SUGGESTED HYBRID ACTIVE POWER FILTER FOR DAMPING HARMONIC RESONANCE IN POWER DISTRIBUTION SYSTEMS

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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 a hybrid active power filter for damping harmonic resonances in distribution power systems. The hybrid filter 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. Moreover, the active filter acts as a positive resistor to prevent an excessive harmonic current from flowing into the passive filter.

1. INTRODUCTION:

Non linear loads such as diode or thyristor rectifiers and cycloconverters draw non-sinusoidal currents from utility grids, thus contributing to degradation of power quality in distribution or industrial power systems. Notably, voltage distortion or voltage harmonics in power systems are becoming so serious that 5^{th} and 7^{th} harmonic voltages are barely acceptable at the customer-utility point of common coupling .

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 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.

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 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.[1-5]

2. HARMONIC RESONANCES:

The studied system shown in fig. 1 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). 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_f + J(X_{lf} - X_{cf})) 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).

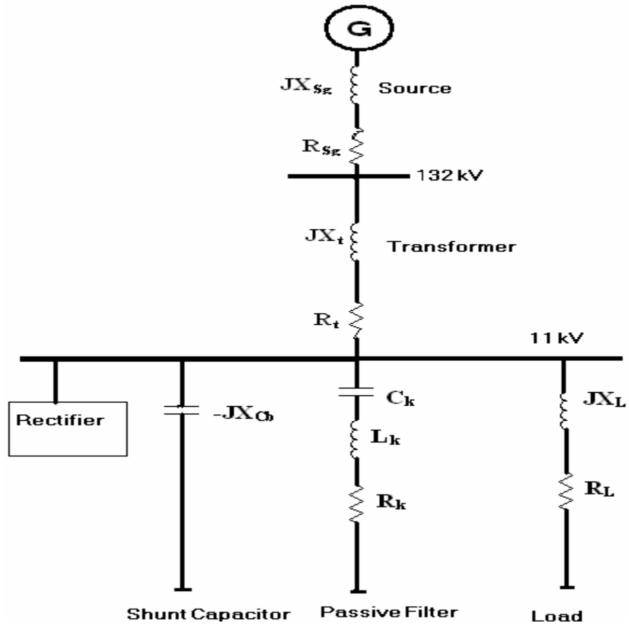

Fig. 1: Studied system configuration.

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.

The equivalent diagram of the RLC filter, the AC network, the power factor correction capacitor, passive tuned filter and the harmonic source is shown in fig. 2.

The equivalent harmonic impedances are given in fig. 2. For each harmonic order (k), we can write the following equations:

$$Z_S = R_S + jkX_S = (R_t + JkX_t) + (R_{sg} + JkX_{sg})$$
$$Y_{eqk} = \frac{1}{R_S + jkX_S} + \frac{jk}{X_{Cb}} + \frac{1}{R_k + j(kX_{Lk} - X_{Ck}/k)} + \frac{1}{R_L + jkX_L} \quad (1)$$

$$Y_{eqk}=\frac{R_S-jkX_S}{R_S^2+k^2X_S^2}+\frac{jk}{X_{Cb}}+\frac{R_k-j(kX_{Lk}-X_{Ck}/k)}{R_k^2+(kX_{Lk}-X_{Ck}/k)^2}+\frac{R_L-jkX_L}{R_L^2+k^2X_L^2} \qquad (2)$$

The anti-resonance harmonic orders (k_{ar}) are get by equating the imaginary part of eq. (2) to zero. This yields:

$$\frac{kX_S}{R_S^2+k^2X_S^2}+\frac{k}{X_{Cb}}-\frac{(kX_{Lk}-X_{Ck}/k)}{R_k^2+(kX_{Lk}-X_{Ck}/k)^2}+\frac{kX_L}{R_L^2+k^2X_L^2}=0 \qquad (3)$$

