Providing Differentiated Quality of Service: Who is Causing Harmonics and Who Should Install active Filters

Dr. Nermeen Talaat, Dr. Jovan Ilic and Prof. Marija Ilic
ECE Department
Carnegie Mellon University

March 11,2009

Outline

- Motivation
- Finding the Source of Harmonics by Using Wavelets.
- Propagation of Harmonics in Future Electric Energy Systems.
- Characteristics, and Choosing Locations for Filters to Cancel the Most Sensitive Customers.

Motivation

- Rapid deployment of power-electronically controlled equipment in electric power systems creates major problems with harmonic pollution.
- Need to identify sources of harmonics and their effects.
- Harmonic resonance of particular concern since significant distortion may happen at the unexpected places.
- We introduce a systematic way of identifying possible harmonic resonance, and the relation to the electrical distance and system load.
- Possible to use this analysis results to implement differentiated quality of service.
- Design filters for ensuring differentiated quality of service to meet broad range of customer needs.

Approach

The harmonic power flow problem can be solved by (1).

$$[Y]^h[V]^h=[I]^h \quad (1)$$

Where

$[Y]^h$: The admittance matrix under harmonic order (h).

$[V]^h$: The bus voltage vector .

$[I]^h$: The injection current vector.

We model every components in the system and take into consider the effect of individual harmonics.

Simulation for 5-Bus Network

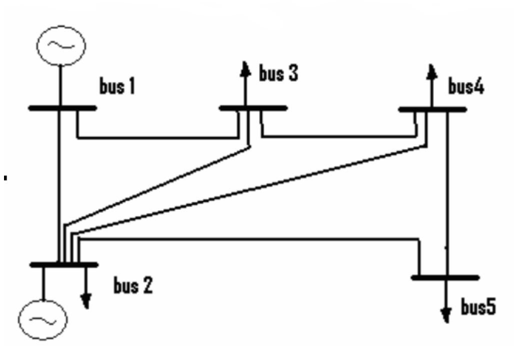


Table 1: Harmonic content in bus voltages using linear flow

V\ h	5th	7th	11th	13th	17th	19th	23rd	25th
Bus 1	0.00007 $\angle 108.12$	0.00005 $\angle 58.543$	0.00001 $\angle -4.728$	0.00000 $\angle -16.52$	0.00000 $\angle -40.39$	0.0000 $\angle -66.91$	0.00000 $\angle 162.95$	0.00000 $\angle 142.81$
Bus 2	0.0057 $\angle 137.75$	0.0030 $\angle 118.91$	0.0015 $\angle 147.36$	0.0016 $\angle 148.11$	0.0020 $\angle 137.44$	0.0026 $\angle 120.68$	0.0022 $\angle 39.513$	0.0012 $\angle 19.029$
Bus 3	0.1675 $\angle 99.19$	0.1235 $\angle 50.809$	0.0304 $\angle -11.68$	0.0188 $\angle -22.73$	0.0126 $\angle -42.19$	0.0134 $\angle -61.16$	0.0098 $\angle -146.1$	0.0056 $\angle -169.1$
Bus 4	0.2107 $\angle 103.58$	0.1540 $\angle 55.324$	0.0360 $\angle -6.193$	0.0213 $\angle -16.89$	0.0123 $\angle -35.55$	0.0116 $\angle -53.89$	0.0060 $\angle -136.2$	0.0026 $\angle -156.2$
Bus 5	0.5213 $\angle 148.76$	0.3302 $\angle 145.76$	0.2307 $\angle 150.37$	0.2217 $\angle 148.30$	0.2621 $\angle 136.65$	0.3293 $\angle 119.83$	0.2795 $\angle 38.675$	0.1512 $\angle 18.173$

