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Research paper

Various Passive Filter Designs Proposed for Harmonic Extenuation in Industrial Distribution Systems

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Abstract

This paper discusses various passive filter designs to reduce the harmonic in the industrial distributions system. The passive filter used is a single and double tuned harmonic filter. In the designing of this filter, analyzing filter properties of passive component of the filter. The study was conducted to examine the efficacy of using single and double tuned filters in reducing harmonic as well as determining the best location to install the filters. Different system effects and load limits on harmonic distortion and performance of filters are also being examined. The output of the simulation indicated that a superior performance in extenuating harmonics by the double tuned filter is more effective in reducing harmonics when it is placed near the harmonic generating loads.

Keywords: *passive filters; harmonic mitigation; single tuned filter; double tuned filter; power factor correction.*

1. Introduction

Nowadays, the general use of non-linear loads and electronic switching loads has resulted in increased voltage and current harmonic deformations in the industrial distribution system. The harmonics can result in the damage and excessive heating of the system's equipment. The problems include overheating and overloads in the transformers, wrong meter readings and failures of the power cable. The proliferation in the use of non-linear loads in the industrial, residential and commercial segments has distorted the current and wave power supply voltage. This disruption is referred as a harmonic distortion, and its occurrence can generate grave consequences on the equipment associated with contaminated source [1].

To resolve these hitches, harmonic extenuation thus, becomes imperative as it affects both customers and the utilities. Harmonic filtering by the use of passive filters has been among the oldest techniques applied in handling issues related to harmonic extenuation. More harmonic mitigation approaches are now available comprising of active and passive methods, and the most appropriate selection of techniques for a specific case can be an intricate process of making decision. The functionality of some of these methods mainly depends on the conditions of the system, whereas some need comprehensive system analysis to avoid problems of resonance and capacitor failure [2]. A lot of researches were conducted on mitigations of harmonics via various types of filters and ASD load effects and its contribution to harmonics near joint coupling points (PCCs). The study on harmonic mitigation produced by a 6-pulse rectifier was conducted by [3]. The design as well as performances of single and high pass filters were discussed by [4].

Conventionally, the problem of distributing harmonic systems has been researched by the use of a passive filter shunt. Although this filter types has the advantage of being a low-cost hardware, the performance of the filter is important to protect the system from high-voltage harmonics and used to enhance power factor of the system as the passive filter provide the power system with reactive power and reduce the resonance problems at all system buses. This depends on the nearness of the bus to the filter position. On the other hand, the passive filters with its different types regarded as one of the inexpensive and most cost-effective way to mitigate harmonic and improving power factor in the power systems. In present days, the application of passive filter includes all linear loads that used in electrical power system. Using passive filters should reduce THD values for both voltage and current below the IEEE standards. Moreover, the disadvantages of passive filters include large volume and parallel resonance possibility. Passive filters have also been widely applied in HVDC system, installation of arc furnaces, and installations of static (Var) compensator.

2. Passive Filter for Harmonic Mitigation

Passive filter has become a very potent answer for reducing harmonic of power systems. This filter has some different topologies in the characteristics of frequency responses. The present practice of industries is combining various filters topologies to attain specific goal for harmonic filtering. Though, there is absence of information concerning the choice of various topologies of the filter. This conclusion is on premised on the current filter designer's experiences [4].

Passive filter shunt is the most commonly used filter type. Configuration of different types of passive filters shunt is presented in Fig. 1. The shunt extension of this filter to the system provides a pathway low impedance for the harmonic currents flow, contrasting shunt filters with series filters, series filters ought to have full current load and must be protected with full line voltages. On the other hand, shunt filters only carry a small portion of the current carried by filter series. Series filter costly nature, and in reality shunt filter may supply reactive power at base frequency, passive filter shunt is more reliable as a harmonic filter.

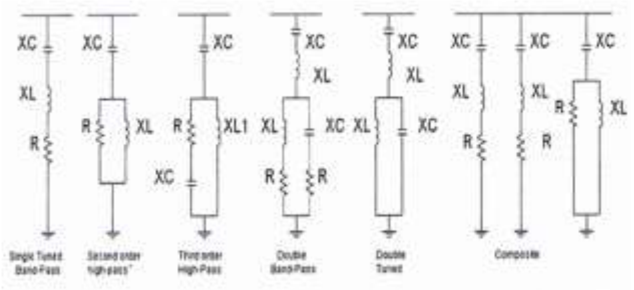


Fig. 1: Types of passive filter configuration

Popularly shunt filters are the most common types of filters in use. The connection of these shunt filters to the system provides a low pathway of impedance where harmonic current will flow, contrasting the filter shunt with the series filter, series filters ought to carry full current load and be protected with full-line voltage. On the other hand, shunt filters only carry a small portion of the current conducted by filter series. The fact that series filters are expensive and that the shunt filters may carry reactive power supply at central frequency, the most realistic method is ordinarily is the use of shunt filter. Fig. 2 shows the connection of the passive filter to power lines in terms of delta and star connections [4].

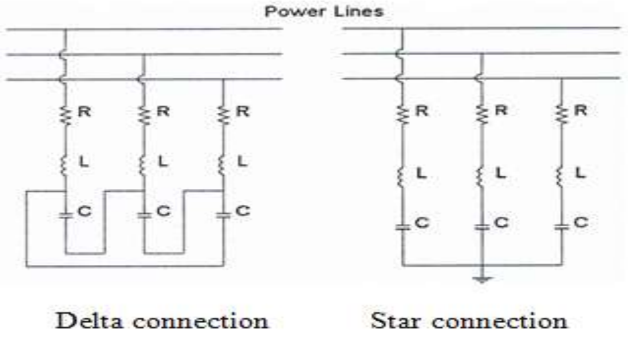


Fig. 2: Shunt passive filter connected to power lines

3. Design of Single Tuned Filter (STF)

In the designing of the single tuned-filter (STF), consideration is made on the fundamental system frequency in which the operation frequency chosen to be 50 Hz. The order of the harmonic tuned is also considered for the harmonic order of (5th and 7th). The 5th harmonic order is taken to be the first harmonic to be tuned in single tuned filter and its frequency is 250 Hz because the 5th and 7th harmonic order are the highest harmonic order among the harmonic orders, therefore decreasing the 5th harmonic order will reduces the other harmonic components in the harmonic spectrum. In case the mitigation of the 5th harmonic was not enough to get THD (Total Harmonic Distortion) below standards, then the 7th harmonic order will be taken and its frequency is 350 Hz.

