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Power Quality Analysis of Harmonics in3.5kVA Single Phase Generator using Electronic Filter in Matlab/Simulink Environment.

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ABSTRACT
The aim of this workis to investigate the harmonic content of nonlinear loads connected to 3.5kVA power supply source and to mitigate the effects using electronic filter (double tuned low pass active shunt filter).The presence of harmonics was investigated by collecting data from the power source, 3.5 kVA using '**Owon Oscilloscope**' metering device. The data was then processed by means of Fourier analysis into harmonic spectrums. Mitigate the harmonics found in this power source a double tuned low-pass active shunt filter was design from discrete elements (resistors, capacitors and inductors) and implemented in the MATLAB/SIMULINK environment.The result obtained for V_{THD} before and after the simulation procedure using the series active passive filter was higher than the expected IEEE standard of 5%; while the result obtained using the double tuned low pass active shunt filter then after simulation gave a satisfactory result less than the expected IEEE standard of 5% after simulation.

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I. INTRODUCTION:

Electrical AC supply is ideally a pure sine-wave of both 50 or 60 Hz fundamental frequency and all electrical equipment are designed for optimal performance on this supply. Harmonics are voltages and currentswhich have frequency componentsthat are integers multiple of thefundamental frequency – pollutingthe pure sinusoidal waveform [1].Power electronics such as those used in rectifiers, variable speed drives, UPS, lighting dimmer switches, televisions and hosts of other equipment, draw current in a non-sinusoidal fashion. This non-sine current interacts with the mains supply and distorts the voltage to a greater or lesser degree depending upon the strength or weakness (fault level) of the supply [2].

Nonlinear loads are not necessarily the only cause of harmonics within the supply system. Generators and the distribution system itself can produce harmonics. Some examples of nonlinear loads that generates harmonic currents are computers, fax machines, printers, refrigerators, TVs and electronic lighting ballasts. If a generator produces a non-ideal sinusoidal waveform, the voltage waveform can contain a certain amount of harmonics [3]. In the distribution system, generators are capable of producing harmonics due to magnetic core saturation.The generator used for the purpose of this analysis is a 3.5 kVA, at F (43.804 Hz), JINLING 3600 with manufacturer's data as: voltage 220V, frequency 50Hz, p.f 1 fuel type petrol.

II. BASICS OF FILTER DESIGN[4]

On the a-c side of the converters, harmonic filters are installed which limit the flow of harmonic in the a-c system, which otherwise may cause interference with telecommunication circuits and produce other deleterious effects.

Choice of Filter Q[5]

In order to develop the fundamental ideas of filter design we will consider the L-C-R single tuned type. For the L-C-R elements in series, and with the arm at resonant frequency f_n (and where) $\omega_n = 2\pi * f_n$ [6].

$$\omega_n^2 LC = 1 \tag{1}$$

by definition

$$Q = \frac{\omega_n L}{R} \tag{2}$$

on substitution

$$R = \frac{1}{\omega_n C Q} \tag{3}$$

Let δ be per unit detuning expected from all causes, expressed as an effective frequency variation from the nominal [6].

$$Y_a = \frac{1}{Z_a} = G_a + jB_a \tag{4}$$

$$Y_f = \frac{1}{Z_f} = G_f + jB_f \tag{5}$$

At an approximate near resonance,

$$G_f = \frac{1}{R(1+4Q^2\delta^2)} \tag{6}$$

$$B_f = \frac{-2Q\delta}{R(1+4Q^2\delta^2)} \tag{7}$$

$$Q = \frac{\omega_n L}{R}$$

$$\delta = \frac{\omega - \omega_n}{\omega_n} \tag{8}$$

$\omega_n = 2\pi$ *x* nominal resonance frequency

$\omega = 2\pi$ *x* actual frequency

$$\therefore Y_T = (G_a + G_f) + j(B_a + B_f) \tag{9}$$

$$V_n = I_n / Y_T$$

$$\therefore |V_n| = \frac{I_n}{\left[\left\{G_a + \frac{1}{R(1+4Q^2\delta^2)}\right\}^2 + \left\{B_a - \frac{-2Q\delta}{R(1+4Q^2\delta^2)}\right\}^2\right]^{1/2}} \tag{10}$$

Some interesting cases arise from equation 1.10 depending on the a-c system impedance.

