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Harmonic Analysis and Comparison of Voltage & Current THD using Excel, PSCAD, PSSE and Sincal Software's

Komal Rohit Kambli[1*], Yugal Kishore[2]
[1,2]*Portfolio Consulting Professional, PTI, Siemens Limited, Melbourne, Australia*

***Abstract*: This research paper compares the voltage and current THD results obtained from excel, PSCAD, PSSE and Sincal simulations. Although, Sincal and ETAP are widely used tools for harmonic analysis, yet the PSCAD (version 5.0) and PSSE software's has good competency which can be utilized for performing harmonic analysis.**

***Keywords*: THD, IHD, Harmonics, PSCAD, PSSE, Sincal.**

1. Introduction

Renewable sources of energy such as solar, wind, and BESS attracting many countries as conventional energy sources are depleting. In renewable energy sector, large-scale photovoltaic PV power plant has become one of the important development trends of PV industry. The generation and integration of photovoltaic power plants into the utility grid have shown remarkable growth over the past two decades. Increasing photovoltaic power plants has increased the use of power electronic devices, i.e., DC/AC converters. These power electronic devices are called inverters. Inverters are mainly used to convert direct current into alternating current & act as interface between renewable energy & grid. Inverter-based technologies and various non-linear loads are used in power plants which generate harmonics in system.

The effects of harmonics are due to both current and voltage, although current produced effects are more likely to be seen in day-to-day performance. Voltage effects are more likely to degrade the insulation and hence shorten the life of the equipment. The following describes some of the common effects of harmonics:

- Increased losses within the equipment and associated cables, lines, etc.
- Pulsating and reduced torque in rotating equipment.
- Premature aging due to increased stress in the equipment insulation.
- Increased audible noise from rotating and static equipment.
- Erroneous operation of equipment sensitive to waveforms.
- Substantial amplification of currents and voltages due to resonances.
- Communication interference due to inductive coupling between power and communication circuits.

IEEE Std. 519-2014 (IEEE recommended practices and requirements for harmonic control in electrical power systems), defines the limits for voltage distortion and current distortions for different voltage levels.

The formulae used to calculate voltage THD and IHD are as follow:

$$\%THDv = \frac{\sqrt{v_2^2+v_3^2+v_4^2+\cdots v_n^2}}{v_1} \times 100$$

Where,

V_n = *Individual harmonic voltage distortion values in volts, per unit volts, or kV.*
V_1 = *Fundamental voltage distortion values in volts, per unit volts, or kV.*
V_2 = *2nd harmonic voltage distortion values in volts, per unit volts, or kV.*

% IHDv for 2nd order= v_2/v_1
% IHDv for 3rd order= v_3/v_1
For 11 kV system the V1= 11/sqrt(3)=6.351 kV
and for 33 kV system V1= 33/sqrt(3)= 19.05 kV

The main objective of this paper is to compare the THD calculated using excel and executed using popular power system software's like PSCAD, Sincal and PSSE.

2. Model Under Study

In this paper, an 11 kV harmonic source with a rated current of 156.3 A is considered. Further, the 11 kV voltage is stepped up to 33 kV through the 50 MVA transformer. The impedance considered for 50 MVA transformer is 0.12 pu. A pure inductor of 0.005067 H is present between the transformer and 11 kV source. At 33 kV level, the equivalent R, L and C parameters for cables are considered as 0.04 ohm, 8.04* (10^-5) H and 0.406518 uF respectively. Furthermore, the voltage is stepped up to 66 kV level through 60 MVA transformer and connects to the grid at 66 kV level. The grid is considered as ideal source with 0 impedance. The impedance considered for 60 MVA transformer is 0.12 pu.

The THD values for voltage are measured at 3 different locations i.e., at 11 kV source terminal, at 50 MVA

*Corresponding author: komal9071@gmail.com

transformers 11 kV and 33 kV terminal.

The THD of current is also measured at 11 kV source terminal. Please note that current THD remains uniform in the series circuit.

