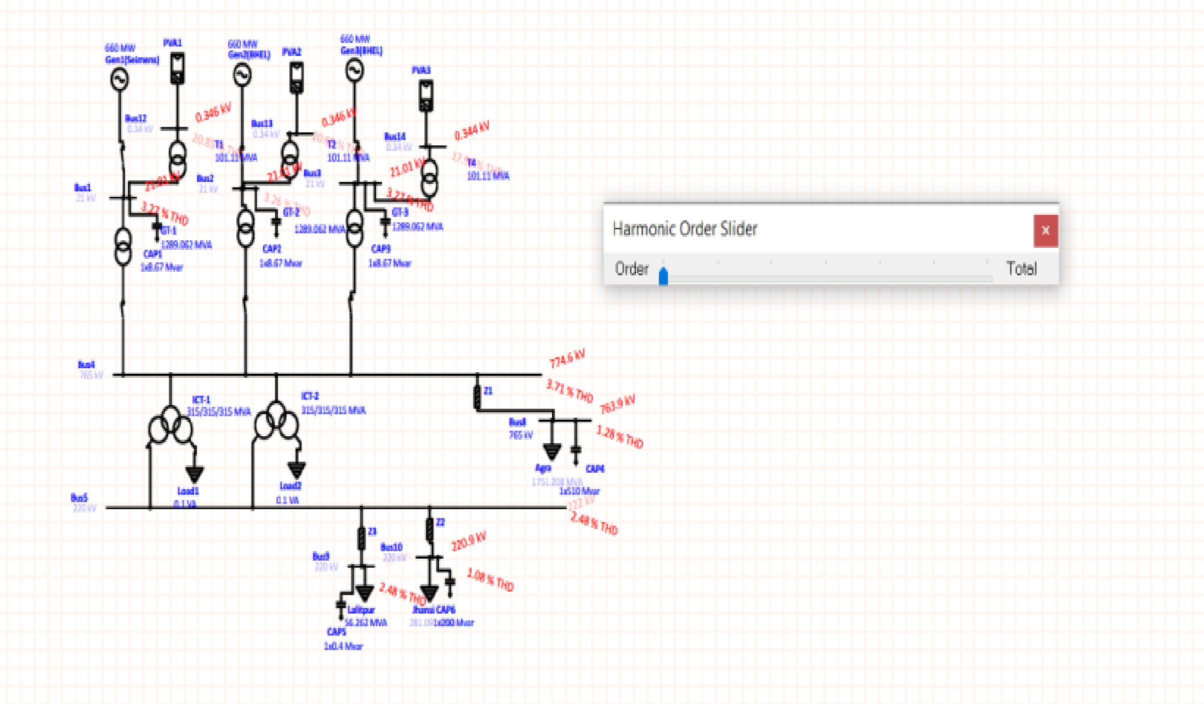

Fig. 9:Harmonic analysis using ETAP

Fig. 9 shows that Harmonic Order Slider can be used in order to see 1st ,3rd ,5th ,7th, 9th and 11th order harmonics. In Fig. 10, slider has been moved to see 1st or fundamental components.