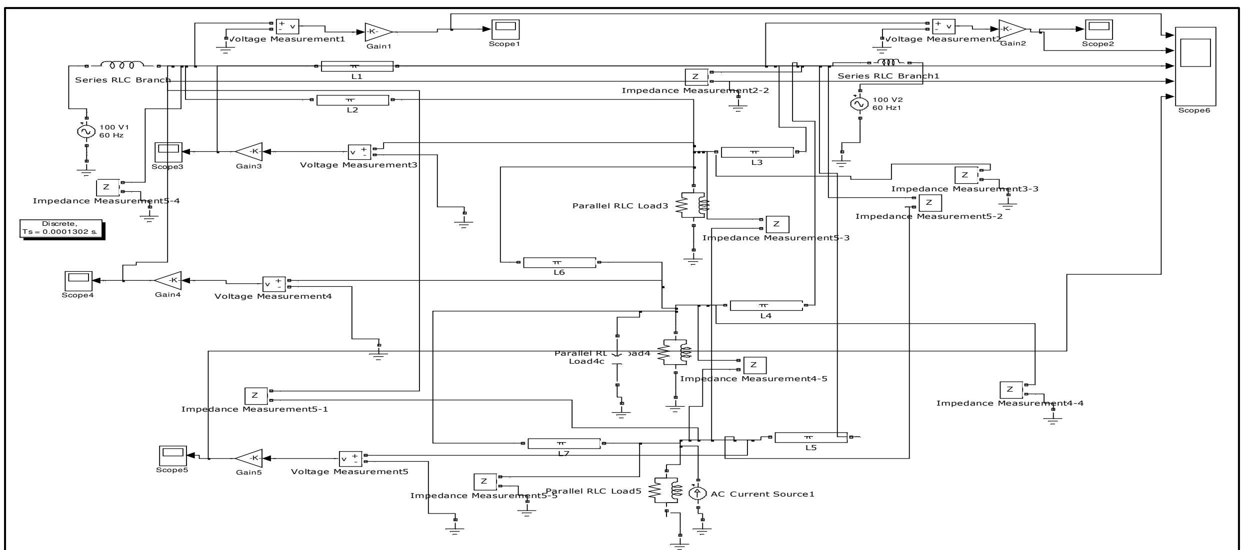
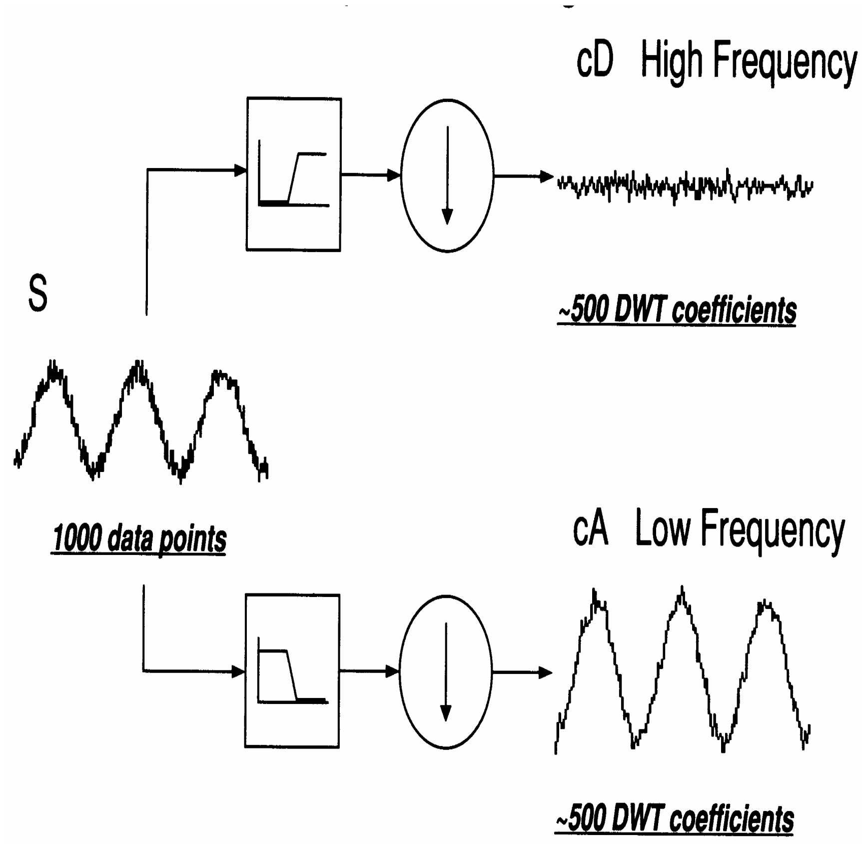