In the designing of the single tuned filter, the capacitor rated (V_{cap}) considered such that it must be higher than the bus voltage to prevent the effect of high harmonic current which may cause capacitor break down due to the increase in temperature. The determinations of the factors of single-tuned filter shown in Fig. 3 are described as follows.

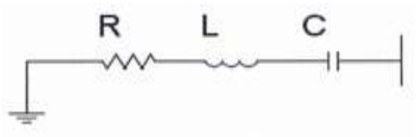


Fig. 3: Single-tuned passive filter circuit

The value of filter capacitance (X_C) is determined using the following relation

$$X_c = \frac{(V_{cap})^2}{KVar_{filter}} \tag{1}$$

where V_{cap} the line-to line is rated capacitor voltage and ($Kvar_{filter}$) filter is the capacitor's reactive power. The capacitance of the filter is therefore determine by following equation

$$C = \frac{1}{2\pi f X_c} \tag{2}$$

where (f) is the fundamental frequency. The value of the reactor for the filter is determine by the equation

$$L = \frac{1}{(2\pi f)^2 (rh)^2 c} \tag{3}$$

where (h) represent the harmonic tuned filter and (r) represent empirical factor less than one, (rh) is the value a little lower than the frequency of the concerned harmonic. This factor reduces the likelihood of undesirable harmonic resonance, which may likely occur if there is a change in the parameters of the system. The normal value r for the fifth harmonic is (0.94).

The resistance of the filter (R) is on the basis of quality factor (Q) that measures the tuning sharpness. The quality factor is explained using the mathematical equation as follows.

$$Q = \frac{\sqrt{LC}}{R} \tag{4}$$

The resistance value could be gotten by choosing one suitable value of quality factor, $20 < Q < 30$.

The double tuned-filter (DTF) is used in the filtration of two components of harmonic concurrently. As compared with STF have similar performances, (DTF) has some advantages like just one reactor which is subjected to full voltage line, and smaller spaces is required and also require a switch-gear. The elementary configurations (DTF) are presented in Fig. 4. It consists of resonant circuit series with parameters (L1) and (C1) and parallel resonant circuits with parameters (L2) and (C2) [3].

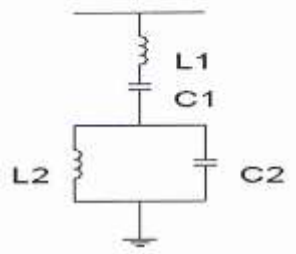


Fig. 4: Double-tuned passive filter circuit diagram

Neglecting the resistance in reactors and dielectrics loss in capacitors, the series circuit impedance and parallel circuit are given respectively as

$$Z_s(\omega) = j({}^{1}/_{\omega L_1} - {}^{1}/_{\omega C_1}) \tag{5}$$

$$Z_P(\omega) = j({}^{1}/_{\omega L_2} - \omega C_2)^{-1} \tag{6}$$

where (ω) $is\ the\ angular\ frequency\ in\ radian$. The series resonance frequency is given by

$$\omega_S = {}^{1}/_{\sqrt{L_1 C_1}} \tag{7}$$

The parallel resonance is given by

$$\omega_p = {}^{1}\!/\!\sqrt{L_2C_2} \tag{8}$$

In the case of resonance, the total impedance of the filter Z (ω) will be equal to zero which is given as

$$Z(\omega) = Z_S(\omega) + Z_P(\omega) = 0 \tag{9}$$

Substituting in (5) and (6) for $Z_S(\omega)$ and $Z_P(\omega)$ into (9) and simplifying it yields

$$\omega^4 L_1L_2C_1C_2 - \omega^2(L_2C_1 + L_1C_1 + L_2C_2) + 1 = 0 \tag{10}$$

In (10), two roots of $\omega_1$and ω_2 which represent the tuned frequencies of the double filter tuned can be obtained in accordance with Vida's theory in which the association between the root and the coefficients L_1, C_1, L_2, C_2 in (10) is given by [5].

$$\omega_1^2\omega_2^2 = (L_1C_1L_2\ C_2)^{-1} \tag{11}$$

Simplifying in (11) and substituting in (7) and (8) yields

$$\omega_1\omega_2 = \left(\frac{1}{\sqrt{L_1C_1\sqrt{L_2C_2}}}\right) = \omega_S\omega_P \tag{12}$$

The tuned frequency ω_1 and ω_2 have to be defined first to obtain the values of $\omega_S\omega_{P,}$ then the parameters $L_1, C_1 and L_2, C_2$. Based on the fact that the impedance of the filter is infinite at the parallel resonance frequency of ω_P, and taking in to account of the network impedance-frequency characteristics, ω_P is selected such that it is a value between ω_1 and ω_2. After knowing the rest steps, the determination of L_1, $C_1$and L_2, C_2, ω_1, ω_2 and ω_P is obtained, ω_S is indeed defined in (12). Substituting in (7) and (8) into (10) yields

$$\left(\frac{\omega^4}{\omega_S^2\omega_P^2} - \left(\frac{C_1}{C_2}\frac{1}{\omega_P^2} + \frac{1}{\omega_S^2} + \frac{1}{\omega_P^2}\right)\omega^2 + 1\right) = 0 \tag{13}$$

For ω_1 being one of the solutions in (13), substituting $\omega = \omega_1$ and simplify the equation, the relationship between the capacitances C_1 and C_2 can be established as

$$\frac{C_1}{C_2} = \left(\left(\frac{\omega_1^2+\omega_2^2-\omega_P^2}{\omega_S^2}\right)\right) - 1 \tag{14}$$

Using in (7) and substituting for $\omega_S = \omega_1\omega_2/\omega_P$ in L_1 can be determined as

$$L_1 = \left(\frac{\omega_P}{\omega_1\omega_2}\right)^2\frac{1}{C_1} \tag{15}$$

Similarly, using in (8) and substituting C_2 in (15), L_2 can be obtained as

$$L_2 = \frac{1}{\omega_P^2C_2} = \frac{1}{\omega_P^2C_1}\left(\frac{\omega_1^2 + \omega_2^2 - \omega_P^2}{\omega_S^2}\right) \tag{16}$$

If the harmonic of interest to be eliminated are of the 5th and 7th harmonics, the values of $\omega_1, \omega_2, \omega_P\ and\ \omega_2$ are determined such that $\omega_1 = 2\pi * 250\,rad$ and $\omega_2 = 2\pi * 350\,rad$, $\omega_P = 2\pi * 300\,rad$ in which ω_P is assumed to be 300 Hz, which is the value that lies between 250 Hz and 350 Hz.