The Choice of Capacitor

The capacitor bank is the most costly item in the filter and usually accounts for about 60% of the filter cost, depending on the var rating of the capacitor bank. After making a decision on the amount of vars to be supplied by the filter circuits at fundamental frequency, the total capacitance of the filter bank is calculated as shown below [7].

$$MVAR = 2\pi * f * C * V^2 * 10^{-6}$$

$$C = \frac{MVAR * 10^6}{2\pi * f * V^2} \tag{11}$$

Having fixed the total value of capacitance it may be equally divided in all the branches. Usually the bulk of capacitance is not put as one unit but it is divided into smaller units and these are connected in series-parallel combinations to give the desired capacitance. Below, the method to divide the capacitance in smaller units is given.

Inductor Rating and Design [8]

Having fixed the value of the capacitor in the arm it is easy to calculate the value of reactor required to produce series resonance at that particular harmonic frequency. For resonance at the n^{th} harmonic

$$X_{L(1)} = \frac{X_{C(1)}}{n^2} \tag{12}$$

where,

$X_{L(1)}$ = fundamental reactance of inductor
$X_{C(1)}$ = fundamental reactance of capacitor

$$L_n = \frac{1}{\omega^2 * n^2 * C} \tag{13}$$

and the fundamental kVA rating of the reactor

$$kVA = \omega C E^2 \frac{n^2}{(n^2 - 1)} \tag{14}$$

The main considerations in the design of an inductor are the impulse test voltage and the power loss. The most satisfactory arrangement is to have the impulse test voltage equal to that for the a-c line.

Development of Double tuned low-pass active shunt filter Circuit[9]

Assume that this reactive power is to be supplied by the filter circuits, connected to the primary side.

$$MVAR = 2\pi * E^2 * f * C * 10^{-6}$$

$$\therefore C = \frac{MVAR * 10}{2 * \pi * 275 * 275 * 6.0}$$

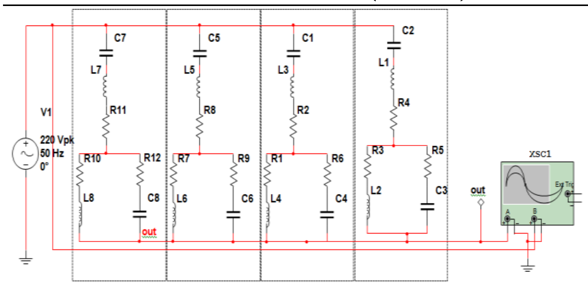

Fig.1: 3.6 A developed section of double tuned low-pass
active shunt filter circuit for simulation [9].

Single tuned arms are provided for the 5th, 7th, 11th and 13th harmonics. The fundamental frequency of a high-pass are nearly that due to its capacitor alone (with remaining components short circuited). But in the case of single-tuned arms, the voltage at the capacitor terminal is somewhat higher than the system voltage. The relationship for individual harmonics is

$$\frac{V_{C1}}{V_{n1}} = 1 + \frac{1}{n^2 - 1} \tag{15}$$

where,

V_{c_1} = fundamental frequency voltage of capacitor

V_{n_1} = fundamental frequency system voltage

n = harmonic number. This gives the following numerical values:

when,

n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

The corresponding values of C, L and R will be computed thus:

$\frac{V_{C1}}{V_{n1}} =$ For various values of *n:*

Therefore using these values, the capacitance of each arm can be reduced accordingly. We now turn our attention to the design of the inductive and resistance components. The following relationship applies for the value of reactance

$$X_{Ln} = \frac{1}{n^2} X_{nC} \tag{16}$$

when,

X_{Ln}= reactance of reactor at fundamental frequency

X_{Cn} = capacitor reactance at the fundamental frequency

n = harmonic number.

$$2\pi f * L_n = \frac{1}{2\pi f_n * C}$$

$$L_n = \frac{1}{\omega_n^2 C} \tag{17}$$

The quality factor of the coil is given by

$$Q = \frac{\omega_n L_n}{R_n} \tag{18}$$

where

$\omega_n = 2\pi *$ normal resonance frequency.