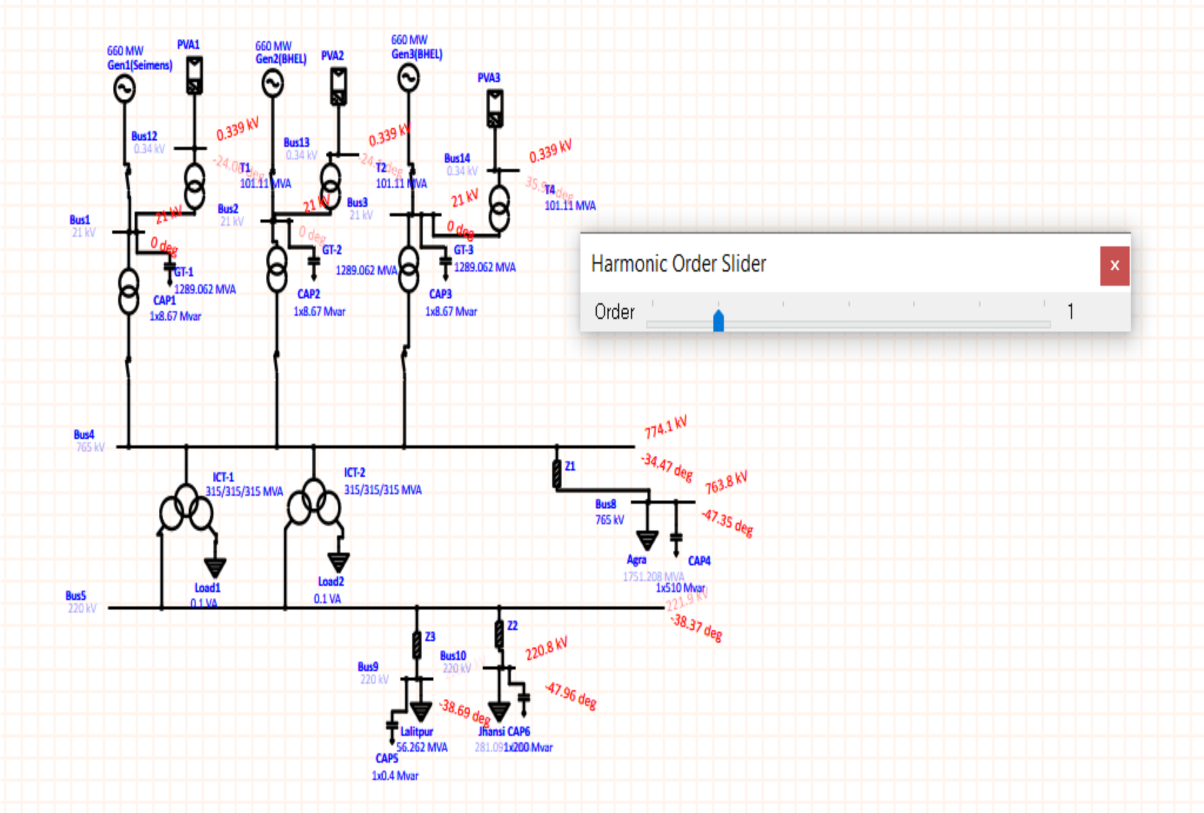

Fig.10: 1st Order or fundamental component of voltage using ETAP

Harmonics in Bus 12, 13 and 14

In Fig. 11, voltage waveform and spectrum of some buses may be observed. It can be observed that the Bus 12 waveform must be sinusoidal, which is not the case in the instant study

