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Review of Harmonioc Detection and Filtering in Power System

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Abstract- A harmonic is defined as a sinusoidal component of a periodic wave or a quantity having frequency that is a multiple of the fundamental frequency. A harmonic can be voltage and/or current present in the electrical system in multiples of the fundamental frequency. It is generally believed that active harmonics filters (AHF) are very expensive therefore, are the last choice for power quality solution. Every harmonics mitigation and power factor correction device has its importance in the market. Active harmonics filters provide controlled current injection to eliminate harmonic current from the source side of electrical system and reactive current to correct the power factor (PF). The main difficulties are stationary and transient distortions in the line voltage such as harmonics, flicker, swells, sags and voltage asymmetries. With the significant development of power electronics technology, especially static power converters, voltage harmonics resulting from current harmonics produced by the non-linear loads have become a serious problem. Active filters have been successfully used in harmonic filtering and power factor reparation but also to perform complex jobs in the context of total power quality management.

Keywords- *Active filters, current reference, instantaneous imaginary power, compensation, reactive power.*

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I. INTRODUCTION

The power quality (PQ) issues in power utility distribution systems are not new, but only newly their effects have gained public awareness. Developments in semiconductor device technology have fuelled a revolution in power electronics over the past decade, and there are indications that this development will carry on. However the power electronics based equipment's which include adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in PQ related problems. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. They fall into two basic categories: short-term and long-term. Short-term effects are usually the most noticeable and are related to excessive voltage distortion. On the other hand, long-term effects often go undetected and are usually related to increased resistive losses or voltage stresses. In addition, the harmonic currents produced by nonlinear loads can relate adversely with a wide range of power system equipment, mostly on capacitors, transformers, and motors, causing additional losses, overheating, and overloading. These harmonic currents can also cause interferences with telecommunication lines and errors in metering devices.

Harmonic distortion in power distribution systems can be suppressed using two approaches namely, passive and active powering. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. Although simple, the use passive elements do not always respond correctly to the dynamics of the power distribution systems. Figure 1 shows common types of passive filters and their configurations. The single-tuned "notch" filter is the most common and economical type of passive filter. The notch filter is connected in shunt with the power distribution system and is series-tuned to present low impedance to a particular harmonic current.

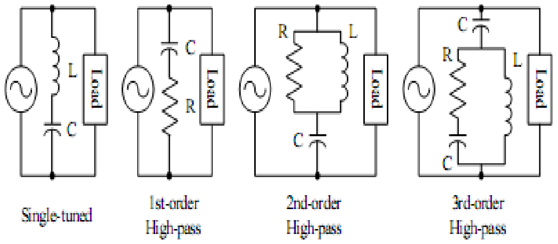

Figure 1 Common type of passive filters.

Thus, harmonic currents are diverted from their normal flow path through the filter. Another popular type of passive filter is the high-pass filter (HPF). A HPF will allow a large percentage of all harmonics above its corner frequency to pass through. HPF typically takes on one of the three forms, as shown in Figure 1. The first-order, which is categorized by large power losses at fundamental frequency, is hardly used. The second-order HPF is the easy to apply while provided that well filtering action and reduced fundamental frequency losses. The filtering performance of the third-order HPF is superior to that of the second-order HPF. However, it is found that the third-order HPF is not commonly used for low-voltage or medium-voltage applications since the economic, complexity, and reliability factors do not justify them. There is a remarkable progress in

Active Filter (AF) applications during last decades, encouraged mainly by the increased performance of the power switches. Furthermore, the evolution of Digital Signal Processors and new control theories enable superior harmonic compensation characteristics and stable operation of AF's compared to classical passive filters. With the significant development of power electronics technology, especially static power converters (well known as nonlinear loads), voltage harmonics resulting from current harmonics produced by the non-linear loads have become a serious problem. Paradoxically, static power converters, the source of most of the perturbations, could also be used efficiently as active power filters in order to cancel or mitigate most of the above mentioned power quality problems as well as other power system problems such as damping of voltage oscillations.

