DAMPING TECHNIQUES OF HARMONIC RESONANCES IN POWER DISTRIBUTION SYSTEMS

M. R. GHALLAB
Upper Egypt Electricity Distribution Company-Aswan-Egypt
(mraghallab@yahoo.com)

ABSTRACT

Harmonic resonances may damage equipments and interrupt electric power customers services. Shutdowns may affect seriously harmonic resonant frequencies and may initiate new resonances in distribution power systems. This paper proposes various techniques for damping harmonic resonances in power systems[1-4]. A series reactor should be connected in series with the shunt power factor correction capacitor, damping resistance across inductor terminals of LC passive filter, increasing the short circuit system power, derating the harmonic generating equipment, and by using hybrid active filters. The hybrid active filters consists of active filter connected in shunt with passive filter. The active filter is characterized by detecting the harmonic current flowing into the passive filter. It is controlled in such a way as to behave as resistor by adjusting certain gain. It is proved that this significantly improves damping of the harmonic resonances, compared with the passive filter when used alone[5-7].

INTRODUCTION

Resonance phenomenon in power systems, including power oscillations, may cause several problems such as voltage distortion, fluctuation and harmonic currents with subsequent instability in the system malfunction of or even damage to electrical equipment and plants.

The resonances can be stimulated not only by fault events and switching transformers, reactors or capacitor banks, but also by operating non-linear loads or power electronic devices, i.e.

- Static VAR compensation ,
- HVDC installations with AC filters,
- Arc furnaces with VAR compensators,
- Uninterruptable power supplies.

Resonances also exist on series-compensated transmission lines, and especially on systems with power factor correction capacitors.

Oscillation due to harmonic generation are nominally eliminated by passive LC filters. Tuned filters and high pass or damped shunt filters offer low impedance for harmonics, limiting harmonic voltages transferred to the network. However, these filters together with the supply impedance cause resonances at other frequencies and therefore, have to be designed carefully. In some cases, resistors are inserted in shunt with the reactor of the filters to damp these resonances. Increasing losses have to be accepted, of course. Another solution is the application of sharply tuned filters which have to achieve constant filter characteristics[5-7].

The efficiency of passive filters depends on the system impedance seen from the point where they are installed. Consequently, passive filter may become expensive depending upon the system impedance and on the required attenuation.

Therefore, severe requirements can lead to the necessity of several filters tuned to different frequencies. Furthermore, filter characteristics have to be matched to changed system conditions to achieve a constant filter performance.

These limitations of passive filters led to the development of a new concept using active filter for damping of resonances together with the other mentioned methods.

2. DAMPING OF HARMONIC RESONANCES:

Harmonic resonances can be damped by either of the following techniques.

2.1 By Using Reactors in Series With The Shunt Power Factor Correction Capacitors:

In order to limit towards the top the variation range of the anti-resonance frequency, a series reactor of inductance (L) should be connected in series with the shunt power factor correction capacitor as shows fig. 1.

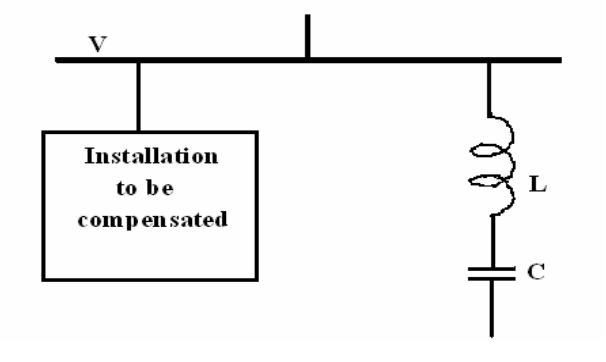

Fig. 1: Shunt capacitor with series reactor to avoid damaging anti-resonances of harmonic sources.

In such a case, there will be a tuning frequency (f_a) of the capacitor (C) with the added series reactor (L), defined by:

$$f_a = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

In order to avoid damaging effects of the coincidence of the anti-resonance frequency (f_{ar}) with the converter chrematistic frequency, f_{ar} should be adjusted so as to be less than the tuning frequency f_a, for all possible expected network elements variations, as shown in fig.2

Therefore that condition can written as:

$$f_{ar} < f_a \tag{2}$$

This condition is fulfilled by taking (f_{ar}) as inferior to the first characteristic harmonic current generated by the converter. Then the anti-resonance frequency will not be able to coincide with a characteristic harmonic current of the converter.