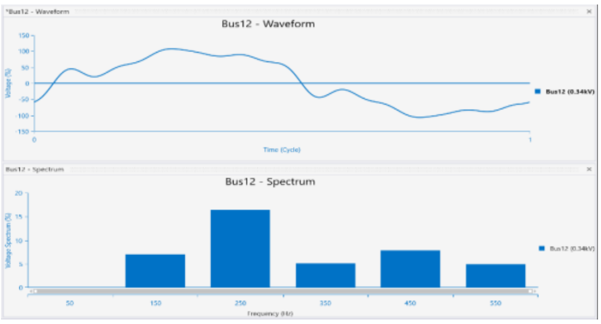

Fig. 11: Waveform and spectrum of voltage of Bus 12

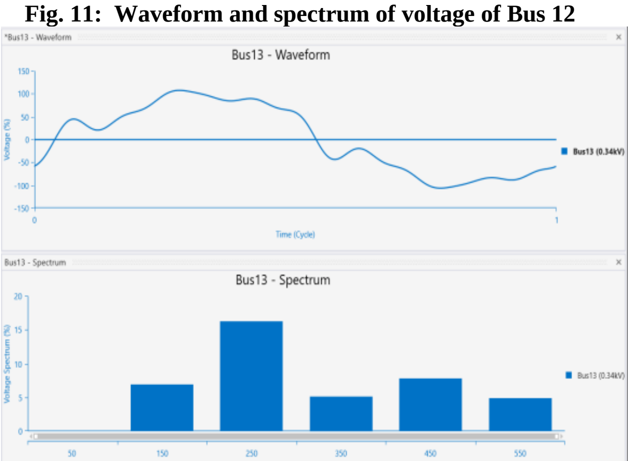

Fig. 12: Waveform and spectrum of voltage of Bus 13

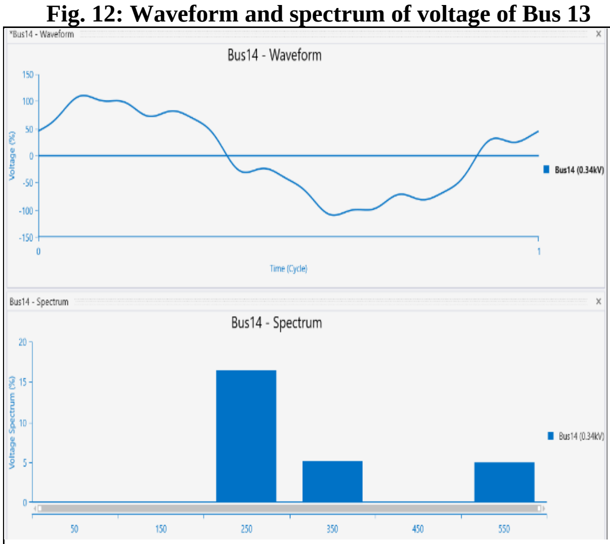

Fig. 13 Waveform and spectrum of voltage of Bus 14

Fig. 12 and 13 shows similar analysis for bus no. 13 and 14 respectively. It can be seen that even for Bus 13 and 14, the wave form is also not sinusoidal.

Bus 12, 13 and 14 are the buses where PV arrays are connected to the switchyard (to the GT of the thermal units). The reason for the non-sinusoidal wave form is the harmonics generated by the inverter in the system.

Harmonics in Bus 4 and 5

Bus-4

Fig. 14 shows similar analysis for bus no. 13 and it can be seen that even for Bus 4, which primarily supplies power to the 765 kV Transmission line to Agra. Here it can be seen that the waves are sinusoidal. Hence, there are no/ negligible harmonics in the Bus. This shows that harmonicas have negligible impact on the high voltage systems.

