HARMONIC FILTER FOR POWER QUALITY IMPROVEMENT

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Abstract: Harmonic currents in particular are receiving more attention as a critical power quality concern, with an estimated 60 percent of electricity now passing through nonlinear loads. This paper shows the principles of how the harmonic filter can be used in radial medium voltage distribution system as a solution to solve harmonic current problems. The well-developed graphic facilities available in an industry standard power system package, namely PSCAD/EMTDC, are used to conduct all aspects of model implementation and to carry out extensive simulation studies.

Keywords: Power system, Non-linear load, Harmonic distortion, Harmonic filter, Power quality, PSCAD/EMTDC simulation.

1. INTRODUCTION

The last decade has seen a marked increase on the deployment of end-user equipment that is highly sensitive to poor quality control electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of even minor lapses in the quality of electricity supply.

Harmonic distortion is today present in almost all power systems and the distortion level varies much from system to system and at different voltage levels. The main source of the distortion is formed by non-linear loads connected at low voltage; mainly rectifiers.

The large decrease of the total current distortion, at higher voltage levels, is due to the fact that nonlinear loads are mixed with linear loads (the fundamental total current increases), also that zero sequence harmonics are blocked by delta connected transformers. There is also an interaction between non-linear loads, mainly single and three phase connected at the same voltage level, which reduces the total current distortion. The decrease of the total voltage distortion is of course due to the decrease of the current distortion but it also depends on the higher ratio of the short circuit power and the rated power at higher voltage levels, compared to lower voltage levels. The voltage and the current distortion cause additional losses in power system components and in linear loads. The flow of the harmonic active power components supplying these losses, between different parts of the power system or different loads, depends on the configuration of the power system and the mix of loads. This power flow, at a certain point, can be positive, negative and sometimes it is not seen at all.

Harmonic filters have been used as a solution to solve harmonic current problems and can be subdivided into two types: passive and active. Passive filtering is based on the series resonance principle (recall that low impedance at a specific frequency is a series-resonant characteristic) and can be easily implemented.

Even with the potential cost of new capacitors, passive filtering still appears to offer the most cost effective solution to the harmonic problem at this time.

2. GENERAL CHARACTERISTICS OF THE HARMONIC DISTORSION IN POWER SYSTEMS

2.1. Voltage and current

The first important characteristic of harmonic distortion in power systems is that the fundamental voltage, applied on a non-linear load, causes harmonic currents (called characteristic harmonics). Three phase unbalanced voltages cause also non characteristic harmonic currents for three-phase equipment. Harmonic voltages also effect the current distortion, but they only give a minor change in the harmonic currents amplitude and phase angle. In most cases the voltage distortion due to a given load reduces the distortion of the load current.

Secondly, the distorted load current causes voltage distortion; i.e. the voltage harmonics are in general, not responsible for the current harmonics. This means that it is not possible to apply the harmonic voltages, as voltage sources, in a real power system to obtain the current harmonics. Further, the source impedance affects the voltage and current distortion. Some system components have a two-fold effect that affects a certain harmonic frequency and also affects the fundamental voltage, e.g. passive harmonic filters. Power-factor correction capacitor banks are linear elements with an impedance that decreases with harmonic order (i.e. with frequency), and they form an additional return path for the harmonic currents. Harmonic resonance is a well-known consequence of this additional return path.

2.2. Active power and losses

The current distortion causes increased losses in power system components. For each harmonic, *n*, the losses can be written as:

$$P_{(n)} = R_{(n)} \cdot I^2{}_{(n)} \,, \qquad (1)$$

with $R_{(n)}$ the resistance for harmonic, *n*.

Voltage distortion causes, in the same way as the current, increased losses in linear loads connected to the power system and in shunt-connected capacitor banks.

The total increase of the losses in a system is the sum of the losses, at each harmonic, for all components and loads:

$$\Delta P_{tot} = \sum_{Comp} \sum_{n \neq 1} P_{(n)} \,. \qquad (2)$$

It is obvious that the active harmonic losses from one non-linear load are affected by the feeding power system and by other loads, i.e. the path for the harmonic currents.

