Harmonic Compensation Techniques in Electrical Distribution System - A Review

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Abstract

Harmonics in the power system is not new issue. This phenomenon has been introduced by technocrat throughout in the history of electrical power system. Maintaining the power quality in a power system is an essential assignment due to increase in wide variety of non-linear loads. The current drawn by such non linear loads are non-sinusoidal and therefore contains harmonics. Therefore, it becomes necessary to compensate these unwanted harmonics for better performance of the system. In this paper, a review of compensations of harmonics in distribution system has been explained.

1. INTRODUCTION

Electrical power system having distorted voltage and current waveform contains harmonics. The compensation of the harmonics is greatly required for better performance of the power system. Harmonic is of major concern for the power system which contains non linear load. Harmonics need to be compensated in low voltage and medium voltage power distribution systems. It starts with passive filtering, active filtering to hybrid filtering. Multilevel inverter (MLI) has also been reviewed for harmonic compensation in power distribution system. Harmonic compensation in a low voltage power distribution system can be implemented by three approaches namely:

- Passive filtering
- Active power filtering and
- Hybrid active power filtering

2. HARMONIC COMPENSATION IN DISTRIBUTION POWER SYSTEM

It presents harmonic compensation in low voltage and medium voltage power distribution systems. It starts with passive filtering, active filtering to hybrid filtering. Multilevel inverter (MLI) has also been reviewed for harmonic compensation in power distribution system. Harmonic compensation in a low voltage power distribution system can be implemented by three approaches namely:

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2.1 Harmonic compensation by using Passive Filter

Gonzalez, D. A. [1] proposed shunt passive filters for harmonic compensation in power system. Shunt passive filters are implemented with inductance, capacitance and resistance and tuned to control the harmonics. The configurations of common types of passive filters are shown in Fig.1

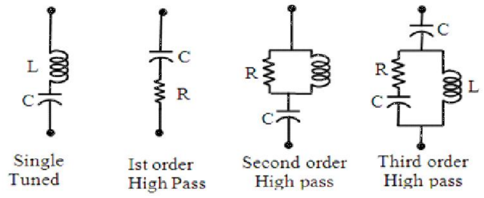

Fig. 2.1: Configurations of common types of passive filters

Shunt passive filters are better than series compensators since they compensate harmonics as well as reactive power and in addition they do not carry large currents followed by associated losses. High pass filter for notch reduction was proposed by Ludbrook, A [2] in a power distribution system containing large electronic loads. Single tuned filters are more effective to suppress harmonics of selected frequency. The first-order filter characterized by large power losses at fundamental frequency is simple to be implemented. The second-order high power filter provides better filtering with reduced losses at fundamental frequency. The filtering performance of the third-order high power filter is again better than that of the second-order filter. The passive filter being simple and least expensive has several drawbacks too. The filter components are bulky because the harmonics that required to be compensated are normally of the low order according to Das. J. C. [3].The passive filter is also prone to resonance which affects the stability of the power system.

2.2 Harmonic compensation by using Active Power Filter

The basic principle of APF is to produce specific harmonic current components that cancel the harmonic current components caused by the nonlinear load. Fig 2.2 shows the components of an APF system and their connections.

APFs have a number of advantages over the passive filters such as they can suppress not only the supply current harmonics.

Akagi, H. [4] proposed the classification of active filters on the basis of their system configuration, electrical circuits and control strategy.

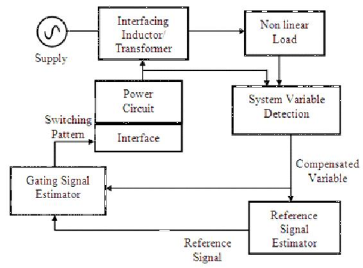

Fig.2.2: Components of an APF system and their connections

APF can be implemented by shunt APF, series APF, and hybrid APF. The configuration of Shunt Active Power Filter (shunt APF) is frequently used in active filtering for current harmonic reduction. The configuration of a VSI based shunt APF has been shown in Fig 2.3.

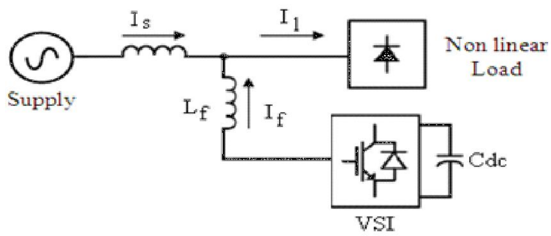

Fig. 2.3: Configuration of a VSI based shunt APF

Bhavaraju V. B. [5] proposed series active filter connected through a coupling transformer for compensating line voltage sag. Rigby B.S. [6] proposed inverter based series compensator which compensates for dynamic changes. The configuration of series Active Power Filter is shown in Fig 2.4.