The above explained SLD is modelled using PSSE, PSCAD and SINCAL software's. And results obtained from the simulations are also envisaged in this paper.

The harmonic spectrum consisting of 50 harmonic orders is modelled in the study.

3. THD and IHD Calculation using Excel

The harmonic spectrum consisting of harmonic order (h) vs harmonic current (Ih) used in the study, is mentioned in below Table 1. The calculation of voltage THD and IHD at 11 kV terminal of source, 11 kV terminal of transformer and 33 kV terminal of transformer is performed. The excel calculated results are as represented in Table 1, Table 2 and Table 3. At all 3 locations, the equivalent impedance Znet is first calculated and then Vdh is calculated by (Znet* Ih) formulae.

Ih: Current for each harmonic order

Znet: Equivalent impedance for each harmonic order

Vdh: Voltage drop caused by each harmonic

IHD: Individual Harmonic Distortion

THD: Total Harmonic Distortion

Table 1
THD & IHD calculated at 11 kV source terminal for voltage and current

At 11 kV source terminal						
h	**Ih (%)**	**Ih (A) at 11 kV**	**Znet ohm**	**Vdh volts**	**IHD_V %**	**IHD_I %**
2	0.264	0.41	4.260	1.758	0.028	0.264
3	1.235	1.93	6.388	12.33	0.194	1.235
4	0.705	1.10	8.518	9.386	0.148	0.705
5	1.12	1.75	10.650	18.64	0.294	1.120
6	0.301	0.47	12.783	6.014	0.095	0.301
7	0.537	0.84	14.920	12.52	0.197	0.537
8	0.627	0.98	17.059	16.71	0.263	0.627
9	0.734	1.15	19.202	22.02	0.347	0.734
10	0.141	0.22	21.348	4.705	0.074	0.141
11	0.177	0.28	23.500	6.501	0.102	0.177
12	0.083	0.13	25.656	3.328	0.052	0.083
13	0.053	0.08	27.818	2.304	0.036	0.053
14	0.09	0.14	29.987	4.218	0.066	0.090
15	0.039	0.06	32.162	1.961	0.031	0.039
16	0.032	0.05	34.346	1.718	0.027	0.032
17	0.054	0.08	36.537	3.084	0.049	0.054
18	0.02	0.03	38.738	1.211	0.019	0.020
19	0.05	0.08	40.949	3.200	0.050	0.050
20	0.05	0.08	43.172	3.374	0.053	0.050
21	0.023	0.04	45.406	1.632	0.026	0.023
22	0.043	0.07	47.654	3.203	0.050	0.043
23	0.053	0.08	49.917	4.135	0.065	0.053
24	0.025	0.04	52.196	2.040	0.032	0.025
25	0.051	0.08	54.493	4.344	0.068	0.051
26	0.043	0.07	56.810	3.818	0.060	0.043
27	0.018	0.03	59.148	1.664	0.026	0.018
28	0.057	0.09	61.509	5.480	0.086	0.057
29	0.081	0.13	63.897	8.090	0.127	0.081
30	0.033	0.05	66.314	3.420	0.054	0.033
31	0.073	0.11	68.764	7.846	0.124	0.073
32	0.084	0.13	71.249	9.354	0.147	0.084
33	0.094	0.15	73.775	10.83	0.171	0.094
34	0.047	0.07	76.346	5.608	0.088	0.047
35	0.035	0.05	78.967	4.320	0.068	0.035
36	0.027	0.04	81.646	3.446	0.054	0.027
37	0.024	0.04	84.391	3.166	0.050	0.024
38	0.028	0.04	87.209	3.817	0.060	0.028
39	0.015	0.02	90.113	2.113	0.033	0.015
40	0.018	0.03	93.116	2.620	0.041	0.018
41	0.012	0.02	96.233	1.805	0.028	0.012
42	0.01	0.02	99.485	1.555	0.024	0.010
43	0.015	0.02	102.896	2.412	0.038	0.015
44	0.01	0.02	106.496	1.665	0.026	0.010
45	0.009	0.01	110.325	1.552	0.024	0.009
46	0.01	0.02	114.433	1.789	0.028	0.010
47	0.011	0.02	118.887	2.044	0.032	0.011
48	0.009	0.01	123.777	1.741	0.027	0.009
49	0.012	0.02	129.225	2.424	0.038	0.012
50	0.011	0.02	135.407	2.328	0.037	0.011
A= Sqrt (Sum of Vdh^2)			47.612	A= Sqrt (Sum of Idh^2)		3.420
B= per ph V1 (V)			6351.03	B= Rated current (A)		156.30
THD Vpu= A/B			0.007	THD Ipu =A/B		0.022
% THD_V= A/B*100			0.750	% THD_I = A/B*100		2.188