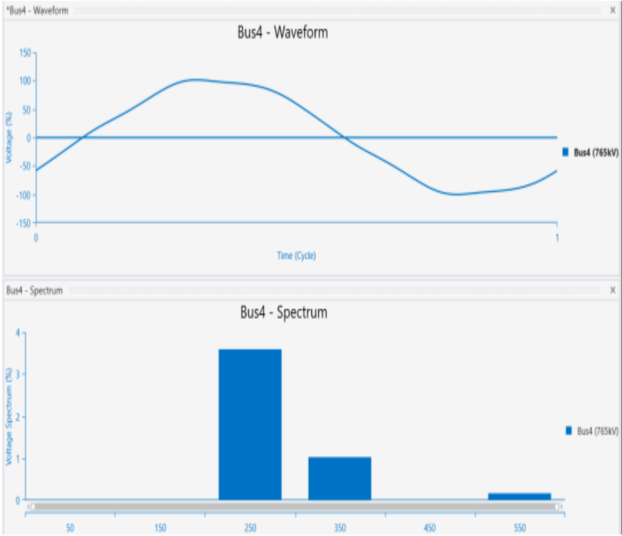

Fig. 14: Waveform and spectrum of voltage of Bus 4

Bus-5

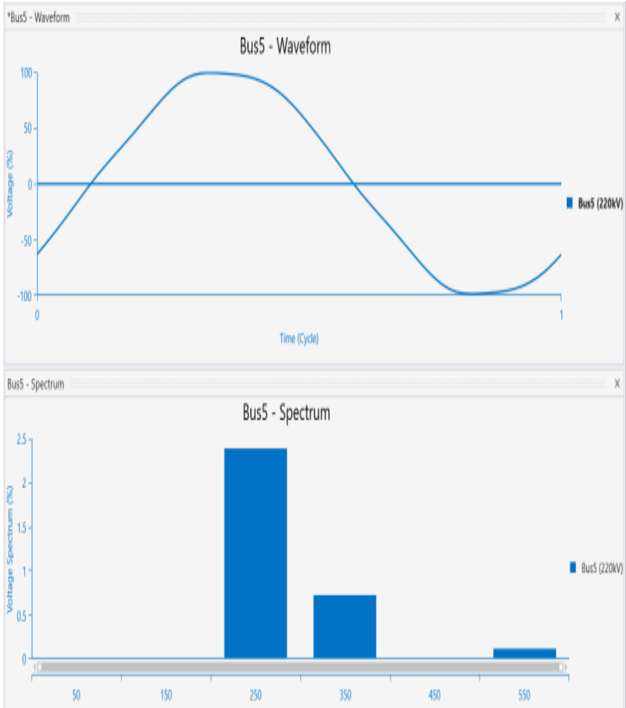

Fig. 15: Waveform and spectrum of voltage of Bus 5

Fig. 15 shows similar analysis for bus no. 5 and it can be seen that even for Bus 5, which primarily supplies power to the 220 kV Transmission line to Jhansi and Lalitpurthe waves are sinusoidal. Hence, there are no/ negligible harmonics in the Bus. This further confirms that harmonicas have negligible impact on the high voltage systems.

6. RESULT AND ANALYSIS

6.1 The Table below shows summary of harmonic analysis in ETAP.

6.2 In the Table the red portion representing Bus 12, 13 and 14, where Solar PV power has been added to the GTs of the thermal units, show harmonics (shown in red colour), whereas, there are negligible harmonics in Bus 1 to 10.

High THD (Total Harmonic Disorder) of about 17.96 % to 20.85 % has been shown in Bus 12, 13 and 14, which will cause mal-tripping.

6.3 Bus 1-10 shown in the Table, however, show no adverse results. It may be noted that the normal limits of Harmonics are upto 5% THD. Buses 1-10 of system show harmonics from 0-3.71%, which is within the normal limits.

6.4 Therefore, Bus 12, 13 and 14, where the PV arrays are connected to the switchyard, through the GTs of the thermal units, show abnormal harmonics.

6.5 However, the above analysis does not conclude that these harmonics will not pass onto the subsequent buses

6.6. There is presumption that Harmonics at Bus nos. 12, 13 and 14 are controlled at these buses itself, and are not passed over to the subsequent buses.

Table: Harmonic Analysis Report on various Buses

			Harmonic Analysis Report					
		Values are specified in KV						
Bus	Total	THD(in percent)	1st	3rd	5th	7th	9th	11th
Bus 1	21.01	3.27	21	0	0.681	0.069	0	0.046
Bus 2	21.01	3.26	21	0	0.679	0.07	0	0.045
Bus 3	21.01	3.27	21	0	0.681	0.069	0	0.046
Bus 4	774.6	3.71	774.1	0	27.55	7.9	0	1.28
Bus 5	222	2.41	221.9	0	5.25	1.59	0	0.265
Bus 6	0	0	0	0	0	0	0	0
Bus 7	0	0	0	0	0	0	0	0
Bus 8	763.9	1.28	763.9	0	9.7	1.24	0	0.075
Bus 9	221	2.48	220.9	0	5.23	1.58	0	0.264
Bus 10	220.9	1.08	220.8	0	2.36	0.305	0	0.019
Bus 12	**0.346**	**20.85**	**0.339**	**0.024**	**0.056**	**0.018**	**0.027**	**0.017**
Bus 13	**0.346**	**20.65**	**0.339**	**0.024**	**0.055**	**0.018**	**0.027**	**0.017**
Bus 14	**0.346**	**17.96**	**0.339**	**0**	**0.056**	**0.018**	**0.027**	**0.017**

7. CONCLUSIONS

7.1. Bus 12 and Bus 13 are showing THD more than 20% whereas Bus 14 is showing THD greater than 5% but much greater than 5 %. As per IEEE 519-2014 standards THD should be less than 5 % in order to ensure reliable operation of power system

7.2. THD of more than 20% can cause malfunction of protection system especially overcurrent protection and differential protection. Bus 12 and Bus 13 are showing THD more than 20%. Hence these protection systems associated with these two buses are prone to malfunction. Also Bus 14 can also malfunction as it has THD OF 17.96%.

7.3. As delta star transformer is employed as generator transformer and star delta transformer is employed as inverter transformer, hence triplen harmonics cancel out at delta side of transformer.

8. ACKNOWLEDGMENTS

Our thanks to the experts who have contributed towards development and analysis in this project.Also, our thanks to Lalitpur Power Generation Company Limited, which permitted us to carry out the above analysis for their power plant and permitted us to access their archives and library.

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