At a certain point in the power system the instantaneous power flow, including fundamental and harmonic flow is the time derivative of the exchange of energy between the two electrical systems, or the electrical system and a mechanical system:

$$p(t)_{tot} = \frac{dW(t)}{dt} \,. \qquad (3)$$

The active power is the average over one cycle of the instantaneous power flow. Expressed in voltages and currents Fourier components the total active power, over the time T, is:

$$P_{tot} = \frac{1}{T}\int_0^T u(t)\cdot i(t)dt = P_{(1)} + \sum_{n\neq 1} P_{(n)} \,. \qquad (4)$$

The active power flow to a non-linear load is in most cases a positive fundamental flow and a negative harmonic flow; i.e. the harmonic part is due to the additional losses in the feeding power system. From the law of conservation of energy and (3) it follows that the harmonic active power is converted from the fundamental power by the nonlinear load. This means that the fundamental active power to a non-linear load, or a non-linear system, includes the harmonic part and (4) can be rewritten as:

$$P_{(1)} = P_{tot} - \sum_{n\neq 1}^{\infty} -\left|P_{(n)}\right| = P_{tot} + \sum_{n\neq 1}^{\infty}\left|P_{(n)}\right| \,. \qquad (5)$$

Linear loads, contrary to non-linear loads, only consume fundamental and active harmonic power, which means that the fundamental power does not include the harmonic part. This reasoning holds, strictly speaking, only for the equipment terminals. Elsewhere in the system, e.g. at secondary side of a transformer, the harmonic power flow may be towards the load or away from the load, depending on the system configuration and the mix of loads (linear and non-linear). The active power flow in a certain point will in most cases not represent the actual flow at harmonic frequencies to the loads (IEEE Task Force, 1993).

3. SUBSYSTEM UNDER STUDY

PSCAD/EMTDC is an industry standard simulation tool for studying the transient behavior of electrical networks. Its graphical user interface enables all aspects of the simulation to be conducted within a single integrated environment including circuit assembly, run-time control, analysis of results, and reporting. Its comprehensive library of models supports most AC and DC of power plant components and controls, in such a way that a power system can be modeled with speed and precision (Wilson, P. and Craig, M., 2004).

For the simulation study a polluting load, such as a 6 pulse rectifier was used. The rectifier has the characteristics of dewing a non-sinusoidal current from a sinusoidal voltage supply. Using Fourier analysis the current drawn from the supply may be split into its fundamental and harmonic components.

This load may be represented as a harmonic current source "injecting" into the power system. The harmonic current will propagate into the system and react with the network impedance to cause harmonic voltage to appear.

En example of typical current spectra for six-pulse rectifiers is given in Fig. 1.

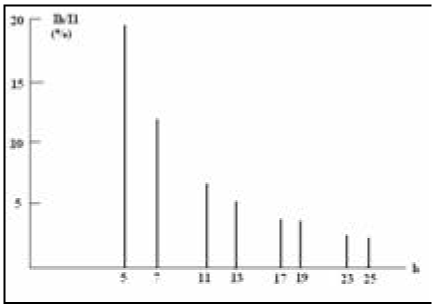

Fig. 1. Typical current spectrum of a six-pulse rectifier.

The simulation analysis was performed for a generalized distribution system model presented in Fig. 2 (Chindris M., *et al.*, 2003).

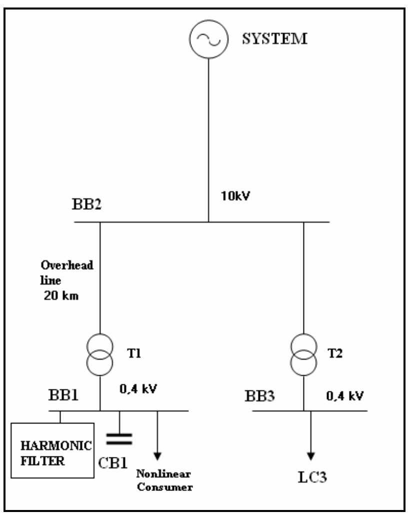

Fig. 2. The MV network under study.