Table 2
THD & IHD calculated at 11 kV terminal of transformer for voltage

At 11 kV terminal of transformer					
h	**Ih %**	**Ih (A) at 11 kV**	**Znet ohm**	**Vdh volts**	**IHD_V %**
2	0.264	0.41	1.075	0.444	0.007
3	1.235	1.93	1.612	3.112	0.049
4	0.705	1.10	2.150	2.369	0.037
5	1.12	1.75	2.689	4.708	0.074
6	0.301	0.47	3.231	1.520	0.024
7	0.537	0.84	3.775	3.168	0.050
8	0.627	0.98	4.322	4.236	0.067
9	0.734	1.15	4.873	5.590	0.088
10	0.141	0.22	5.427	1.196	0.019
11	0.177	0.28	5.987	1.656	0.026
12	0.083	0.13	6.551	0.850	0.013
13	0.053	0.08	7.121	0.590	0.009
14	0.09	0.14	7.697	1.083	0.017
15	0.039	0.06	8.281	0.505	0.008
16	0.032	0.05	8.872	0.444	0.007
17	0.054	0.08	9.471	0.799	0.013
18	0.02	0.03	10.080	0.315	0.005
19	0.05	0.08	10.699	0.836	0.013
20	0.05	0.08	11.330	0.885	0.014
21	0.023	0.04	11.972	0.430	0.007
22	0.043	0.07	12.628	0.849	0.013
23	0.053	0.08	13.299	1.102	0.017
24	0.025	0.04	13.986	0.546	0.009
25	0.051	0.08	14.691	1.171	0.018
26	0.043	0.07	15.415	1.036	0.016
27	0.018	0.03	16.161	0.455	0.007
28	0.057	0.09	16.930	1.508	0.024
29	0.081	0.13	17.726	2.244	0.035
30	0.033	0.05	18.551	0.957	0.015
31	0.073	0.11	19.409	2.215	0.035
32	0.084	0.13	20.302	2.665	0.042
33	0.094	0.15	21.236	3.120	0.049
34	0.047	0.07	22.214	1.632	0.026
35	0.035	0.05	23.244	1.272	0.020
36	0.027	0.04	24.331	1.027	0.016
37	0.024	0.04	25.483	0.956	0.015
38	0.028	0.04	26.709	1.169	0.018
39	0.015	0.02	28.021	0.657	0.010
40	0.018	0.03	29.432	0.828	0.013
41	0.012	0.02	30.957	0.581	0.009
42	0.01	0.02	32.616	0.510	0.008
43	0.015	0.02	34.435	0.807	0.013
44	0.01	0.02	36.443	0.570	0.009
45	0.009	0.01	38.680	0.544	0.009
46	0.01	0.02	41.196	0.644	0.010
47	0.011	0.02	44.058	0.757	0.012
48	0.009	0.01	47.356	0.666	0.010
49	0.012	0.02	51.212	0.961	0.015
50	0.011	0.02	55.801	0.959	0.015
A= Sqrt (Sum of Vdh^2)					12.538
B= per ph V1 (V)					6351.039