Figure (1) : The Simulation of 5-bus system in MATLAB

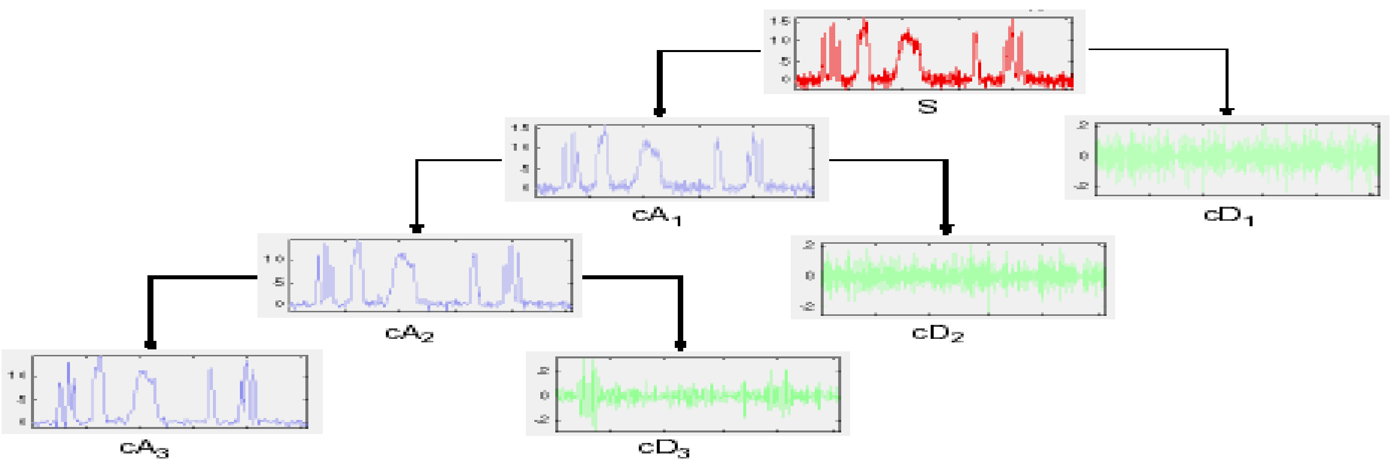
The Discrete Wavelet Transform

- a signal is decomposed into approximations and details.
- The approximations are the high-scale, low-frequency components of the signal.
- The details are the low-scale, high-frequency components of the signal.



Multiple Signal Decomposition (MSD)

- Wavelet decomposes a signal into different scales with multiple levels of resolution by dilating a single mother wavelet.
- Decomposes a signal into its detailed and smoothed versions.



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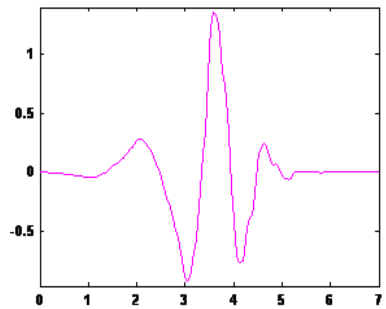
Multiple Signal Decomposition (MSD)



db4 wavelet

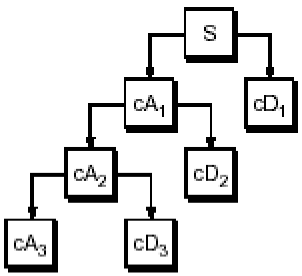


Table (2) Different resolution levels and their frequency bands

Res. Level	Frequency Band Hz	Res. Level	Frequency Band Hz
1	1920-3840	5	120-480
2	960-1920	6	60-120
3	480-960	7	30-120
4	240-480	8	15-30