ω_S is then calculated using in (12) in which ω_S = 291.66 Hz. Before starting to evaluate the values of L_1, $C_1$and L_2, C_2 for double tuned filter circuit. The value of filter capacitor voltage V_{cap} and the reactive power supplied by the filter capacitor Q_{cap} must be limited, V_{cap} must higher than the bus voltage to protect filter capacitor from high temperature due to high harmonic currents. The values of C_1can be determined in (17).

$$C_1 = \left(\omega_f\left(\frac{\omega_p}{\omega_1\omega_2}\right)^2\frac{1}{\omega_f} + \left(\frac{\omega_f(\omega_1^2+\omega_2^2-\omega_p^2)\omega_p - \omega_1^2\omega_2^2}{(\omega_1^2\omega_2^2(\omega_p^2\omega_s^2))}\right)\right)\frac{V}{Q} \tag{17}$$

Using the magnitude of $C_1$to find the value of L_1 in (15). The value of C_2 is determined in (14) finally, in (16) is used to obtain the value of L_2

4. Example of Harmonic Filter Design

Fig. 5 shows the 13-bus IEEE test system for harmonic mitigation study. The steady state analyses of harmonic filters are performed using PSCAD/EMTDC simulation program, which was developed by HVDC Manitoba. The IEEE 13-bus industrial distributions system is applied in this work. Specific details of the data for the system and the parameters can be found at [5-7]. The system from utility supplies at 69 K_V and local generator operates at 13.8 Kv. The system operate at 3 different voltages level, which are high voltage (69K_V), medium voltage (13.8 K_V, 4.16 K_V and 2.4K_V) and low voltage (0.48 K_V). A capacitor rated at (6000K_{Var}) is connected at point of common coupling (PCC), which is bus 3 to correct the plant's load power factor [7-9]. The harmonic producing load's considered in the simulation are the two ASD loads rated at 1186 K_{Var} connected to bus 7 and bus 10. The data for all test system components are given as in appendix.

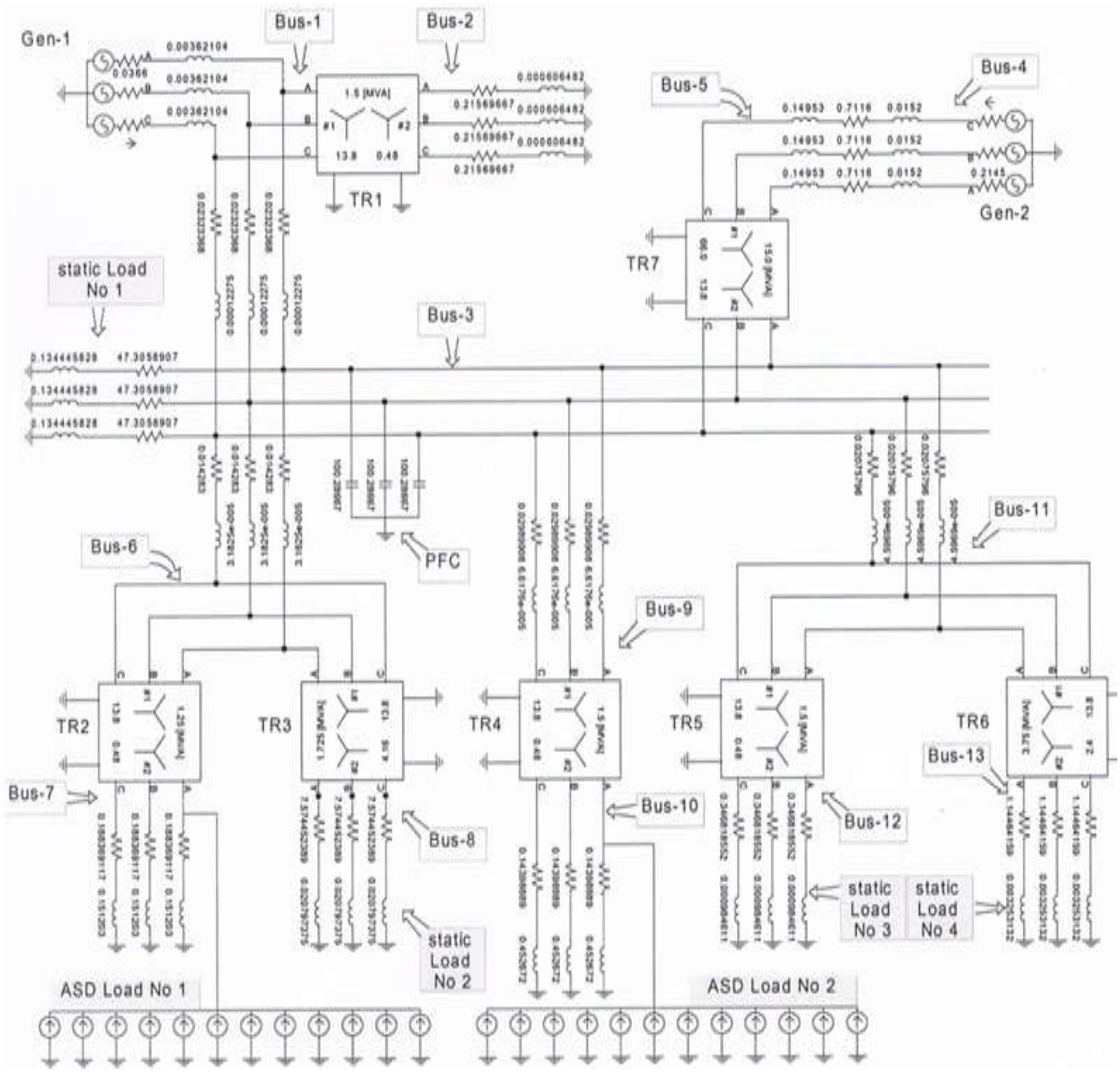


Fig. 5: The simulation circuit of IEEE test system

5. Results and Discussion

Simulation results are presented giving as insight on the variation of both voltage and current harmonic distortion level as effected by the following:

i) Installing of single tuned and double tuned filters.
ii) Effect of power factor correction capacitors.
iii) Changing the loading level of static load.

5.1. Propagation of Harmonic before Installing Filters

Before installing filters, the propagation of harmonics in the system is investigated using the frequency domain analysis. The harmonic spectrum of individual harmonic voltage is obtained as shown in Fig. 6. The values THD for both voltage and current are recorded at various buses and results are tabulated as shown in Table 1. It is noted that both voltage and current THD record high values which exceed their limits at bus 7, 9 and 10. This is due to the fact that the ASD loads are connected at busses 7, 10 and bus 9 is connected to bus 10 via a transformer. The voltage and current waveform at bus 3 and bus 7 are shown in Fig. 7a-d respectively.