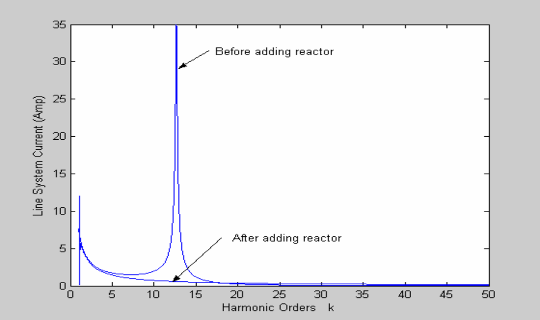

Fig. 2: Damping anti-resonance by adding series reactor with shunt capacitor.

Harmonic resonance is recorded at the 13th order, without the series inductor L. Upon connecting L, the resonance state disappears and no resonance exists. For all frequencies the resonance is damped upon using this 'L'.

2.2 By Using Shunt Resistor With The Reactor of The LC Passive Filter:

When a damped filter is connected to the bus containing a harmonic source in order to prevent its harmonic from penetration to the network as shown in fig.3. The resonance and anti-resonance frequencies are identical to those of the resonant type (or the single tuned) filters. However, the damping resistance has the effect of:

- Reducing the anti-resonance: $|Z(\omega_{ar})| << \infty$.

- Making the filter less effective at the tuning range:

$$|Z(\omega_a)| \neq 0 \text{ (in case of a filter).}$$

- Widening the impedance curve of the damped filter, thus filtering the high frequencies.

The variation of line system current with harmonic orders as shown in fig. 4.

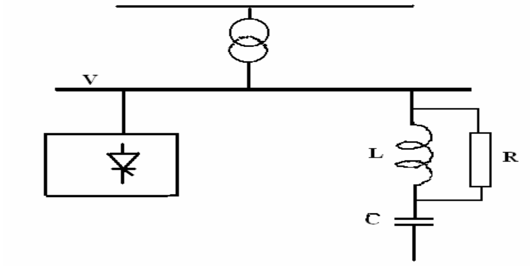

Fig.3: AC network with harmonic source and damped filter .

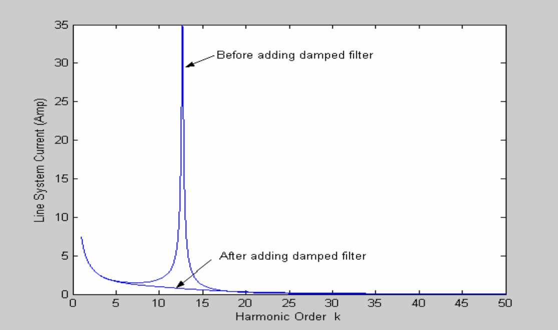

Fig. 4: Damping anti-resonance by adding damped filter.

Harmonic resonance is recorded at the 13th order, without the shunt resistor R. Upon connecting R, the resonance state disappears and no resonance exists. For all frequencies the resonance is damped upon using this 'R'.

2.3 By Increasing The Nodes Short Circuit Levels:

The studied system shown in fig. 5 consists of a network feeding a static load (R_L+JX_L) through a transmission line. The equivalent system impedance including the line is (R_S+JX_S).

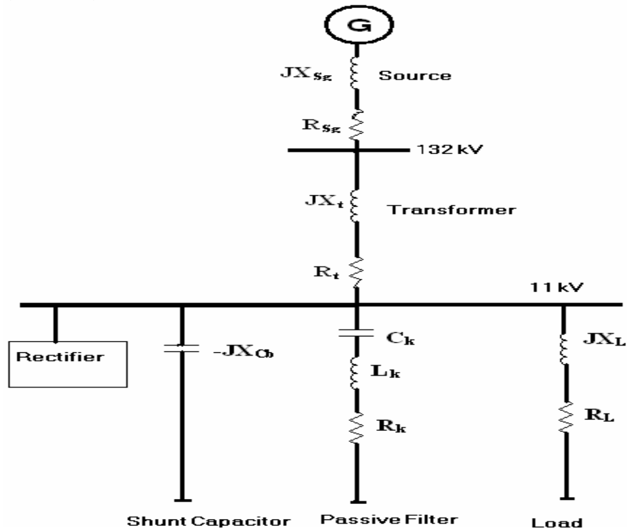

Fig. 5: Studied system configuration.