The optimum value of Q as derived as in

$$Q = \frac{1 + Cos\phi_a}{2\delta + Sin\phi_a} \tag{19}$$

where,

Φ_a= system impedance angle *a*

δ = total detuning expected due to all causes.

The presented example of the designed double-tuned filter demonstrates the generic algorithm usefulness as a tool for optimization for filter parameters without the need for unnecessary simplifications that may lead to erroneous solutions. The use of generic algorithm allows maximum filter currents/voltages across the filter components.

Efficient filter performance should give a distortion value of less than 5% at a-c system terminal. The effectiveness of the filters in eliminating a particular harmonic depends largely on the harmonic impedance of the a-c system at that frequency. But at present the harmonic impedance of a-c system cannot be computed or measured accurately and reliably at major harmonics. So usually it is assumed that the a-c system impedance can have any magnitude but a maximum impedance.

Table (1)(a)Power source 3.5 kVA, F (43.804 Hz), before loading [9]

				Magnitude	Phaseangle	
harm	time	(Voltage)	(Voltage)	(Voltage)	before filtering	
no	(sec)	a_{na}, (%)	b_{na}, (%)	C_{na}, %	(rad)	scope_data
1	0	1895130.78	1141118.73	2212164.70	0.541985613	6800000
2	0.01	0.00	0.00	0.00	0	6600000
3	0.02	694397.69	297808.68	755564.80	0.40514685	6600000
4	0.03	0.00	0.00	0.00	0	6600000
5	0.04	446610.57	199096.51	488978.96	0.419351071	6600000
6	0.05	0.00	0.00	0.00	0	6600000
7	0.06	346852.19	154009.83	379506.88	0.417871103	6600000
8	0.07	0.00	0.00	0.00	0	6800000
9	0.08	284898.38	153378.68	323561.59	0.49386479	6600000
10	0.09	0.00	0.00	0.00	0	6600000
11	0.1	264992.47	130502.70	295384.43	0.457611126	6600000
12	0.11	0.00	0.00	0.00	0	6600000
13	0.12	217863.88	126348.67	251850.47	0.525541249	6600000
14	0.13	0.00	0.00	0.00	0	6600000
15	0.14	187247.33	121925.44	223444.34	0.577180776	6600000
16	0.15	0.00	0.00	0.00	0	6600000
17	0.16	130519.73	112058.09	172024.46	0.709438559	6600000
18	0.17	0.00	0.00	0.00	0	6600000
19	0.18	107524.52	98205.78	145622.45	0.740133178	6400000
20	0.19	0.00	0.00	0.00	0	6400000
21	0.2	96619.19	87612.38	130426.98	0.736548553	6400000
22	0.21	0.00	0.00	0.00	0	6400000
23	0.22	91737.95	43560.77	101554.88	0.443317087	6400000
24	0.23	0.00	0.00	0.00	0	6200000
25	0.24	81743.99	38858.77	90510.13	0.443751528	6200000