A band pass RLC filter was used and this filter branch will only pass only a range of frequencies. Placing the branch between a line and ground will thus act as a notch filter, absorbing the resonant frequency from the line. Filter parameters may be entered as R, L & C or Q, f_0 & MVAr.

Two different network configurations are discussed:

1) Nonlinear load located at the bush bar 1 (BB1) – linear load (LC3) located at bus bar 3 (BB3), with/without harmonic filter;
2) Nonlinear load located at the bush bar 1 (BB1) - linear load (LC1) located at the bus bar 1 (BB1) and capacitor banks (CB1) located at BB1, with/without harmonic filter.

4. HARMONIC FILTER SIMULATION RESULTS

Fig. 3 and Fig. 4 present simulation results for a three-phase power system without/with a harmonic filter and it includes the current waveforms for case study 1) measured at BB1.

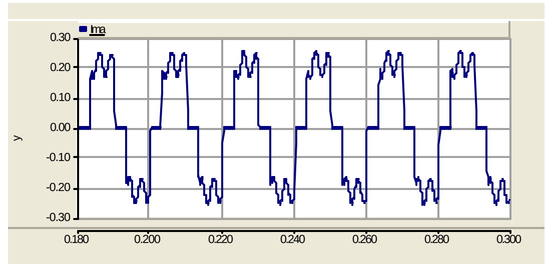

Fig. 3. The current waveform at BB1 without harmonic filter for case study 1.

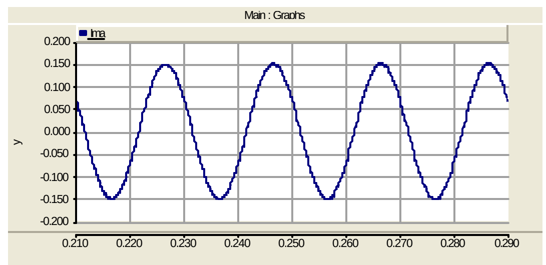

Fig. 4. The current waveform at BB1 with harmonic filter for case study 1.

Fig. 5 and Fig. 6 present the current waveforms for case study 2) measured at BB1 without/with a harmonic filter.

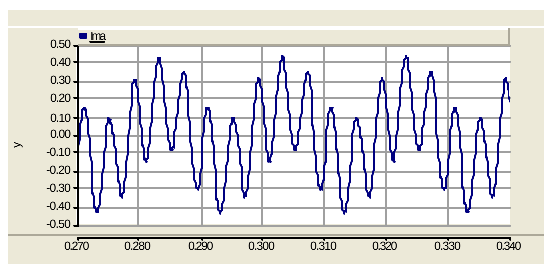

Fig. 5. The current waveform at BB1 without harmonic filter for case study 2.

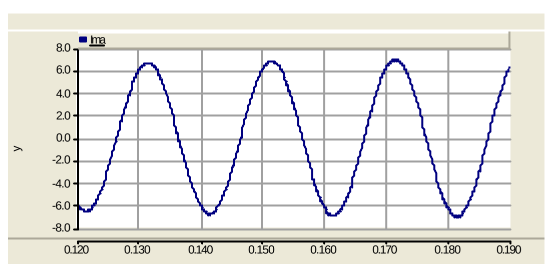

Fig. 6. The current waveform at BB1 with harmonic filter for case study 2.

The simulated case study 1 shows the power system with a non-linear load (three-phase rectifier) and a linear load with and without harmonic filter. Without the harmonic filter the current is distorted (Fig.3). After the filter is used becomes sinusoidal and the compensation is immediate (Fig. 4).