Determine The Location Of Harmonic Source

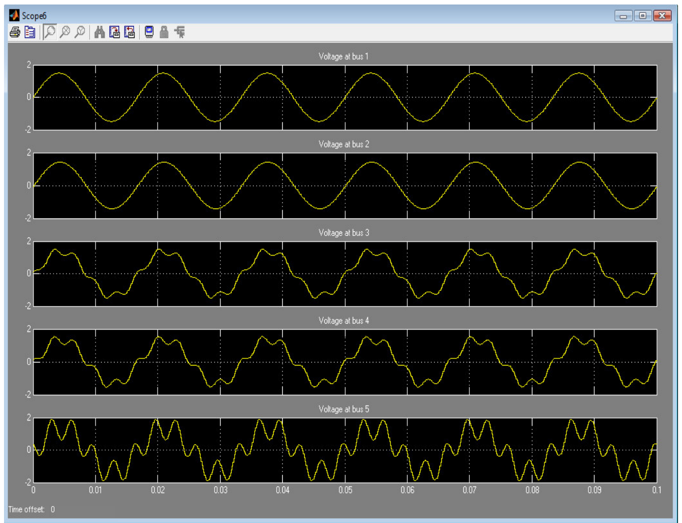


Figure (2): Voltage signals at each bus when harmonic source is connected to bus 5.

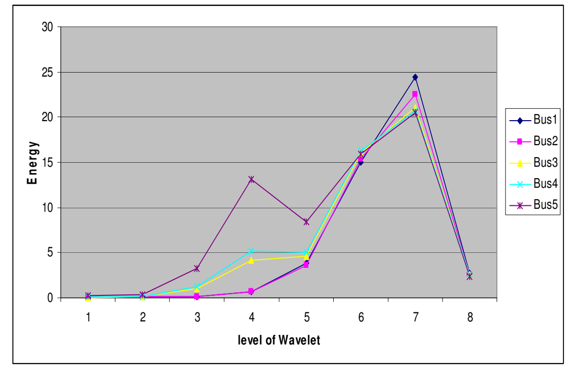


Figure (3): the features of voltage signals when the source of harmonic located at bus 5 with 5th order of harmonic.

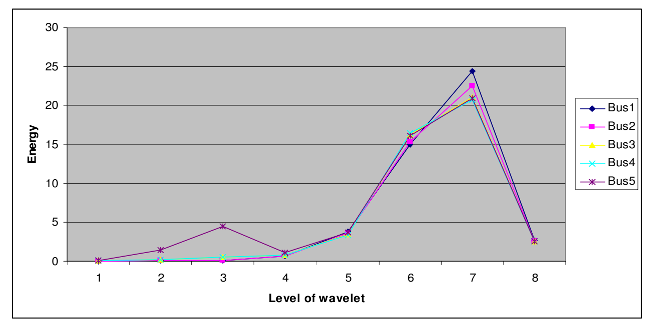


Figure (4): the features of voltage signals when the source of harmonic located at bus 5 with 11th order of harmonic.

IEEE 14 bus system

IEEE 14 bus system is used to study the propagation of the harmonic in the system, there are three positions of harmonic source at bus 3 ,bus 6 and bus 8, in each case we study the resonance and the harmonic propagation under different conditions.

The harmonic source is Static Var Compensator (SVC), So the harmonic current is calculated for different harmonic order, we obtained the value of that current from the table (3).

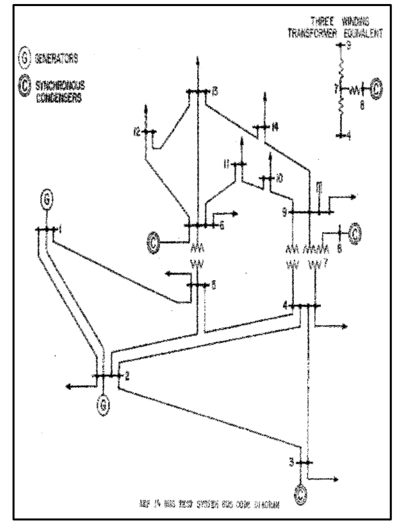


Table (3) : Maximum amplitudes of harmonic current in SVC

Harmonic order	% of Fundamental	Harmonic order	% of Fundamental
5	5.05	17	0.44
7	2.59	19	0.35
11	1.05	23	0.24
13	0.75	25	0.2

Case I

- The harmonic source (non-linear load) is connected to the bus no. 3, the percentage of the harmonic voltage to rated voltage is shown in figure (5).
- the highest voltage distortion is at third harmonic order and the propagation of that is indicate in figure (6).