The step down transformer impedance is (R_t+JX_t). The static load power factor is corrected by shunt capacitor of reactance ($-JX_{Cb}$) and passive filters of impedance (R_k + $J(X_{lk} - X_{ck})$) are connected on a common bus. A rectifier load at the point of common connection (PCC) is connected and will be the harmonic source, which generates harmonic order (k).

The power system may cause harmonic propagation as a result of series and/or parallel resonances between the power capacitors and the leakage inductor of the distribution transformer.

Using system data given in table 1 , a voltage resonance occurs with k=13. There are two possible current resonances (k_{ar1} and k_{ar2}) , the first at frequency less than 650 HZ ,the other at higher frequency as shown in fig. 6.

Table 1: Circuit Constants

13th tuned passive filter	C_k= 0.083μF, L_k=0.72 H R_k = 72 Ω
System impedance	R_S= 2.27 Ω, X_S=12.1 Ω
Load impedance	R_L= 180 Ω, X_L= 94.25 Ω
Shunt capacitor	C_b= 1.75μF
Base: 3-ph, 800kVA. 11kV, 50 Hz	

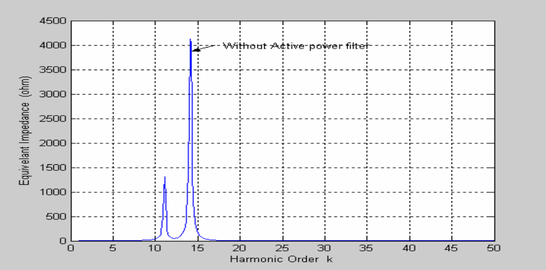

Fig. 6: Equivalent impedance versus harmonic orders for 13th single tuned harmonic filter and shunt capacitor

Fig 7 and table 2 shows the anti-resonance orders and anti-resonance impedance, upon increased and their amplitudes are decreases with increasing the short circuit system nodes level.

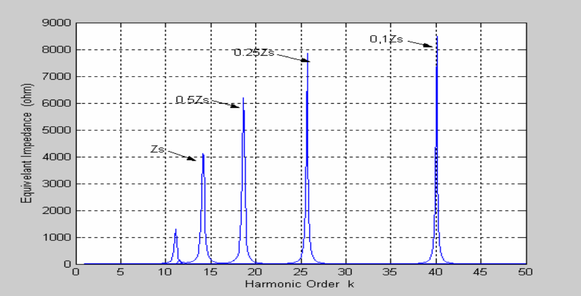

Fig. 7: Equivalent impedance verses harmonic orders for 13th single tuned harmonic filter and shunt capacitors (at various values of system impedance)

Table 2: Anti-resonance orders at different values of system impedance

System Impedance	Anti-resonance orders		Anti-resonance impedance (ohm)
	k_{ar1}	k_{ar2}	
Z_S	11	14	1410, 3730
0.5 Z_S	12	18	180, 5520
0.25 Z_S	-	25	7400
0.1 Z_S	-	39	8670

2.4 By Derating The Harmonic Generating Equipment:

Fig. 8 and table 3 shows the varying of load impedance with harmonic orders and anti-resonance orders occurred.

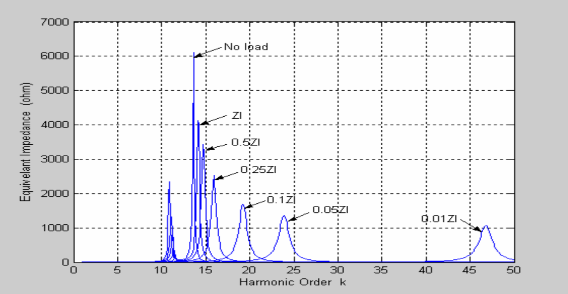

Fig. 8: Equivalent impedance versus harmonic orders for 13th single tuned harmonic filter and shunt capacitors (at various values of load impedance)