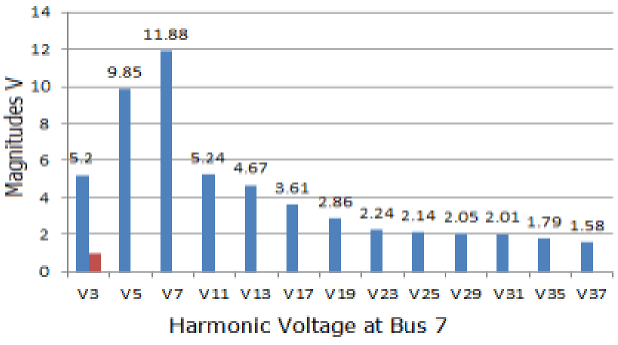
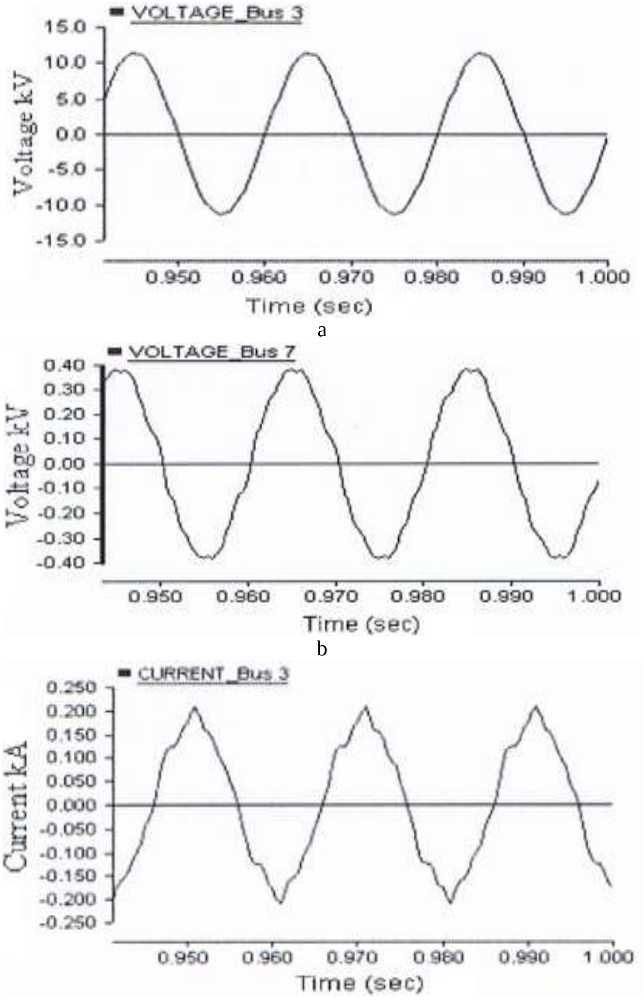


Fig. 6: Voltage at Bus 7

Table 1: THD at different buses before installing filters

Bus No.	THD (V)	THD (I)
7	5.1442 *	21.446 *
9	0.6263	23.143 *
10	6.0274 *	23.852 *
13	0.6075	0.1378
3	0.628	6.6123
4	0.1289	4.2112

The asterisk (*) indicates the voltage and current exceeds its limits of 5% and 20% respectively.



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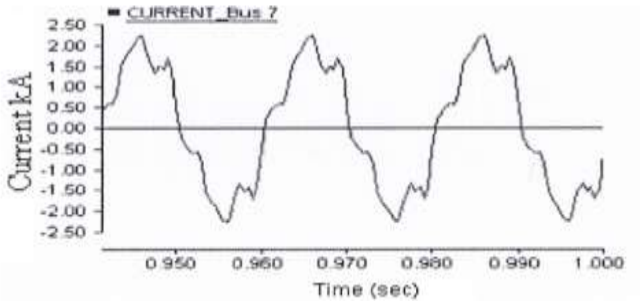

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Fig. 7: a-b for voltage waveform at bus 3 and 7; c-d for current waveform at bus 3 and 7 respectively

Both buses are of interest in which bus 7 is close to the harmonic source ASD load and bus 3 is at the point of common coupling.

5.2. Harmonic Propagation after Installing Filters

For single tuned filter the derived values for both L and C are as below.
In case the filter installed at bus 7 or bus 10, the value of L = 0.0009167 H and C = 7.07353μF.
In case the filter installed at bus 3, the value of L = 0.05729 H and C = 4421μF.

And for double tuned filter are as in below.
In case the filter installed at bus 7 or bus 10, the value of L_1= 8.8654 E-5, C_1 = 3586.34 μF and L_2 = 0.851516 E-5, C_2=0.019659.97 μF .
In case the filter installed at bus 3, the value of L_1 = 12.974 E-5, C_1 = 0.002295μF and L_2 = 1.43158 E-5, C_2 = 0.019659.97 μF.

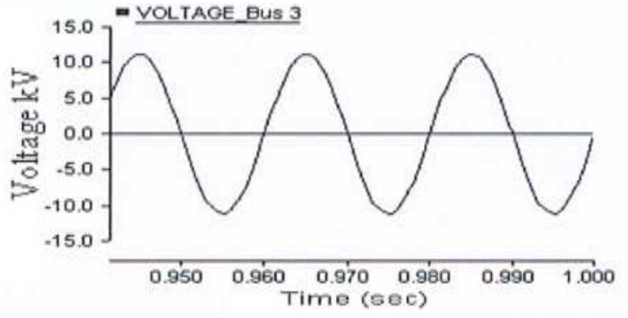
Comparison of results with single tuned and double tuned filter where the two filters are placed one at the time at bus 7, 10 and 3 and at both buses 7 and 10. The THD for voltages and currents are calculated at the three buses and the results are shown in Table 2.

Table 2: THD (V & I) for single tuned filter and double tuned filter

Filter Position	Monitoring	For Single Tuned Filter		For Double Tuned Filter	
		THD (V)	THD (I)	THD (V)	THD (I)
Bus 7	7	2.96	10.58	2.6198	7.953
	9	0.76	23*	1.1316	22.973 *
	10	6.36 *	23.7 *	6.653 *	23.97 *
	13	0.73	0.17	1.0837	0.239
	3	0.61	6.28	1.1212	6.274
	4	0.15	4.78	0.2235	6.433
Bus 10	7	5.5*	21.29 *	5.788 *	21.167 *
	9	0.66	13.27	1.058	8.563
	10	3.38	12.92	3.0213	8.809
	13	0.65	0.151	1.028	0.227
	3	0.67	7.112	1.064	12.41
	4	0.13	4.254	0.211	6.065 *
Bus 3	7	5.06	21..55 *	5.586	20.79 *
	9	0.46	23.14 *	0.682	24.013 *
	10	5.9 *	23.82 *	0.682	24.013 *
	13	0.09	0.075	0.725	22.984
	3	0.46	3.267	0.469	2.584
	4	0.094	2.53	0.1189	3.521
Bus 7 and 10	7	3.11	9.71	2.63	6.11 *
	9	0.35	12.06 *	0.325	7.104
	10	3.51	12.39 *	3.028	7.31
	13	0.34	0.586	0.3223	0.05
	3	0.35	2.335	0.3337	4.081
	4	0.07	2.251	0.0716	2.117

The asterisk (*) indicates the voltage and current exceeds its limits of 5% and 20% respectively.