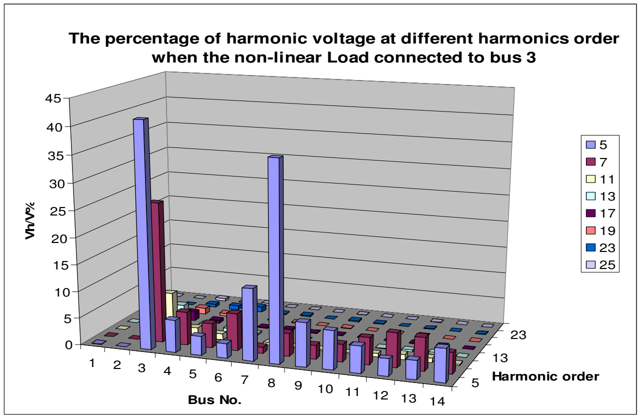


Figure (5): The percentage of harmonic voltage to normal voltage in case I.

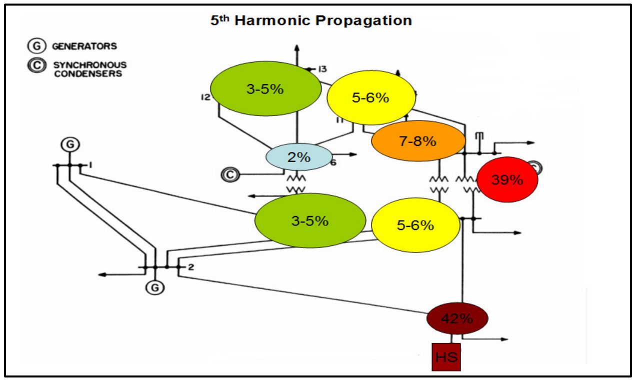


Figure (6): 5^{th} Harmonic propagation in case I.

Case II

- In this case we change the place of harmonic source and connect it to bus no. 6.
- The figure (7) illustrated the magnitude of harmonic voltage under different order of harmonic.
- The highest harmonic voltage is located not at the bus no.6 which is direct connect to the source but at remote bus no 8.

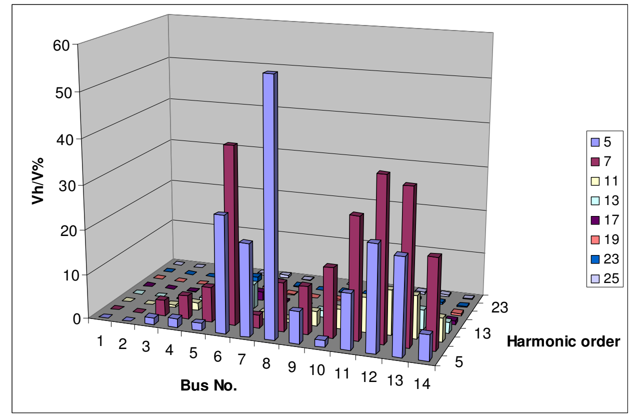


Figure (7): The percentage of harmonic voltage to normal voltage in case II.

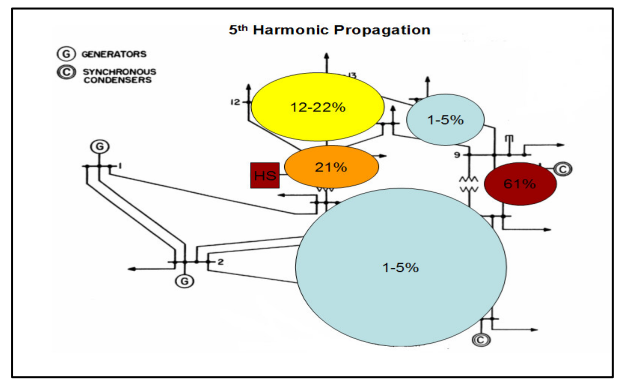


Figure (8): 5th Harmonic propagation in case II.

Case III

➢Also connect the non-linear load to bus no.8 and calculate the harmonic propagation in the system.