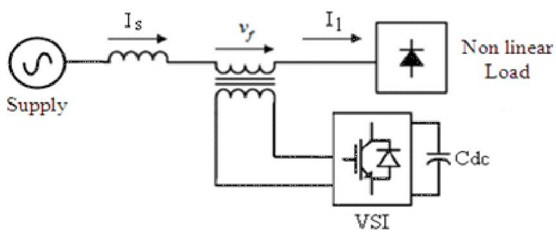

Fig. 2.4: Connection of Active Power Filter with a non linear load

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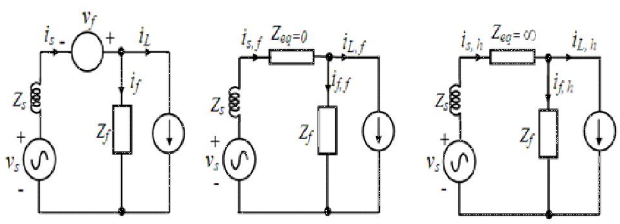

(a) (b) (c)

(a) Single-phase equivalent of series of APF (b) Fundamental equivalent circuit (c) Harmonic equivalent circuit

Fig.2.5: Diagrams of operations of Active Power Filter with a non linear load

The operations of Active Power Filter with a non linear load in three different conditions have been shown in Fig 2.5. Series APFs are less common than the shunt APF because they have to handle high load currents which will increase their current rating considerably compared with shunt APF especially on the secondary side of the interfacing transformer. This increases the I^2R losses. However, the main advantage of series APF over shunt APF is that they are ideal for voltage harmonics elimination. It provides the load with a pure sinusoidal waveform for voltage sensitive devices such as power system protection devices. Series APFs are therefore quite suitable for improving the power quality of the distribution system. There are number of new ideas proposed in literature for harmonic active filtering in power distribution systems.

Principle of magnetic flux compensation was proposed by [7]. This is achieved by using the current to produce a flux to interact the flux produced by the harmonics. The drawback of this idea is its inability to suppress the lower order harmonics (2^{nd}, $3^{rd}$and 4^{th}). In order to compensate the harmonics of choice, Bird [8] proposed that the harmonic currents produced by pulse converters could be eliminated by injecting a third harmonic component current to the rectangular waveform produced by the converter. The results proved that the method is effective in eliminating one harmonic of choice. But Bird's work was inefficient and its drawback was that it was impossible to fully eliminate more than one harmonics. Later on, Bird's work was improved by [9-10] to eliminate multiple harmonics. In 1976 Gyugyi and Strycula gave the concept to compensate for harmonics by the applications of semiconductor switches for PWM inverters [11]. Both of them proposed a switching system which consisted of a simple bridge circuit of transistors switched in pairs to generate a two-level current waveform by implementing PWM technique. Two topologies based on CSC and VSC were proposed which were controlled to counteract the flow of harmonic currents from the nonlinear load to the utility system. Active power conditioning system developed during 1970s were earlier stage because the circuit technology was not enough sound technically to implement.

There was a remarkable progress in power electronic in 1980s that encouraged the study of active power line conditioners for reactive power and harmonic compensations. p – q theory was developed a PWM-voltage type converter topology for instantaneous reactive power compensation [12] was implemented. The authors decomposed the instantaneous voltages and currents into orthogonal components. The active filter is controlled to eliminate the instantaneous reactive power resulting in reactive power compensation in time domain which proved more effective to compensate harmonics.

Hayashi and others developed current source active filters [13] for harmonic compensation. The current compensation in this scheme was done in the frequency domain. A research group in Korea presented an active power filter that reduced the magnitude of harmonics by means of the injection of PWM currents made up of sine and cosine terms of a compensating current [14].

Enjeti [15] proposed an evaluation of different PWM techniques to eliminate harmonics for single phase and three phase inverters. The main problem with the schemes is high switching losses due to the fast switching rates.

2.3 Harmonic compensation by using Hybrid Filters

To reduce the ratings of active power filters, active filters and passive filters were combined together by many researchers [16, 17-21]. Peng [17] proposed the use of a series active filter to operate in parallel with passive filters. This technique was different for harmonic current compensation and it got improved the filtering performance of the passive filters. The determination of the harmonic currents to be injected by the active filter is based on p-q theory developed by Akagi .The drawback of this circuit is the series transformer that would require a high basic insulation level to withstand the large switching transients and lightning surges. Another point is that the current calculated by the active filter will also include the fundamental component of the load current and the fundamental leading power factor current of the shunt passive filter. To avoid the problems with the active filter in parallel with passive filters topology of another system of active filters and passive filters was proposed by Fujita and Akagi [18] and Tokuda [19]. In these schemes, the active filters are connected in series with either a shunt passive filter or an LC tuned filter. The difference between these topologies and the one presented in reference [17] is that the single-phase PWM inverters are replaced by one three-phase inverter and the DC-side voltage source is regulated by a feedback loop. In another work, Van Zyle [20-21] proposed a converter with a passive filter that is permanently installed on the line and is termed as the Power Quality Manager (PQM). The passive filter consists of tuned filters for fifth and seventh order harmonics. The PQM **is** used to improve the voltage regulation and has the capability to work as a harmonic isolator. The weakness of these schemes is that the active filter always carries the capacitive fundamental component of the current through the shunt passive filter or the LC tuned filter. Fig 2.6 shows the combination of series APF and shunt passive filter and combination of shunt APF and shunt passive filter.