THD_Vpu = A/B	0.002
% THD_V = A/B*100	0.197

Table 3
THD & IHD calculated at 33 kV terminal of transformer for voltage

At 33 kV terminal of transformer					
h	**Ih %**	**Ih (A) at 33 kV**	**Znet ohm**	**Vdh volts**	**IHD_V %**
2	0.264	0.14	4.41	0.607	0.003
3	1.235	0.64	6.63	4.264	0.022
4	0.705	0.37	8.85	3.252	0.017
5	1.12	0.58	11.09	6.474	0.034
6	0.301	0.16	13.35	2.094	0.011
7	0.537	0.28	15.64	4.375	0.023
8	0.627	0.33	17.95	5.863	0.031
9	0.734	0.38	20.29	7.760	0.041
10	0.141	0.07	22.67	1.665	0.009
11	0.177	0.09	25.09	2.314	0.012
12	0.083	0.04	27.56	1.192	0.006
13	0.053	0.03	30.07	0.830	0.004
14	0.09	0.05	32.65	1.531	0.008
15	0.039	0.02	35.28	0.717	0.004
16	0.032	0.02	37.99	0.633	0.003
17	0.054	0.03	40.77	1.147	0.006
18	0.02	0.01	43.64	0.455	0.002
19	0.05	0.03	46.60	1.214	0.006
20	0.05	0.03	49.65	1.293	0.007
21	0.023	0.01	52.82	0.633	0.003
22	0.043	0.02	56.11	1.257	0.007
23	0.053	0.03	59.54	1.644	0.009
24	0.025	0.01	63.11	0.822	0.004
25	0.051	0.03	66.84	1.776	0.009
26	0.043	0.02	70.74	1.585	0.008
27	0.018	0.01	74.84	0.702	0.004
28	0.057	0.03	79.15	2.351	0.012
29	0.081	0.04	83.70	3.532	0.019
30	0.033	0.02	88.51	1.522	0.008
31	0.073	0.04	93.62	3.560	0.019
32	0.084	0.04	99.04	4.334	0.023
33	0.094	0.05	104.83	5.134	0.027
34	0.047	0.02	111.03	2.719	0.014
35	0.035	0.02	117.68	2.146	0.011
36	0.027	0.01	124.85	1.756	0.009
37	0.024	0.01	132.60	1.658	0.009
38	0.028	0.01	141.03	2.057	0.011
39	0.015	0.01	150.22	1.174	0.006
40	0.018	0.01	160.30	1.503	0.008
41	0.012	0.01	171.41	1.072	0.006
42	0.01	0.01	183.74	0.957	0.005
43	0.015	0.01	197.49	1.543	0.008
44	0.01	0.01	212.95	1.109	0.006
45	0.009	0.00	230.47	1.081	0.006
46	0.01	0.01	250.50	1.305	0.007
47	0.011	0.01	273.64	1.568	0.008
48	0.009	0.00	300.71	1.410	0.007
49	0.012	0.01	332.80	2.081	0.011
50	0.011	0.01	371.49	2.129	0.011
A= Sqrt (Sum of Vdh^2)					18.562
B= per ph V1 (V)					19053.12
THD_Vpu = A/B					0.001
% THD_V = A/B*100					0.097

4. THD and IHD Calculation using PSCAD

The PSCAD model developed for the study in version 5.0.2 is illustrated in Fig. 1.

In PSCAD, the harmonic source data can be entered in the form of text files. The text file should contain each harmonic order vs peak magnitude of the harmonic current in kA. The 3rd element in text file should be phase angle. Here, in text files A.txt, B.txt and C.txt the phase angle is considered as 0, 120 and -120 degrees.