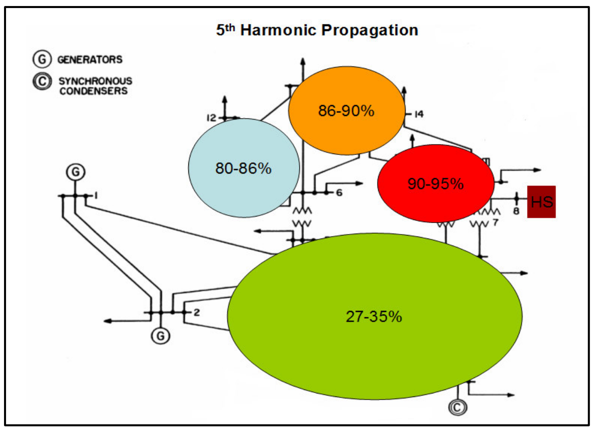


Figure (9): 5th Harmonic propagation in case II.

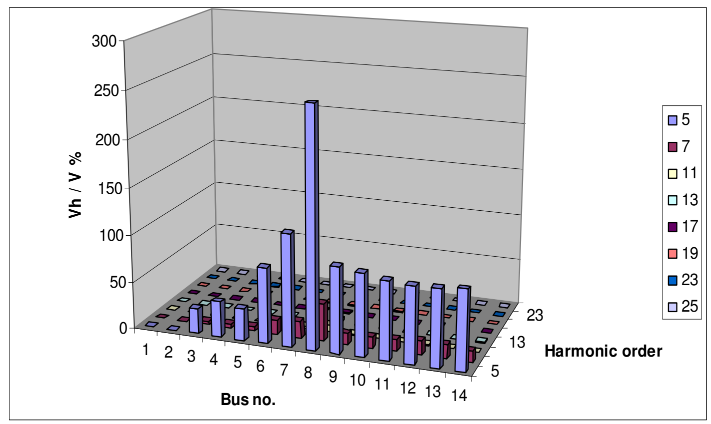


Figure (10): The percentage of harmonic voltage to normal voltage in case II.

Electrical distance

Calculate the electrical distance by calculating the transfer impedance between that bus (j) and others buses for each harmonic order, figures (11) indicates the Z between the bus3 and all other buses in the system to understand the behavior of harmonic propagation when the non-linear load connected to bus 3.

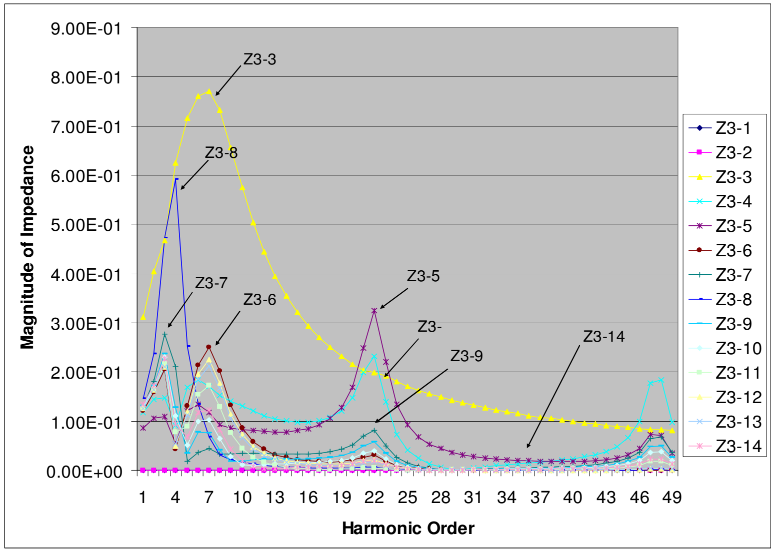


Figure (11): The magnitude of the impedance of bus no.3 and all buses.