Table (2) Power source 3.5 kVA, F (43.804 Hz), before filtering

				Magnitude	Phaseangle	
harm	time	(Voltage)	(Voltage)	(Voltage)	after filtering	
no	(sec)	a_{na}	b_{na}	C_{na}, %	(rad)	scope_data
1	0	2598777.76	1150992.83	2842257.97	0.41693202	6800000
2	0.01	0.00	0.00	0.00	0	6600000
3	0.02	828384.15	328301.65	891068.05	0.37732623	6600000
4	0.03	0.00	0.00	0.00	0	6600000
5	0.04	470467.69	264435.49	539690.63	0.51206229	6600000
6	0.05	0.00	0.00	0.00	0	6600000
7	0.06	337176.13	200629.98	392352.04	0.53675722	6600000
8	0.07	0.00	0.00	0.00	0	6800000
9	0.08	257663.57	152281.53	299299.49	0.53378236	6600000
10	0.09	0.00	0.00	0.00	0	6600000
11	0.1	241702.13	145644.95	282192.09	0.54231464	6600000
12	0.11	0.00	0.00	0.00	0	6600000
13	0.12	203652.78	113977.75	233378.20	0.51023482	6600000
14	0.13	0.00	0.00	0.00	0	6600000
15	0.14	156743.89	102925.76	187516.29	0.58103538	6600000
16	0.15	0.00	0.00	0.00	0	6600000
17	0.16	148662.93	61974.19	161063.55	0.39497052	6600000
18	0.17	0.00	0.00	0.00	0	6600000
19	0.18	122543.50	37964.44	128289.55	0.30042667	6400000
20	0.19	0.00	0.00	0.00	0	6400000
21	0.2	116742.87	30693.21	120710.28	0.25709461	6400000
22	0.21	0.00	0.00	0.00	0	6400000
23	0.22	103213.56	30526.67	107633.25	0.28756437	6400000
24	0.23	0.00	0.00	0.00	0	6200000
25	0.24	98394.73	25273.60	101588.77	0.25142399	6200000

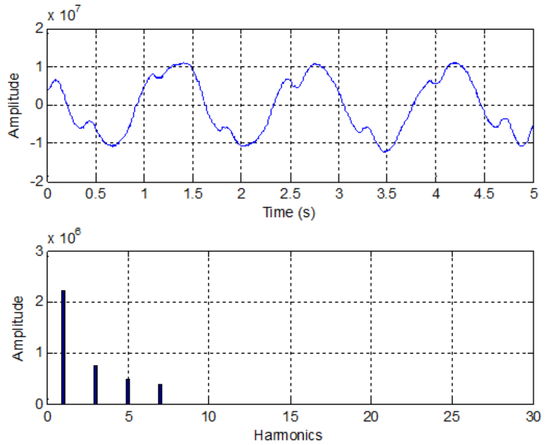

Figure 2: Power source 3.5 kVA, processed waveform and harmonic before loading with a non- linear load.

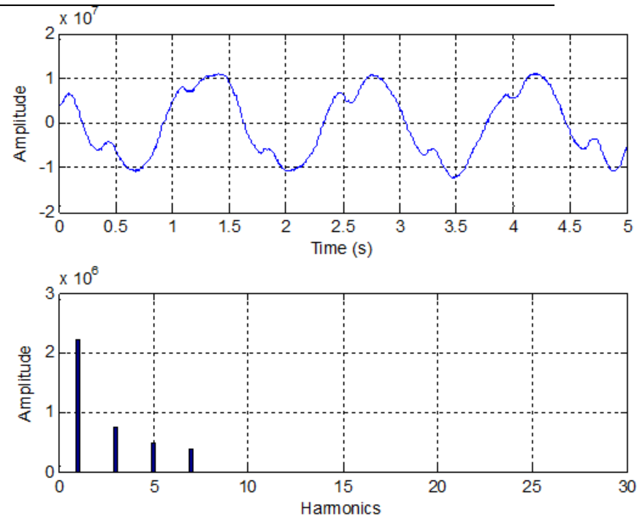

Figure3: Processed waveform and harmonic after filtering with a ofpower source 3.5kVA, waveform without load using the series active power filter harmonic spectrumshowing the fundamental, 3rd, 5th and 7th harmonics.

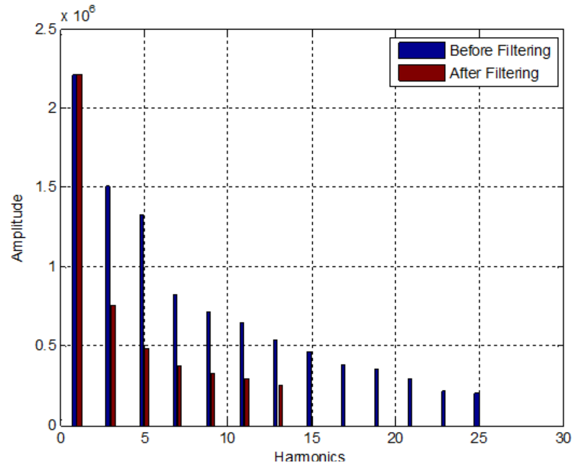

Figure4: Harmonic spectrum of Power source 3.5kVA using series active power filter with passive filter shows the combined effect of the and after filtering showing 1st – 13th harmonics