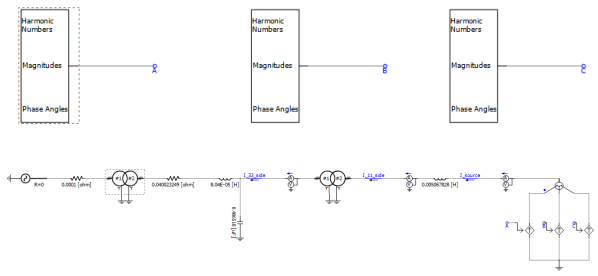

Fig. 1. PSCAD model

The THD and IHD results obtained from the PSCAD simulation are indicated in Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

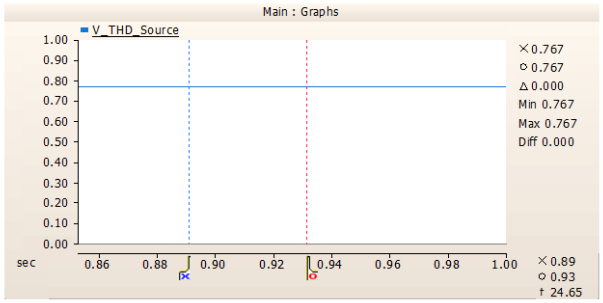

Fig. 2. THD at 11 kV source

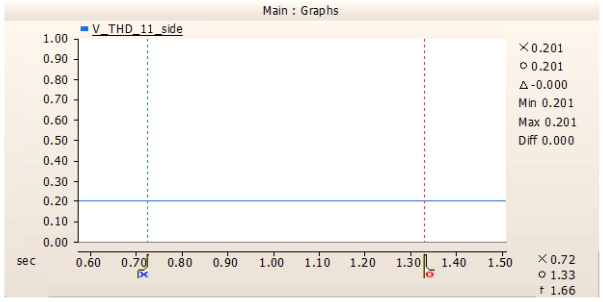

Fig. 3. THD at 11 kV terminal of transformer

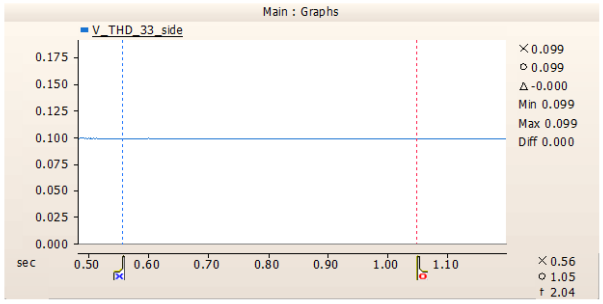

Fig. 4. THD at 33 kV terminal of transformer

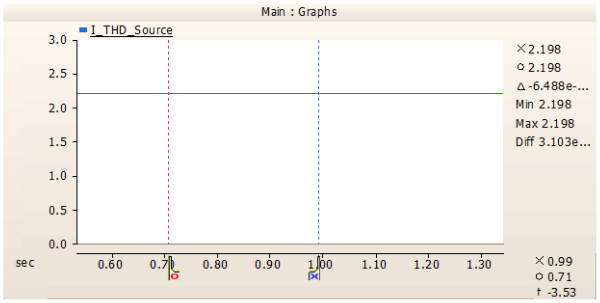

Fig. 5. THD of current at 11 kV source

5. THD and IHD Calculation using Sincal

The Sincal model developed for the study in version 19.0 is illustrated in Fig. 6. The THD and IHD results obtained from the Sincal simulations are indicated in Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