The anti-resonance harmonic order can be obtained after solving eq. (3), it can be expressed in the following form:

$$\begin{aligned}
&k^8\left(X_S^2X_L^2X_{Lk}^2\right)+\\
&k^6\begin{pmatrix} R_S^2X_L^2X_{Lk}^2-X_SX_{Cb}X_L^2X_{Lk}^2+X_S^2R_L^2X_{Lk}^2\\ +X_S^2X_L^2R_k^2-2X_S^2X_L^2X_{Lk}X_{Ck}-\\ X_LX_{Cb}X_S^2X_{Lk}^2-X_{Lk}X_{Cb}X_S^2X_L^2\end{pmatrix}+\\
&k^4\begin{pmatrix} 2X_SX_{Cb}X_L^2X_{Lk}X_{Ck}-X_SX_{Cb}R_L^2X_{Lk}^2-\\ X_SX_L^2X_{Cb}R_k^2+R_S^2R_L^2X_{Lk}^2+X_L^2R_S^2R_k^2-\\ 2R_S^2X_L^2X_{Lk}X_{Ck}+X_S^2R_L^2R_k^2-\\ 2X_S^2R_L^2X_{Lk}X_{Ck}+X_S^2X_L^2X_{Ck}^2-\\ X_LX_{Cb}R_S^2X_{Lk}^2-X_S^2X_LX_{Cb}R_k^2+\\ 2X_LX_{Cb}X_S^2X_{Lk}X_{Ck}-X_{Lk}X_{Cb}X_L^2R_S^2-\\ X_{Lk}X_{Cb}X_S^2R_L^2+X_{Cb}X_{Ck}X_S^2X_L^2\end{pmatrix}+\\
&k^2\begin{pmatrix} 2R_L^2X_SX_{Cb}X_{Lk}X_{Ck}-X_SX_{Cb}X_L^2X_{Ck}^2-\\ X_SX_{Cb}R_L^2R_k^2-R_S^2R_L^2R_k^2-2R_S^2R_L^2X_{Lk}X_{Ck}+\\ R_S^2X_L^2X_{Ck}^2+X_S^2R_L^2X_{Ck}^2-X_LR_S^2R_k^2X_{Cb}+\\ 2X_LX_{Lk}X_{Cb}X_{Ck}R_S^2-X_LX_{Cb}X_S^2X_{Ck}^2-\\ X_{Lk}X_{Cb}R_S^2R_L^2+X_{Ck}R_S^2X_{Cb}X_L^2+\\ X_{Ck}X_{Cb}X_S^2R_L^2\end{pmatrix}+\\
&+\begin{pmatrix}-X_SX_{Cb}R_L^2X_{Ck}^2+R_S^2R_L^2X_{Ck}^2-\\ X_LX_{Cb}X_{Ck}^2R_S^2+R_S^2R_L^2X_{Ck}X_{Cb}\end{pmatrix}=0
\end{aligned} \qquad (4)$$

Then, solving equation (4), gets the anti-resonant harmonic orders '$k=k_{ar}$'.

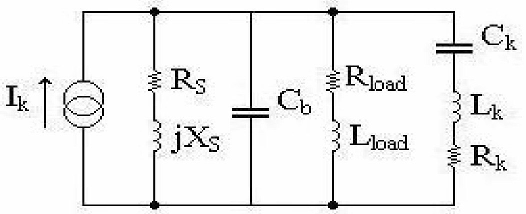

Fig. 2: Equivalent single line diagram of RLC filter, static nonlinear load, shunt capacitor C_b and harmonic source

The total susceptance with frequency at neglecting the resistances R_S , R_L and R_k is determined by using the following relations, for k^{th} order harmonic:

$$B_k=-\frac{k_{ar}^2\,k}{k^2-k_{ar}^2}\omega C_k-\frac{1}{k\omega L_{esc}}+k\omega C_b \qquad (5)$$

After some manual calculations ,we obtain :

$$B_k=\frac{\omega^2C_bL_{esc}k^4-[k_{ar}^2\omega^2L_{esc}(C_5+C_b)+1]k^2+k_{ar}^2}{k\omega L_{esc}(k^2-k_{ar}^2)} \qquad (6)$$

Therefore, there will be a current resonance when:

$$\omega^2C_bL_{esc}k^4-\left[k_{ar}^2\omega^2L_{esc}(C_k+C_b)+1\right]k^2+k_{ar}^2=0 \qquad (7)$$

Table I summarizes the circuit constants in fig. 2.

Using system data given in table 1 and with eq. (7), 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. 3.