From the results shown in Table 2, it can be seen that harmonics can be mitigated when double tuned filter are placed at both buses 7 and 10. Therefore, this is the optimal placement for the installation of passive filters. By installing double tuned filters at the buses 7, 10 and 3 at a time harmonics cannot be eliminated. For the results with single tuned filters installed at all considered buses, for all cases. Fig. 8a-c show the voltage waveforms at bus 3, 7 and 9 respectively and Fig 8d-f show the current waveform at bus 3, 7 and 9 respectively for double tuned filters placed at both bus 7 and bus 10.



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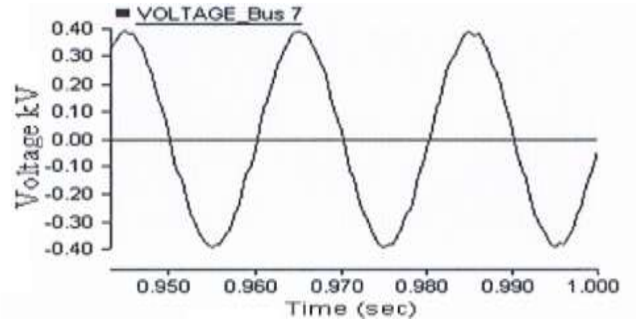

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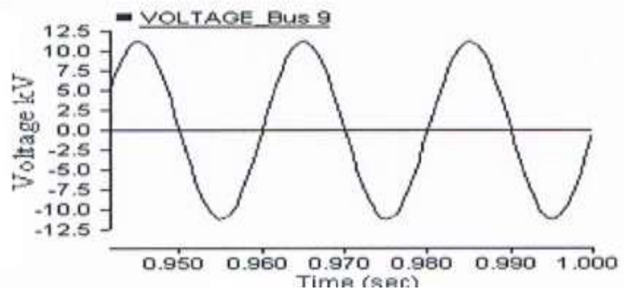

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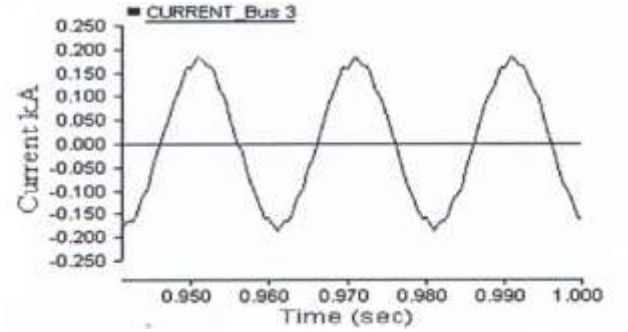

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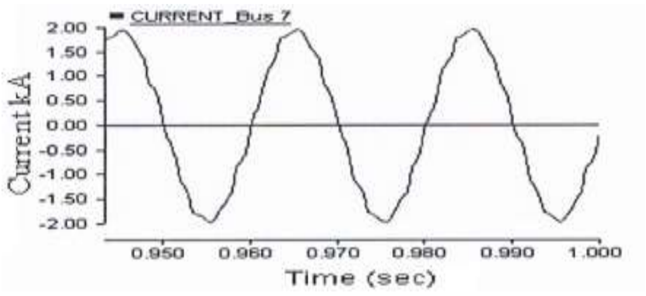

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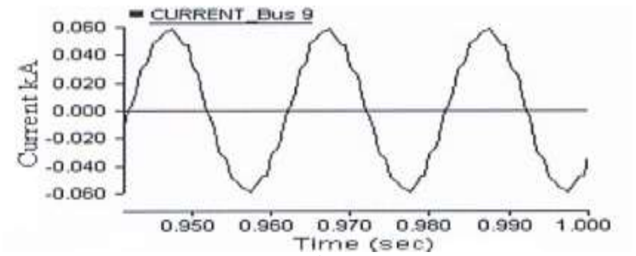

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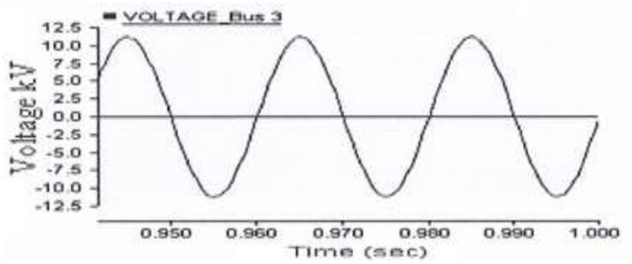
Fig. 8: a-c for voltage waveform at buses 3, 7 and 9; d-f for current waveform at buses 3, 7 and 9 with DTF



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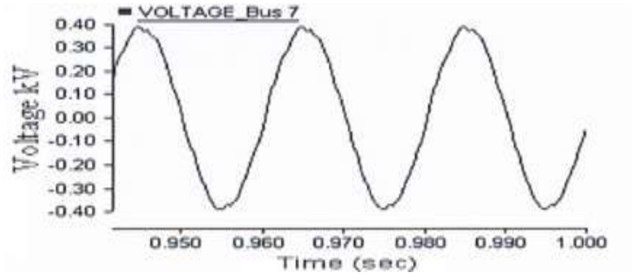

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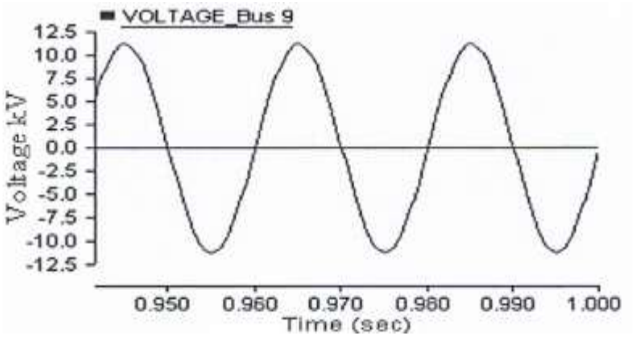