Fig. 7 to Fig. 10 show the evolution of the most significant current and voltage harmonics.

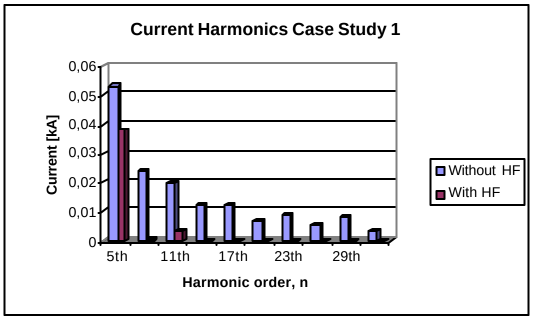

Fig. 7. BB1 current spectrum for case study 1, before and after compensation.

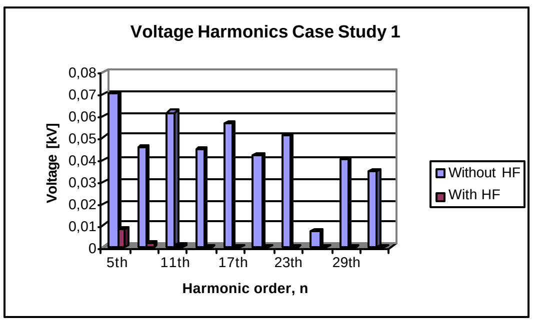

Fig. 8. BB1 current spectrum for case study 1, before and after compensation.

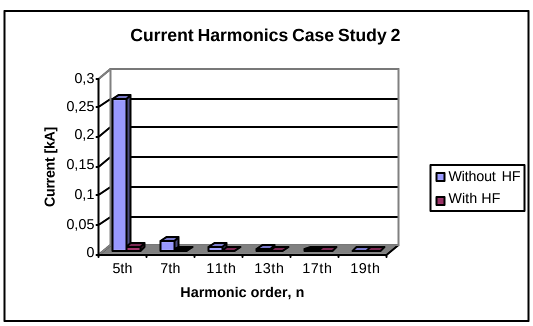

Fig. 9. BB1 current spectrum for case study 2, before and after compensation.

From the simulation results we can conclude that the current and voltage harmonics with the filter connected is clearly reduced.

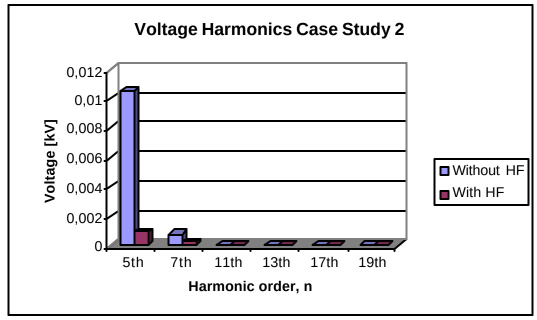

Fig. 10. BB1 current spectrum for case study 2, before and after compensation.

5. CONCLUSIONS

Widespread use of loads that involve power electronic systems can cause major distortion of voltage and especially current waveforms, and even cause substantial DC currents to flow in power transformer secondary. An accurate study on the harmonic filters as a possibility for power quality improvement is a lower-cost solution that can be implemented before problems arise.

In order to show the performance of the harmonic filter the spectrum of the voltages and currents are used as figures of merit along with the voltage and current waveforms themselves. With passive filters of higher harmonics, harmonic currents can be reduced greatly so that the total harmonic distortion (THD) is kept within the acceptable standards. Passive filters (L, C) could also be used in order to compensate at the same time the reactive power and the current harmonics. Unfortunately, these devices can create an anti resonance harmonics and these performances should be degraded after few years.

Passive filters present several disadvantages, namely:

- they only filter the frequencies they were previously tuned for;
- their operation cannot be limited to a certain load;
- resonances can occur because of the interaction between the passive filters and other loads, with unpredictable results.

For these reasons is possible to have active filters combined with passive filters acting together.

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