Table 1: Circuit Constants

13^{th} 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	

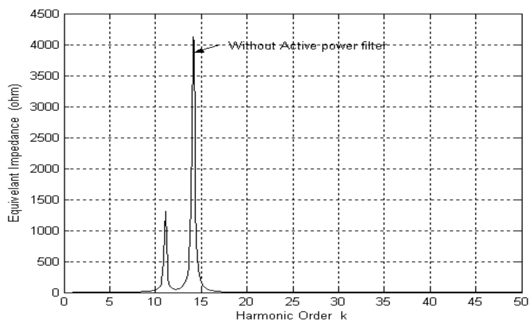

Fig. 3: Equivalent impedance verses harmonic orders for 13^{th} single tuned harmonic filter and shunt capacitor

3. HARMONIC RESONANCES DAMPING:

The methods for damping harmonic resonance are:

(a) Increase The Short Circuit System Power:

This shown in fig 4 and table 2 shows the anti-resonance orders and anti-resonance impedance, to be increased and their amplitudes are decreases.

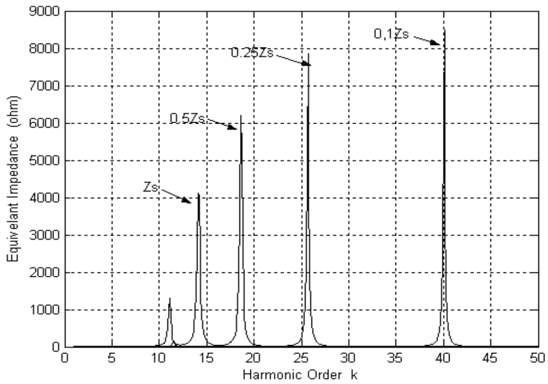

Fig. 4: Equivalent impedance verses harmonic orders for 13^{th} single tuned harmonic filter and shunt capacitors (at various values of system impedance)

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

(b) Derating The Harmonic Generating Equipment:

Fig. 5 and table 3 shows the varying of load impedance with harmonic orders and anti-resonance orders occurred.

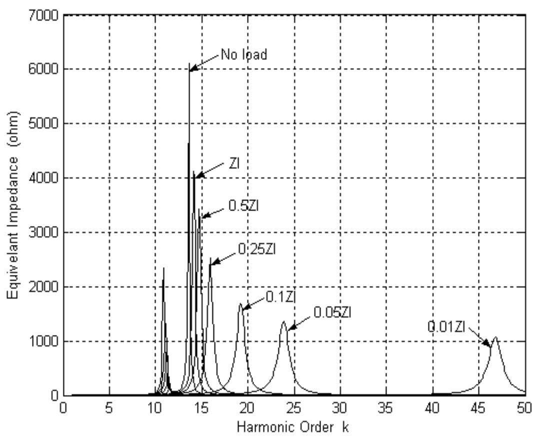

Fig. 5: Equivalent impedance verses harmonic orders for 13^{th} single tuned harmonic filter and shunt capacitors (at various values of load impedance)

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

Load impedance	Anti-resonance orders		Anti-resonance impedance
	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

Slight variations are noticed in the anti-resonant frequencies.

(C) Using Suggested Hybrid Active Filter:

This is the suggestion of this paper.

(C-1) Hybrid Active Filter Configuration:

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. 6.

The characteristics of this hybrid active power filter gives the advantages of passive and active filtering solutions and covers a wide range of power and performance. It can perform the following:

- Filtering on a wide frequency band (damping of harmonic resonance and eliminating harmonics),
- Compensation of reactive power,
- Large capacity for current filtering,
- Good technical-economic solution for "network"

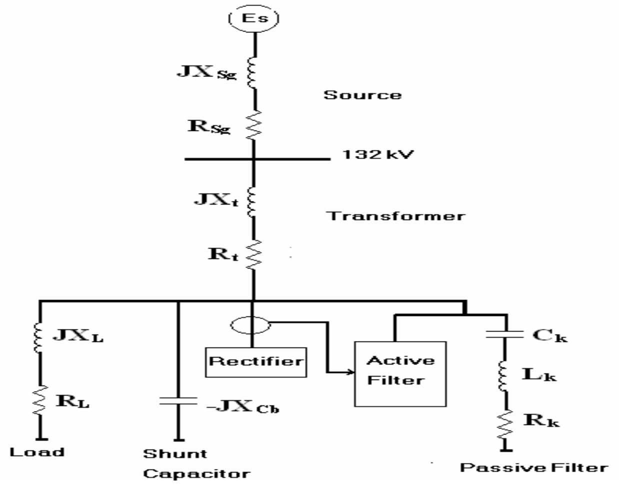

Fig. 6: Single phase circuit diagram of a typical distribution power system with active damping.