II. ACTIVE POWER TOPOLOGIES

Active filters are primarily static power converters configured to synthesize a current or voltage source. Since their basic compensation principles were suggested around 1970, active filters have been effectively used in harmonic filtering and power factor compensation but also to do complex tasks in the context of total power quality management. Advantages of active filters over conventional means contain; very fast control response, more suppleness in defining and implementing control functions (more than one function can be performed), and no further resonance introduced into the ac supply [1].

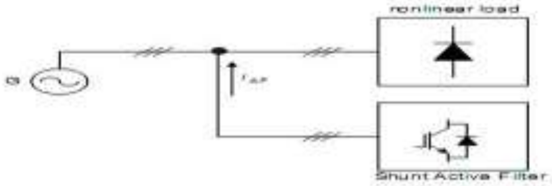

Figure 2 Shunt active filter used alone.

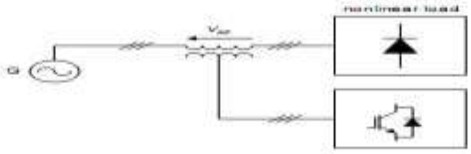

Figure 3 Series active filter used alone.

A. Principle of active power filtering:

Figure 4 explains the basic structure configuration for a shunt active compensation. It includes the power line, the active filter and the nonlinear load. The electrical parameters that have to be considered are: source voltage system V, line current system I, load voltage system VL, load current system I L, power line impedance Z (that depends on the frequency of the current's I), Voltage across the power line impedance Vs and filter current system i.

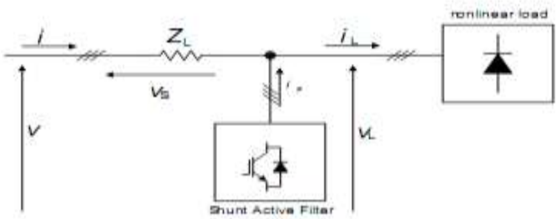

Figure 4 Principle of active filtering (shunt active filter operation) block diagram.

$$\mathbf{v}=\begin{bmatrix}v_1\\v_2\\v_3\end{bmatrix};\quad i=\begin{bmatrix}i_1\\i_2\\i_3\end{bmatrix};\quad \mathbf{v_S}=\begin{bmatrix}v_{s1}\\v_{s2}\\v_{s3}\end{bmatrix};$$

$$\mathbf{i_F}=\begin{bmatrix}i_{F1}\\i_{F2}\\i_{F3}\end{bmatrix};\quad \mathbf{i_L}=\begin{bmatrix}i_{L1}\\i_{L2}\\i_{L3}\end{bmatrix};\quad \mathbf{v_S}=\begin{bmatrix}v_{L1}\\v_{L2}\\v_{L3}\end{bmatrix}. \tag{1}$$

The current systems can be divided in two parts

$$i_X = i_{Xa} + i_{Xr} \tag{2}$$

That is,

- An active component, related with the conventional essential active current and the harmonic currents produced by the ac component of the instantaneous real power;
- A reactive component related with reactive power generate by the fundamental components of voltage and currents and the harmonic currents produced by the ac component of instantaneous reactive power;

B. Active Power Filter [2]

Remarkable development in power electronics had spurred attention in APF for harmonics distortion mitigation. The basic principle of APF is to employ power electronics technologies to create specific currents components that cancel the harmonic currents components caused by the nonlinear load. The information concerning the harmonic currents and other system variables are passed to the compensation current/voltage reference signal estimator. The compensation reference signal from the estimator drives the overall system controller. This in turn affords the control for the gating signal generator. The output of the gating signal generator controls the power circuit via a suitable interface. Finally, the power circuit in the comprehensive block diagram can be connected in parallel, series or parallel/series configurations depending on the interfacing inductor/transformer used. APF s has a number of compensations over the passive filter. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APFs have some drawbacks. Active filtering is a relatively new technology, practically less than four decades old. There is still a need for further research and expansion to make this technology well recognized.

An unfavorable but devoted feature of APF is the necessary of fast switching of high currents in the power circuit of the APF this results I a high frequency noise that may reason an electromagnetic interference (EMI) in the power distribution system. APF can be connected in numerous power circuit configurations as proved in the block diagram shown in figure 3.4 in general, they are divided in to three men types namely shunt APF, series APF and hybrid APF.