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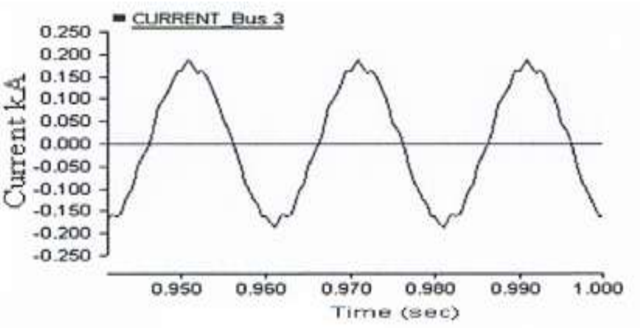

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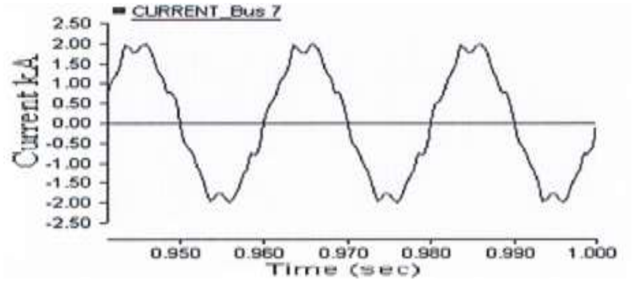

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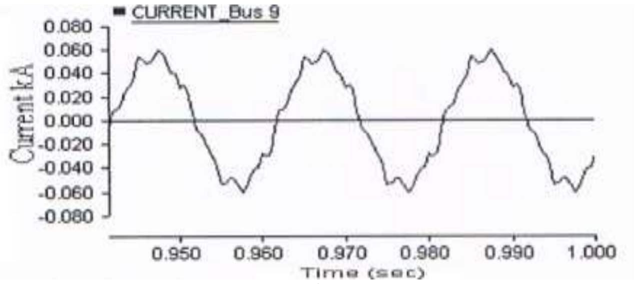

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Fig. 9: a-c fore voltage waveform at buses 3, 7 and 9; d-f for current waveform at buses 3, 7 and 9 with (STF)

From the tables and figures above, it can be observed that the THD have high values, especially for the current THD. The high distortion values are due to the harmonics generated by the two ASD loads at bus 7 and bus 10. Since bus 7 and 10 are the buses close to the harmonic sources, it can be observed that the individual harmonic distortion at other buses are less than the distortion at bus 7, 10 and 9. The distortion is less at bus 3 the point of common coupling bus. The results are also show that by placing filters close to harmonic source such as bus 7 and bus 10 reduction of harmonic is greater comparing to the placement of filter farther from the harmonic sources. In this study, better results obtained when placing two passive filters at the time one in bus 7 and the other in bus 10.

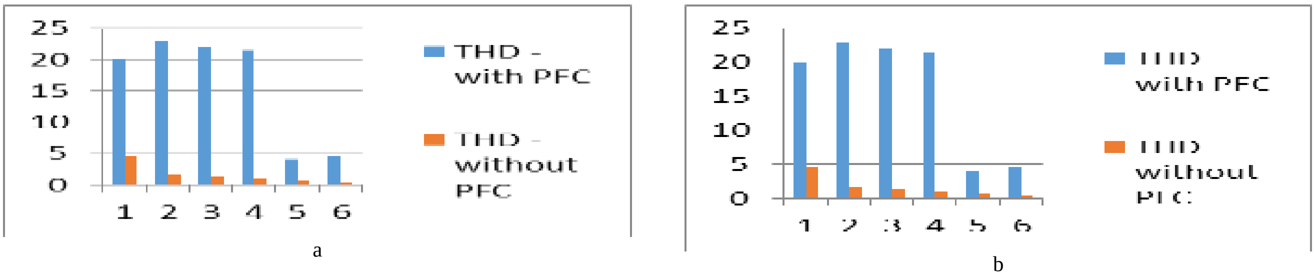
5.3. Effect of Power Factor Corrector in Harmonic Mitigation

Power factor correction capacitor (PFCC) is usually used in industry power systems to improve system power factor and usually connected at the point of common coupling. The disadvantage of the capacitor that it creates multi system resonance, and changes the impedance of the system.
Table 3 shows that the results of the voltage and current THD after placing DTF with and without capacitor. The results show that harmonic distortion is less without installing PFC, especially for the current.

Table 3: THD (V and I) for double tuned filter with and without connecting (PFC)

Filter Position	Monitoring	For Double Tuned Filter			
		With PFC		Without PFC	
		THD (V)	THD (I)	THD (V)	THD (I)
without placing filters	7	5.623	21.783 *	5.144	21.446 *
	9	0.602	23.54 *	0.588	23.143 *
	10	6.506	24.25 *	6.027	23.853 *
	13	0.569	0.0914	0.507	0.078
	3	0.589	5.9881	0.528	5.6251
	4	0.119	2.1721	0.109	2.0211
Bus 7	7	2.620	5.788	2.119	5.68
	9	1.132	22.97 *	0.602	23.539 *
	10	6.65 *	23.68 *	6.505	24.256 *
	13	1.084	0.239	0.569	0.0914
	3	1.121	6.274	0.118	25.988
	4	0.224	6.434	3.158	2.173
Bus 10	7	5.788	21.17 *	3.158	20.206 *
	9	1.058	18.56	0.637	18.061 *
	10	3.021	8.809	3.685	8.18
	13	1.028	0.227	1.019	0.184
	3	1.064	9.416	0.124	7.588
	4	0.211	5.065	5.309	3.995
Bus 3	7	5.586	20.8 *	5.309	19.695 *
	9	0.68	22.01 *	0.604	21.605 *
	10	0.68	23.61 *	0.623	22.414 *
	13	0.725	0.984 *	0.576	0.7044
	3	0.47	2.58	0.457	2.027
	4	0.119	3.521	0.118	3.331
Bus 7 and 10	7	2.632	6.112	2.244	6.038
	9	0.325	7.104	0.308	7.104
	10	3.028	7.311	3.138	7.316
	13	0.322	0.0502	0.500	0.023
	3	0.334	4.08	0.311	4.023
	4	0.072	2.117	0.067	1.564

The asterisk (*) indicates the voltage and current exceeds its limits of 5% and 20% respectively. Fig. 10a-b for THD plot for both voltage and current at bus 3 for the case with and without capacitors connected respectively.



a

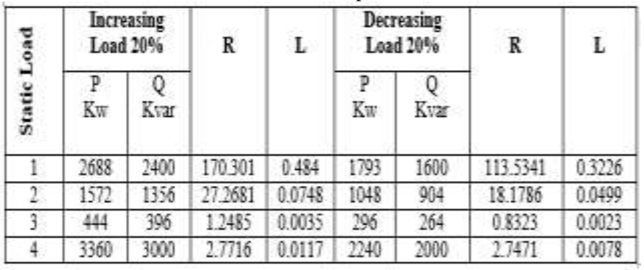
b

Fig. 10: a-THD V and I with capacitor at bus 3; b-THD V and I without capacitor at bus 3

5.4. Effect of Changing Load Parameters

The change static loads (1, 2, 3 and 4) to the ratio -20% and +20% is shown in Table 4 to investigate the effect of changing load parameters on harmonic propagation.