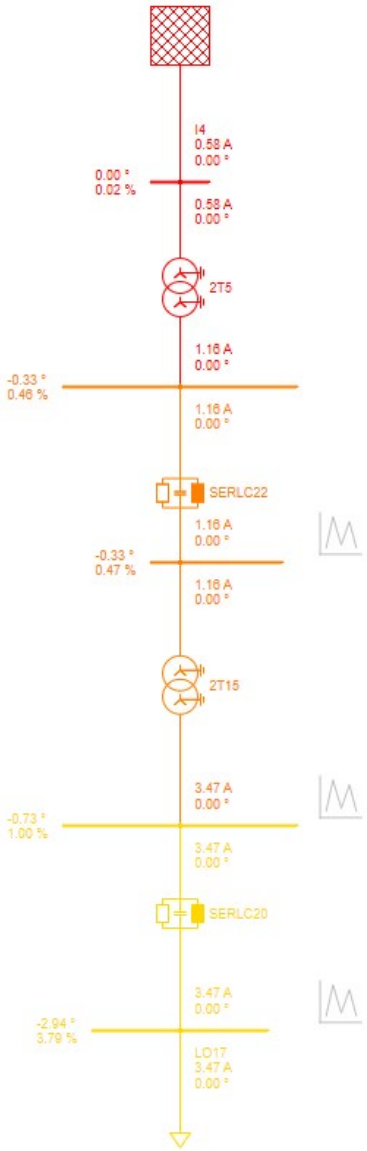

Fig. 6. Sincal model

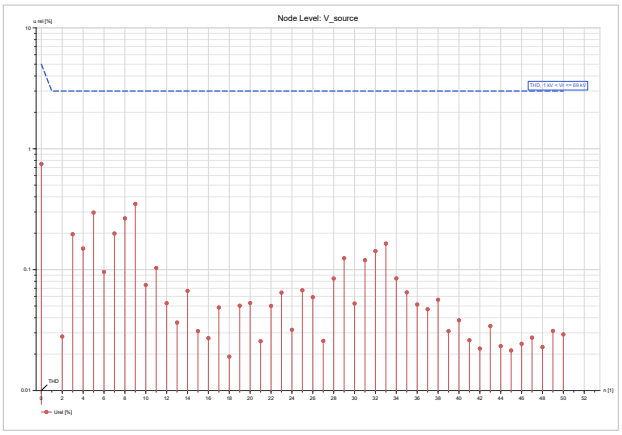

Fig. 7. THD at 11 kV source = 0.747%

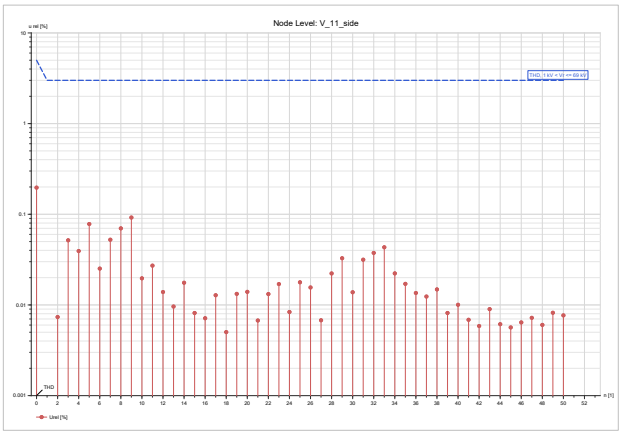

Fig. 8. THD at 11 kV terminal of transformer = 0.197%

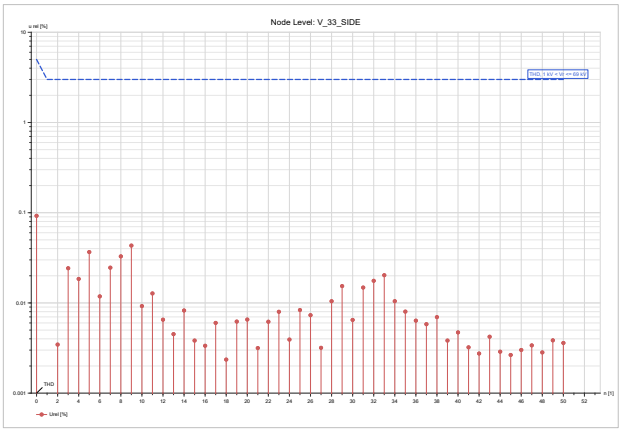

Fig. 9. THD at 33 kV terminal of transformer = 0.092%

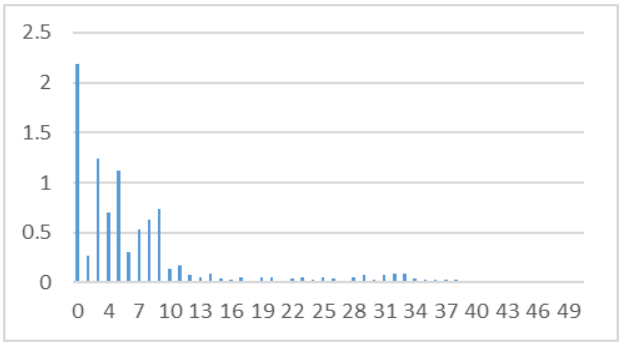

Fig. 10. THD of current =2.188%

6. THD and IHD Calculation using PSSE

The PSSE model developed for the study in version-35.0 is illustrated in Fig. 11. The THD and IHD results obtained from the PSSE simulation are as mentioned in Table 4 and Table 5.

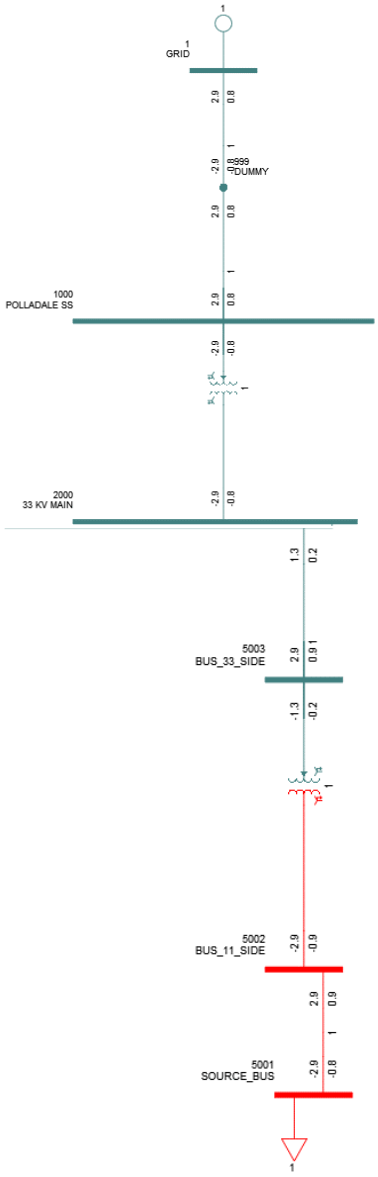

Fig. 11. PSSE model

Table 4
Voltage THD results obtained from PSSE simulation

Bus Number	Bus ID	V THD %
5001	SOURCE_BUS	0.7723
5002	BUS_11_SIDE	0.2004
5003	BUS_33_SIDE	0.0984

Table 5
Current THD results obtained from PSSE simulation

From Bus	To bus	I THD %
5002	5003	2.1879
5001	5002	2.1879

7. Summary

The summary of voltage and current THD calculated using excel, PSCAD, Sincal and PSSE is mentioned in Table 6 and Table 7.

Table 6
Summary of Voltage THD

Location	Voltage THD %			
	EXCEL	PSCAD	Sincal	PSSE
11 kV source	0.75	0.767	0.747	0.772
11 kV terminal of transformer	0.197	0.201	0.197	0.2
33 kV terminal of transformer	0.097	0.099	0.092	0.098

Table 7
Summary of Current THD

Current THD %			
EXCEL	PSCAD	Sincal	PSSE
2.188	2.198	2.188	2.187

8. Conclusion

In this paper the detailed comparison of the Voltage and Current THD calculated using excel and power system software's like PSCAD, Sincal and PSSE is performed.

From Table 6 and Table 7 it is envisaged that the calculated results matches with each other. Also proves the competency of PSCAD and PSSE software's for carrying out the harmonic analysis.

References

[1] IEEE-519 Standard for Harmonic Control in Electric Power Systems
[2] Sterling & Wilson, Harmonics in Photovoltaic Inverters & Mitigation Techniques.
[3] PSCAD Simulation of Grid-Tied Photovoltaic Systems and Total Harmonic Distortion Analysis: Abdulrahman Kalbat, Electrical Engineering Department, Columbia University in the City of New York, New York, NY 10027.