C. Shunt Active Power Filter

This is most significant configuration and widely used in active filtering application a shunt APF contain of a controllable voltage or current source the voltage source invertor (VSI) base shunt APF is by far the most common type used today , due to its well none topologies and state advancing installations procedure. Fig. 5 shows the principle configuration of a VSI base shunt APF. It consist of DC-bus capacitor © Power electronics switch and interfacing inductors shunt APF acts as a currents source compensating the harmonic current due to nonlinear loads. The operation of shunt APF is built on injection of compensation current which is equals to the distorted currents, thus eliminating the original distorted current. This is achieved by “Shaping” the compensation current waveforms (I), using the VSI switch the shape of compensation currents is gained by calculating the load current and subtracting it from a sinusoidal reference

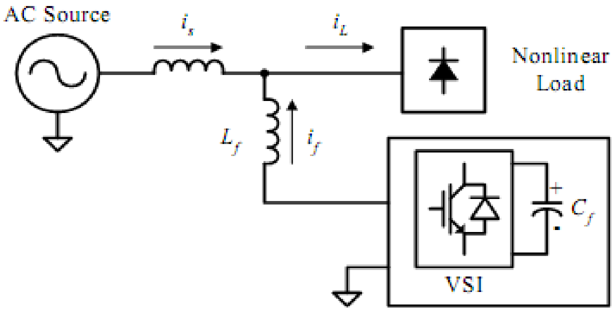

Figure 5 Principle configuration of a VSI based shunt APF

D. Series Active Power Filter

The series APF is shown in figure 6. It is connected in series with the distribution line through a matching transformer. VSI is used as the controlled source, thus the principle configuration of series APF is similar to shunt APF, except that the interfacing of shunt APF is replaced with the interfacing transformer. The process principle of series APF is based on isolation of the harmonics in source. This is found by the injection of harmonic voltages (v) across the interfacing transformer. The injected harmonic voltages are added / subtracted, to/from the source voltage to maintain pure sinusoidal voltage waveforms across the nonlinear load. The series APF can be thought of as a harmonic isolator as shown in figure 7. It is controlled in such a way that is present zero impedance for the fundamental components, but appears as a register with high impedance for harmonic frequencies constituents. That is, no current harmonics can flow from nonlinear load to source, and vice versa. Series APFs are less common than their competing, i.e. the shunt APF. This is because they have to handle high load currents. The resulting high capacity of load currents will rise their current rating considerably compared with shunt APF, especially in the secondary side of the interfacing transformer.

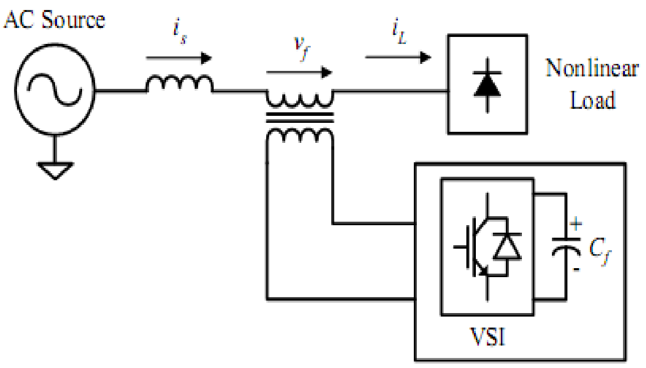

Figure 6 Principle configuration of a VSI based series APF

This will increase the I^2R losses. However, the main benefit of series APFs over shunt one is that they are ideal for voltage harmonics removal. It affords the load with a pure sinusoidal waveform, which is important for voltage sensitive devices (such as power system protection devices). With this feature, series APF is suitable for improving the quality of the distribution source voltage.