Table 4: New load parameters



Static Load	Increasing Load 20%		R	L	Decreasing Load 20%		R	L
	P Kw	Q Kvar			P Kw	Q Kvar		
1	2688	2400	170.301	0.484	1793	1600	113.5341	0.3226
2	1572	1356	27.2681	0.0748	1048	904	18.1786	0.0499
3	444	396	1.2485	0.0035	296	264	0.8323	0.0023
4	3360	3000	2.7716	0.0117	2240	2000	2.7471	0.0078

The static loads are changed by 20% increasing and decreasing. The results due to changing the loads are as shown in Table 5 with the double tuned filter.

Table 5: Effect of changing static loads on THD I and THD V

Filter Position	Monitoring	Without Changing Static Load		Increasing Load 20%		Decreasing Load 20%	
		With PFC				Without PFC	
		THD (V)	THD (I)	THD (V)	THD (I)	THD (V)	THD (I)
Without DTF	7	5.144	21.445 *	5.088	21.17*	5.096	21.21*
	9	0.606	23.144 *	0.648	22.84*	0.643	22.89*
	10	0.027	24.851 *	5.972	23.55*	5.977	23.59*
	13	0.603	0.144	0.646	0.125	0.635	0.146
	3	0.628	9.315	0.654	8.294	0.644	8.785
	4	0.128	4.021	0.134	8.782	0.133	7.373
Bus 7	7	2.619	7.953	2.393	7.743	2.396	7.701
	9	1.131	22.97 *	1.213	22.66*	1.193	22.71*
	10	23.68*	6.647*	6.647*	23.37	6.644	23.41*
	13	0.241	1.199	1.192	0.222	1.165	0.258
	3	6.434	0.241	1.199	5.821	1.183	6.077
	4	0.224	13.99	0.241	13.99	0.237	11.83
Bus 10	7	5.788	21. 17	5.77	20.87	5.775	20.91*
	9	1.058	8.563	1.122	8.784	1.107	8.702
	10	3.021	8.809	2.735	8.985	2.735	8.944
	13	1.028	`0.227	1.121	0.208	1.096	0.243
	3	1.064	12.42	1.128	11.66	1.112	12.25
	4	0.211	6.065	0.226	13.1	0.222	11.06
Bus 3	7	5.586	2.79	5.5433	2.123	5.476	20.57*
	9	0.682	24.01	0.1582	22.95*	0.685	24.02*
	10	0.682	24.01	0.605	23.89*	0.668	23.96*
	13	0,726	22.98	0.711	22.29*	0.755	23.29*
	3	0.369	2.584	0.428	2.501	0.477	2.455
	4	0.118	3.521	0.108	3.222	0.122	3.688
Bus 7 and 10	7	2.633	6.114	2.407	5.561	2.412	5.602
	9	0.325	7.104	0.292	6.784	0.294	6.6796
	10	3.028	7.313	2.742	6.692	2.745	6.975
	13	0.322	0.050	0.298	0.042	0.297	0.049
	3	0.333	4.042	0.299	3.253	0.301	3.458
	4	0.072	2.117	0.066	4.229	0.067	3.643

The asterisk (*) indicates the voltage and current exceeds its limits of 5% and 20% respectively.

From the results in Table 5, it can be observed that in case of decreasing the load the THD will be higher than the case of increasing load because this loads increases system impedance in then decrease THD of the system.

5.5. Parallel and Series Resonance

To avoid resonance occurrence in the system the passive filters are designed by selecting suitable ω_s and ω_p such that the resonant frequencies approach to the harmonic order frequencies values of 250 Hz and 350 Hz, shifting the resonance frequencies to the harmonic to be attenuated. In this case, the resonance impedance will be close to zero and all harmonic current will pass through the filter path. Fig 11 shows the frequency scans for double tuned filter impedance according to the change in frequency. Another method to avoid resonance performed by adding additional impedances to the system to change system total reactance $(X_C \pm X_L)$ that will effect on the resonance magnitude.

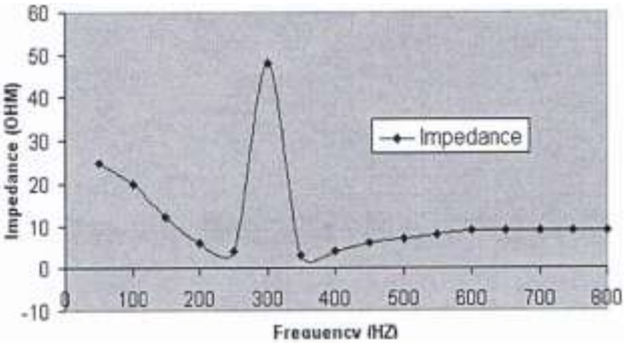


Fig. 11: Frequency scans for double tuned filter

6. Conclusion

This paper investigates several critical issues for distribution system harmonic distortion generation and propagation. The iterative process of filter design is illustrated through step-by step calculation. The badly designed filters have failed or resulted in operation problems when the constraints of their applications are not realized. The design of these filters depend on the system demands such as the harmonic order to be eliminated and the reactive power to be compensated. Also, the parameters depend on system parameters such as bus voltage and system frequency (angular frequencies ω_s and ω_p) which will effect on resonance impedance. Using the 13 bus bar test system to simulate a test system by using (PSCAD/EMTDC) software gives a good results for harmonic study and mitigation. using passive filters (single and double) tuned filters will reduce harmonic distortion for both voltage and current, double tuned filter have better results because it is used to mitigate two harmonic orders at the same time. The most suitable place for installing a filter is near the source of harmonics to eliminate harmonic before it separate to other part of the system, the results shows that one filter disable of reduce the effect of two harmonic sources in the same time especially if the two harmonic sources are far from each other so far to get good results, we must install one filter for each harmonic source. Increasing the loading levels of the distribution system result in a reduction for the system harmonic contents for both voltage and current. Also increasing the feeders and transformer X/R ratios can further reduce the harmonic distortion level by changing the phase angle of the generated harmonic currents.