Electrical distance

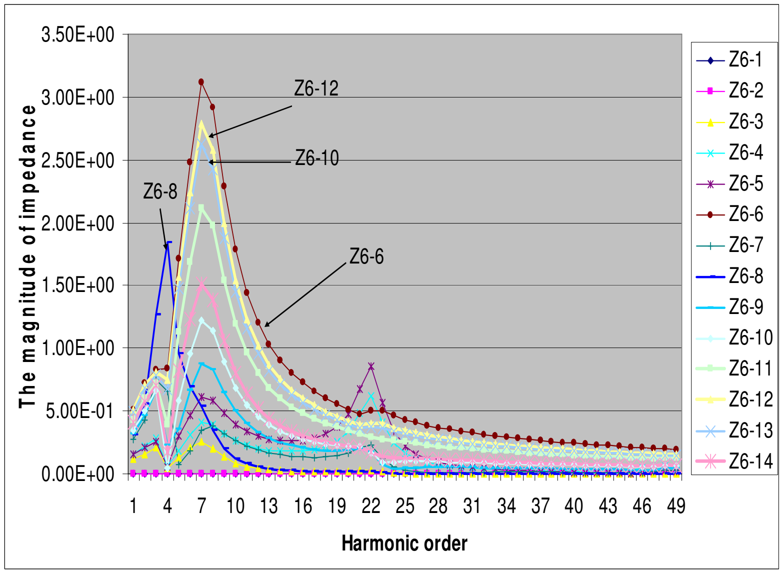


Figure (12): The magnitude of the impedance of bus no.6 and all buses.

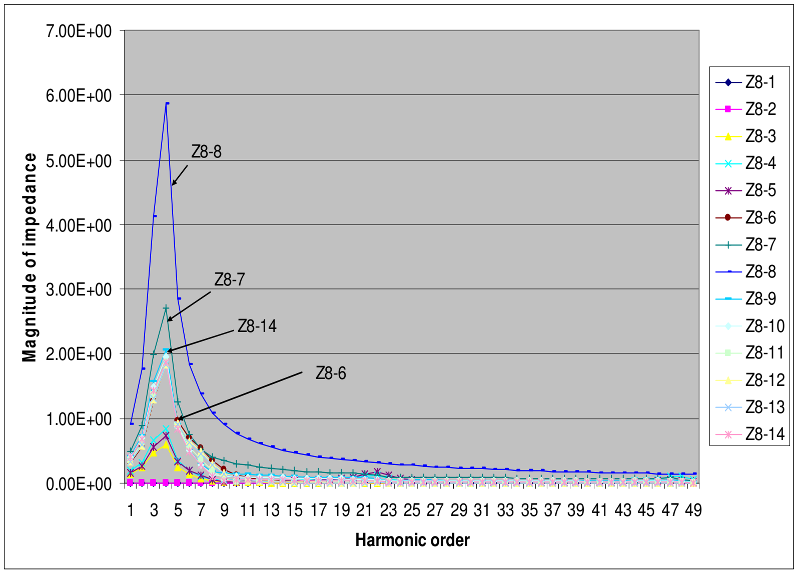


Figure (13): The magnitude of the impedance of bus no.8 and all buses.

Who should install the filter ?

The decision table illustrates the qualitative analysis for who should install filter?.

	Sensitive Load	Not Sensitive Load	Local harmonic response	remote harmonic response	Filter installation
First scenario	No	No	Yes	No	No
Second scenario	Yes	No	Yes	No	Yes
Third scenario	No	Yes	No	Yes	Yes
Fourth scenario	Yes	Yes	No	Yes	Yes

Design active filters

To find the best placement of the harmonic active filters to be installed in a distribution system with their minimum power size. The objective is to minimize the power size in view of maximum savings in the equipment cost.

Problem formulation

$$V^h = Z^h * (I^h + I_f)$$

Where :

If is the vectors of the filtering current.

Zh is the harmonic impedance matrix.

The approach is to minimize the total filtering power so that can be achieved by minimize the total current *If* .

$$\min \left[I_f \right] = \min \left[\sum_{m=1}^{K} I_f \right]$$

Where:

K= the total number of buses that filters are connected.

The constraint is all harmonic voltage in every bus is minimum than certain limit.

$$V_{h_k} \leq V_{\lim}$$

Conclusions

- Wavelet technique can determine the source of harmonics and also the harmonic order in any polluted signals.
- Impedance versus frequency for each bus of the system is useful feature in a modeling system, a self impedance plot gives a quick visual indication of the natural frequencies at a specific bus.
- A peak in the impedance plot indicates a parallel resonant frequency.
- The effect of a parallel resonance is to amplify one or more current harmonics if they fall at or near a natural frequency of the system.
- Design active filter with optimal place improves the power quality of the distribution system.

THANKS

Questions?