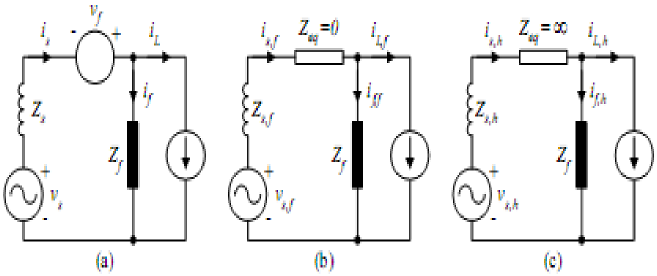

Figure 7 Operation principle of series APF: (a) single-phase equivalent of series APF, (b) fundamental equivalent circuit, and (c) harmonic equivalent circuit

E. Passive filter

It offers together power-factor correction and high current-filtering capacity. Passive filters also decrease the harmonic voltages in installations where the supply voltage is disturbed. If the level of reactive power complete is more, it is advised to turn off the passive filter at times when the percent load is low. Preliminary studies for a filter must take into account the conceivable occurrence of a power factor correction capacitor bank which may have to be removed [5].

III. MODELING OF THE SYSTEM

The modeling approach accepted in this paper permits the basic representation of the system harmonic impedance variation at all buses and the execution of harmonic load flow calculations, to determine the resultant voltage distortion. Models and applied methodologies are based on pertinent CIGRE guides, the IEEE Task Force recommendations, as well as on the relevant literature. Specific models of system components are presented in the following section (including components such as rotating electric machines, not present in the study case system). It is stressed that more sophisticated models exist for each component. Nevertheless, their application is usually contradicted by the lack of reliable data, as well as by the over-simplified representation of other components (particularly the consumer load). Following are the fundamental assumptions and considerations adopted in this paper: Harmonic sources are modeled as current injections of given amplitudes per frequency. This statement is justified for current controlled converters with PWM hysteresis controllers, as is the situation with the output converters of the examined WTs. A direct harmonic result is obtained, that is the coupling between harmonics of different order is ignored. The network is modeled by its 3-phase equivalent, transformed in the symmetrical component domain. Thus, the propagation of zero sequence harmonics is properly represented and possible differences in the positive and negative sequence characteristics of the system are accounted for. The modeling approach adopted in this paper permits the basic representation of the system harmonic impedance distinction at all buses and the execution of harmonic load flow calculations, to determine the resulting voltage distortion. Models and functional methodologies are founded on relevant CIGRE guides, the IEEE Task force recommendations, as well as on the relevant literature. Specific models of system works are presented in the following section (including components such as rotating electric machines, not present in the study case system) it is stressed that more refined models occur for each component. However, their application is usually contradicted by the lack of reliable data, as well as by the over-simplified representation of other components predominantly the consumer load). Following are the fundamentals assumptions and consideration accepted in this paper: Harmonic sources are modeled as current injections of given amplitudes per frequency. This statement is justified for current controlled converters with PWM hysteresis controllers, as is the case with the output converters of the examined WTs. A direct harmonic solution is obtained, that is the coupling between harmonics of different order is overlooked. The network is modeled by its 3-phase equivalent, transformed in the symmetrical component domain. Thus, the promulgation of zero sequence harmonics is correctly represented and possible modifications in the positive and negative sequence characteristics of the system are accounted for [3].

A. Harmonic sources

Meanwhile harmonic sources are preserved as current injections, to completely describe a 3-phase source, three current pastors (magnitudes and angles P per harmonic frequency would be essential data existing in practice, nevertheless, usually include only one current magnitude per frequency (for instance, as in the power quality certificates per IEC 6140021. Based on such data, the modeling should account for superposition (summation) effects of harmonics from dissimilar sources, in addition to the sequence characteristics of harmonic current injections. For the summation of harmonics, the second summation law of is adopted, as it is recommended in the WT power quality assessment standard IEC 61400-21:

$$I_h = \sqrt[a]{I^{a}_{h,k}} \tag{2}$$

Where $I_{h,k}$ is the h_{th} order contribution from source k. Values recommended in for the summation exponent are a=1.0 for h<5, a=1.4 for and a=2.0 for h>10, reflecting the fact that individual harmonic vectors tend to become uncorrelated at higher frequencies. For harmonic sources connected at different buses, their phase angles and possibly their magnitudes may be reflected to be random variables, with increasing variance as the harmonic order h increases, to create a summation effect similar to eq. (2). The harmonics of switching converters, however, may completely deviate from the standard sequence characteristics, as is the case with hysteretic PWM controllers. In this case, all high order harmonics may include positive and negative sequence components, but not zero-sequence ones when the source does not permit it (delta connected windings, three-leg converters etc.).