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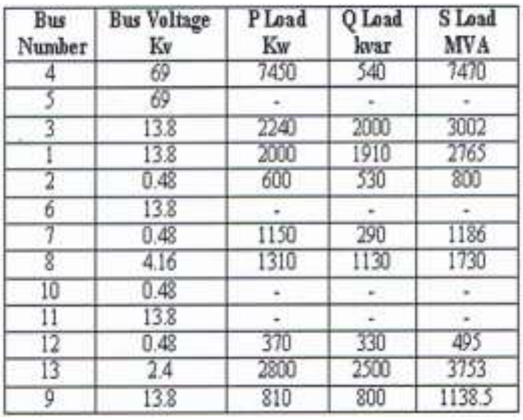
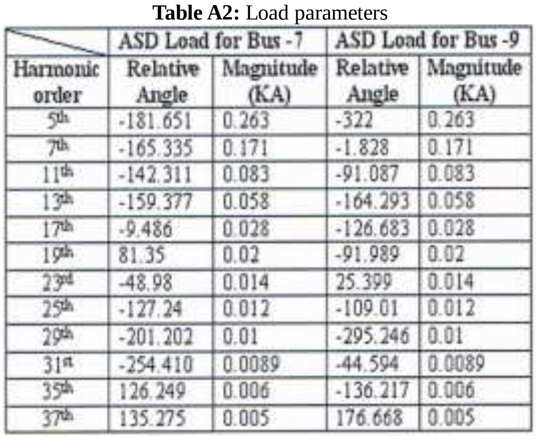
Appendix

Table A1: Generation



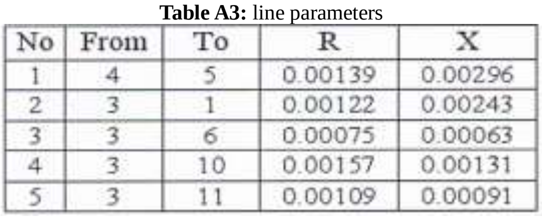
Bus Number	Bus Voltage Kv	P Load Kw	Q Load kvar	S Load MVA
4	69	7450	540	7470
5	69	-	-	-
3	13.8	2240	2000	3002
1	13.8	2000	1910	2765
2	0.48	600	530	800
6	13.8	-	-	-
7	0.48	1150	290	1186
8	4.16	1310	1130	1730
10	0.48	-	-	-
11	13.8	-	-	-
12	0.48	370	330	495
13	2.4	2800	2500	3753
9	13.8	810	800	1138.5

Table A2: Load parameters



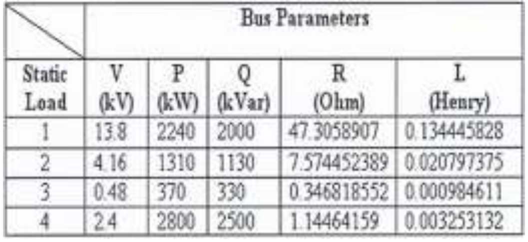
	ASD Load for Bus -7		ASD Load for Bus -9	
Harmonic order	Relative Angle	Magnitude (KA)	Relative Angle	Magnitude (KA)
5th	-181.651	0.263	-322	0.263
7th	-165.335	0.171	-1.828	0.171
11th	-142.311	0.083	-91.087	0.083
13th	-159.377	0.058	-164.293	0.058
17th	-9.486	0.028	-126.683	0.028
19th	81.35	0.02	-91.989	0.02
23rd	-48.98	0.014	25.399	0.014
25th	-127.24	0.012	-109.01	0.012
29th	-201.202	0.01	-295.246	0.01
31st	-254.410	0.0089	-44.594	0.0089
35th	126.249	0.006	-136.217	0.006
37th	135.275	0.005	176.668	0.005

Table A3: line parameters



No	From	To	R	X
1	4	5	0.00139	0.00296
2	3	1	0.00122	0.00243
3	3	6	0.00075	0.00063
4	3	10	0.00157	0.00131
5	3	11	0.00109	0.00091

Table A4: Bas parameter

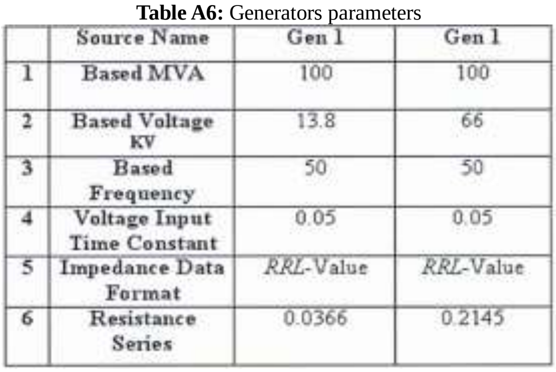


	Bus Parameters				
Static Load	V (kV)	P (kW)	Q (kVar)	R (Ohm)	L (Henry)
1	13.8	2240	2000	47.3058907	0.134445828
2	4.16	1310	1130	7.574452389	0.020797375
3	0.48	370	330	0.346818552	0.000984611
4	2.4	2800	2500	1.14464159	0.003253132

Table A5: Transformers parameters

No	Transformer name		TR1	TR2	TR3	TR4	TR5	TR6	TR7
1	Based MVA 3 Phase		1.5	1.25	1.725	1.5	1.5	3.75	15
2	Transformer Voltage ratio (KV)	W1	13.8	13.8	13.8	13.8	13.8	13.8	69
		W2	0.48	0.48	4.16	0.48	0.48	2.4	13.8
3	Winding Type	Y	Y	Y	Y	Y	Y	Y	Y
		Y	Y	Y	Y	Y	Y	Y	Y
4	Based Frequency HZ		50	50	50	50	50	50	50
5	Ideal Transformer Model Enable		No	No	No	No	No	No	No
6	Saturation Enable		Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Magnetization Current (%)		2.0	2.0	2.0	2.0	2.0	2.0	2.0
8	Positive Sequence Leakage Impedance [P.U]		0.04724	0.03699	0.049614	0.047339	0.0453	0.045675	0.066332

Table A6: Generators parameters



	Source Name	Gen 1	Gen 1
1	Based MVA	100	100
2	Based Voltage KV	13.8	66
3	Based Frequency	50	50
4	Voltage Input Time Constant	0.05	0.05
5	Impedance Data Format	*RRL*-Value	*RRL*-Value
6	Resistance Series	0.0366	0.2145