(C-2) Operation Principle of Hybrid Active Filter:

Fig. 7 present a scheme of an hybrid active filter for damping harmonic resonance, the active filter acts as a pure resistor of R_d (Ω) for the k^{th} harmonic voltage and current.

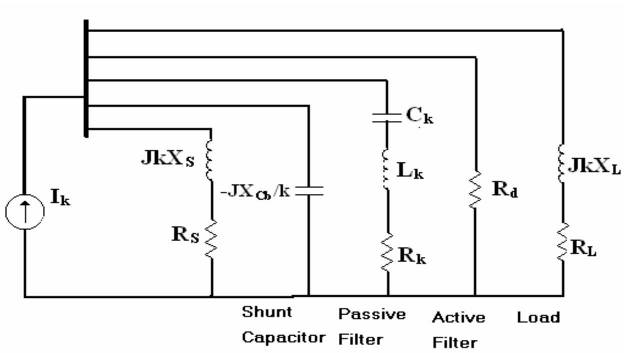

Fig. 7: Hybrid active damping network.

The impedance of the hybrid filter at the kth harmonic frequency, Z_k is given by:

$$Z_{HFk} = \frac{(R_k + J(kX_{Lk} - X_{Ck}/k)(R_d)}{(R_k + R_d) + J(kX_{Lk} - X_{Ck}/k)} \tag{8}$$

The harmonic current present in the supply current, are given by:

$$I_{HFk} = \frac{I_k(Z_{eq2})}{Z_{eq3}} \tag{9}$$

Where:

$$Z_{eq2} = \frac{Z_S \times Z_L \times Z_{Cb}}{Z_L + Z_{Cb}} \tag{10}$$

$$Z_{eq3} = Z_{eq2} + Z_{HFk} Z_S + \frac{Z_{HFk} \times Z_{Cb} \times Z_L}{Z_L + Z_{Cb}} \tag{11}$$

$$I_k = I_1 / k \tag{12}$$

Where:

R_d : Active filter gain in ohm, which equal to the passive filter resistance R_k. Z_{HFk} : Hybrid active filter impedance. k : Harmonic order. I_1: Fundamental current in amperes. I_k : Harmonic current at order k.

Assuming that R_d=R_k yields . Harmonic phase voltage at common busbars is : $V_{HFk} = I_{kFh} \times Z_{hk}$ (13)

4. RESULTS AND DISCUSSION:

Fig. 8 shows the anti-resonant orders when studied system is connected with nonlinear load, shunt capacitor and hybrid filter.

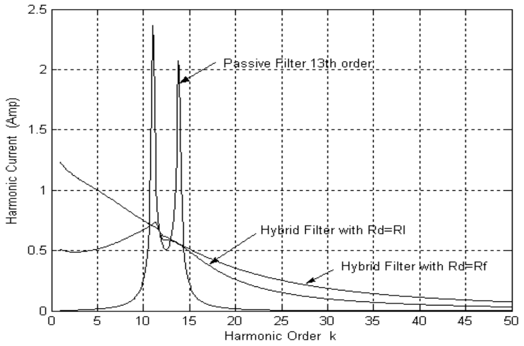

Fig. 8: **:** Harmonic current versus harmonic orders for 13th passive filter and hybrid active filter.

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

System	Anti-resonance orders		Anti-resonance current
	k_{ar1}	k_{ar2}	
System with static nonlinear load and shunt capacitors	13	-	34
System with static nonlinear load, shunt capacitors and 13th passive filter	11	14	2.4, 2.05
System with static nonlinear 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 shows that using the hybrid proposed filter eliminates totally the harmonic resonances.

5. CONCLUSION:

This paper has proposed a hybrid active filter intended for damping harmonic resonances in distribution power systems. The theoretical analysis developed in this paper have verified the viability and cost-effectiveness in the hybrid filter. This paper has led to the following conclusions.

(1) The hybrid filter can reduce the 13th harmonic voltage appearing on the common bus as the passive filter used alone.

(2) The active filter acting as a positive resistor at the 13th harmonic frequency prevents the passive filter from over current.

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

The hybrid active filter is expected to be installed in distribution power system which are subjected to harmonic resonances.

6. REFERENCES:

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