B. System load

Appropriate selection of the load model is vital for correctly assessing the magnitude of harmonic resonances. However, no generally relevant harmonic model exists and case-specific measurements and evaluations are needed of detailed studies.

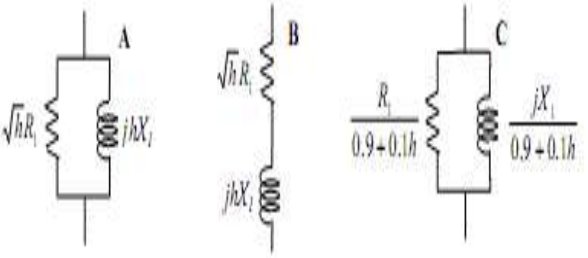

Figure 9 Alternative harmonic models considered for the system load.

Models considered for the system load. From the variability of harmonic load models proposed in the literature, three alternative representations are shown in fig. 9, selected for their simplicity. In all cases, R and X are the fundamental frequency resistance and reactance, corresponding to the nominal power of the load.

C. Overall Harmonic Compensation

The overall harmonic compensation (hereafter referred to as OHC) aims to provide as harmonic reference current the entire harmonic spectrum contemporary in the load current excluding the fundamental frequency, which is to be supplied by power network. Therefore, the main function of the harmonic detection block is to filter out the fundamental frequency. This can be proficient in different manners: - in stationary abc-frame, by using Notch Filters (although this may be prone to phase deferrals if not carefully implemented, affecting improper harmonic compensation) or Fourier based filters adjusted to remove the fundamental component. By using the instantaneous power theory, which again continues to removal of the fundamental component (dc-component) by High-Pass Filter.

IV. ADVANTAGES AND DISADVANTAGES

It is extensively believed that active harmonics filters (AHF) are very costly and, therefore, are the last choice for power quality explanations. The answer is it depends. Every harmonics mitigation and power factor correction technique has its reputation in the market. Knowing what a result does for power quality and the benefits and drawbacks of each solution afford enhanced results with extreme benefits for the user. Active harmonics filters organize for controlled current injection to remove harmonic current from the source side of electrical system and reactive current to accurate for displacement power factor (PF). Active harmonics filters can be beneficial to a single nonlinear load. The nonlinear loads can be numerous types or apparatus's, such as variable frequency drives (VFD), DC motor speed controls (aka DC drives), uninterruptible power supplies (UPS), or thyristor (DC) power supplies, to name a limited [6].

V. CONCLUSION

This paper defines two harmonic detection methods used in industrial shunt Active Filters. The paper attention on presenting practical issues met in both methods. It is determined that the Selective Harmonic Compensation is suitable for cases where balanced network conditions exist and the rating power of the AF is to be sustain. The Overall Harmonic Compensation is appropriate for more general purpose Active Filter provided the rating power is accessible. Both simulations and measurement are provided to back up the comparisons and considerations.

It gives a complete view on the development of APF technologies. A brief discussion on the harmonic distortion problems and their impacts on electric PQ are given. The conventional mitigation procedures using passive filters are presented first, followed by the improved mitigation methods using APFs. It also reviews different types of reference signal estimation techniques which are an integral part of the APF. An overview of the control strategies for APF is presented. In this a harmonic penetration study has been presented, for a power system where a wind farm consisting of variable speed turbines is scheduled to be connected. After giving the system modeling approach, application outcomes are given from the frequency scan and the harmonic load flow analysis. The harmonic features of the system and their sensitivity with respect to operating and modeling parameters have been discussed. Potential voltage distortion problems have been recognized, due to the coincidence of the first harmonic resonance frequency of the system with the ultimate of the harmonic spectrum of the WT current. However, harmonic distortion issues appear only for the local MV network and not for the HV system, which was the initial point of anxiety.

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