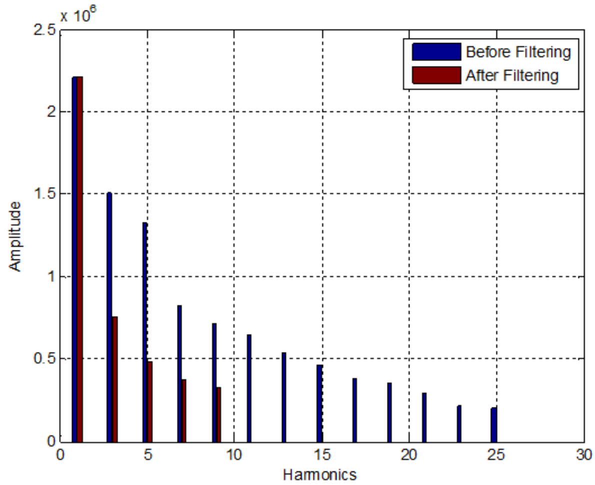

Figure5: Harmonic spectrum of Power source 3.5kVA using double tuned low-passactive shuntfilter shows the combined effect of the and after filtering showing $1^{st} – 9^{th}$ harmonics

III. DISCUSSIONS: Power source 3.5 kVA, F (43.804 Hz)

1. Figure2 shows power source 3.5kVA waveform without load, the harmonic spectrum showing the fundamental frequency up to 7^{th} harmonics, generators are expected to damped out all harmonics, but for the fact that the frequency (43.804 Hz at a rating of 3.5 kVA) at which the measurement was taken it was found out lower than the normal frequency (50 Hz) hence the associated harmonics found out when it was not loaded.

2. Figure3 shows the V_{THD} results before / after simulation using the series shunt active filter 8.04%, 5.24% which is 0.24% higher than the expected IEEE standard of 5% after simulation. The spectrum shows $1^{st} – 7^{th}$ harmonic.

3. Figure 4 shows harmonic spectrum of Power source 3.5kVA using series active power filter with passive filter shows the combined effect of the and after filtering showing 1^{st} – 13^{th} harmonics

4. Figure 5 shows the V_{THD} results before / after simulation using the double tuned low-pass active shunt filter 6.24%, 1.51% which is 3.49% less than the expected IEEE standard of 5% after simulation. The spectrum shows $1^{st} – 9^{th}$ harmonic.

5. The frequency of the power source 3.5kVAis 43.804Hz which less than the actual standard 50Hz of operation, this could be a possible reason for the high harmonic present in this power source.

IV. CONCLUSION

An efficient but simple technique has been developed for improvement of power quality disturbances during faulty conditions using double tuned low-pass active shunt filter circuit for simulation of harmonic in the electrical power system. The proposed model of the system is simulated in the MATLAB/Simulink environment. The results show that double tuned harmonic filter is effective in reducing the magnitude and frequency of voltage spikes significantly.

The presence of a parallel $C_3 – L_3$, $C_4 – L_4$, $C_6 – L_6$and $C_8 – L_8$ circuit will result in circulating harmonic currents, which in the case of the capacitor current can exceed the fundamental current. The magnitude of such circulating currents can be controlled by lowering the Q value that is increasing the resistance or installing a resistor R in the circuit. The effectiveness of the filters in eliminating a particular harmonic depends largely on the harmonic impedance of the nonlinear load used in the system at that frequency.

It may be concluded that more economic and efficient designs for the filters may be obtained by better knowledge of and greater experience in the following:

1. A-C system parameters, especially the network impedance at harmonic frequencies.
2. Reactive power capabilities of the a-c system.
3. Correlation between the calculated distortion values and those experienced in practice, and the determination of acceptable levels.
4. Generators and the distribution system itself can produce harmonics.

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