Table 3: Anti-resonance orders at different conditions of loading

Load impedance	Anti-resonance orders		Anti-resonance impedance (ohm)
	k_{ar1}	k_{ar2}	
Z_L	11	14	1410, 3730
0.5 Z_L	12	15	860, 3350
0.25 Z_L	12	16	410, 2400
0.1 Z_L	12	19	120, 1600
No load	11	13	2715, 4780

2.5 By Using Hybrid Active Filter:

Active power filters can be used with passive filters improving compensation characteristics of the passive filter, and avoiding the possibility of the generation of series or parallel resonance The combination of passive and active power filters is by connecting the active filter in shunt with the passive one, as shown in fig. 9.

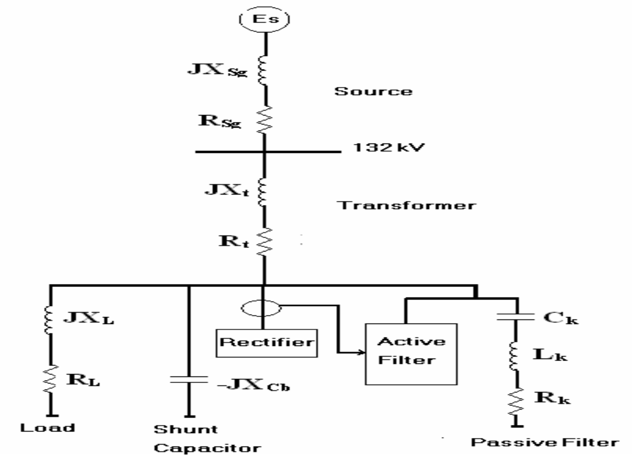

Fig. 9: Single phase circuit diagram of a typical distribution power system with active damping.

2.5.1. Results and Discussion:

Fig. 10 shows the anti-resonant orders when studied system is connected with static load, shunt capacitor and hybrid filter.

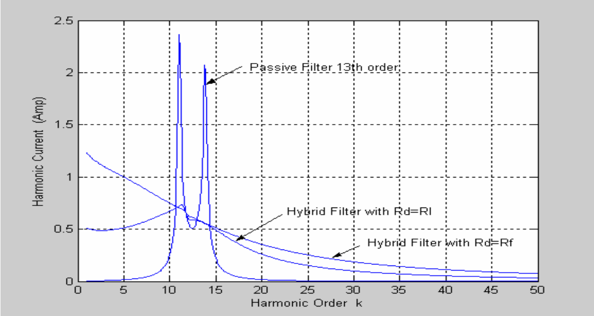

Fig. 10: : Harmonic current versus harmonic orders for 13th passive filter and hybrid active filter.

Table 4: Comparative between system without filtering, with passive filter and with hybrid filter

System	Anti-resonance orders		Anti-resonance current (Amp)
	k_{ar1}	k_{ar2}	
System with static load and shunt capacitors	13	-	34
System with static load, shunt capacitors and 13th passive filter	11	14	2.4, 2.05
System with static load, shunt capacitors and hybrid filter	-	-	-

Table 4 shows a comparative results between system without filtering, with passive filter and with hybrid filter. It is shown that using the hybrid proposed filter eliminates totally the harmonic resonances.

3. CONCLUSION:

This paper has proposed several techniques for damping harmonic resonances in distribution power systems. The theoretical analysis developed in this paper have verified the viability and cost-effectiveness of those methods. This paper has led to the following conclusions.

(1) Harmonic resonance can be damped by series reactors with the shunt power factor correction capacitors or by shunt resistors with the inductor of the LC single tuned filters or by increasing the nodes short-circuit level or by derating generators or by using the hybrid active filters.

(2) It is proved that all those methods are effective in harmonic resonance damping, however the generator rating slightly effect resonance damping..

(3) The hybrid filter can reduce the 13th harmonic voltage appearing on the common bus resulting from the passive filter when used alone.

(4) Moreover, the active filter acting as a pure resistor at the 13th harmonic frequency which prevents the passive filter from over current.

(5) The hybrid filter eliminates totally the harmonic resonances when $R_d=R_k$.

4. REFERENCES:

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