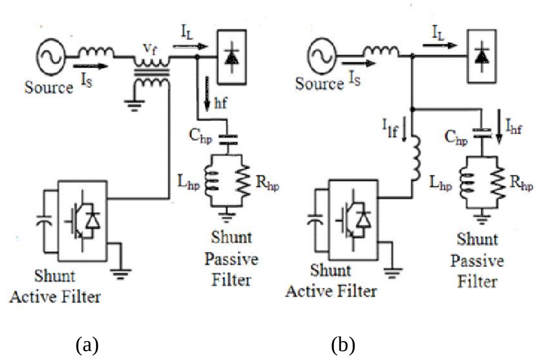

Fig. 2.6: Hybrid APFs (a) Combination of series APF and shunt passive filter and
b) Combination of shunt APF and shunt passive filter.

2.4 Harmonic compensation by FACTS devices

Harmonic generation in the power system is an issue that is getting important to the electricity users at all the levels of the usages. The FACTS devices are the solutions to shield the sensitive loads against the harmonics and other power quality problems in the system [22].The DVR is popular and is cost effective solution for the protection of varying load from voltage sag and voltage swell and its control has been mentioned in [23]. The author in [23] has proposed a method in which an electrical arc furnace (EAF) is a major flicker source that causes major power quality problems. In the proposed method CMC-based

STATCOM was presented and verified through a transient network analyzer (TNA). The STATCOM capacity was first realized through a generalized steady-state analysis. Secondly, the STATCOM control strategy for flicker mitigation is introduced and simulation results were produced. Finally, a TNA system of the STATCOM and an EAF system were implemented. The author [25] has the simulation for the unified series-shunt compensator (USSC) for investigating power quality in power distribution system. The USSC simulation consists of two 12-pulse inverters which were connected in series and in shunt with the system. A generalized sinusoidal pulse width modulation (SPWM) switching technique was developed in the proposed controller for fast control action of the USSC. Simulation from the proposed model demonstrated the performance of USSC and its effectiveness for voltage sag compensation, flicker reduction, voltage unbalance compensation and power flow control and harmonics elimination.

In [26], the author introduced a new FACT device called UPQC (Unified Power Quality Conditioner) which does not require any energy storage. It is designed to compensate any sag above a certain magnitude and it is independent of duration. This is able to compete with the uninterruptible power supply (UPS) typically used for the protection of low power and low voltage equipment. The D-STATCOM is less flexible than UPQC. The connection of UPQC with the power system has been shown in the Fig. 2.7.

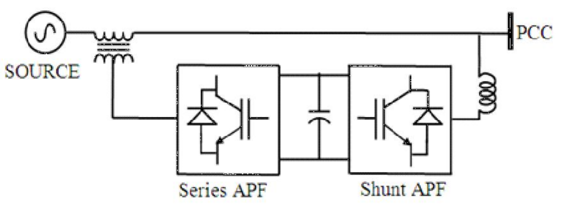

Fig. 2.7: Connection of UPQC with the power system

2.5 Harmonic compensation by Multi Level Converters

For low-power applications the active power filter is realized by one PWM converter [28-31]. The required voltage and current carrying capacity can be obtained by series and parallel connections of switches. Bit in a high power applications, the filtering cannot be performed by one converter alone, due to the power rating and switching frequency limitations and the problems associated with connecting a large number of switches in series or in parallel. To overcome the above-mentioned restrictions, the concept of multi level topologies was introduced by [32-37] .The general structure of the multilevel converters is to synthesize a staircase voltage waveform from different levels voltages, typically obtained from capacitor voltage sources. Menard and Foch [32] proposed a multi-level converter in which a simulation was presented of 20 kV power systems. The compensation of the current harmonies was carried out up to 19th order. The drawbacks of the multi-level converter are the switching frequency and neutral voltage fluctuation. Cascade multi-converter active power filters based on VSC topology have been proposed by [33-37]**.** They have neither the switching frequency nor neutral voltage fluctuation limitations of multi-level configuration [98]. The drawbacks of cascade multi-converter active power filters are low reliability and control circuit complexity. Another multi-converter active filtering approach is proposed by Huang and WU [37].

The above approach is an extension of the fundamental filtering concepts introduced by the author [36] using three phase voltage source converters. One phase leg of n-level inverter has been shown in Fig 2.8.

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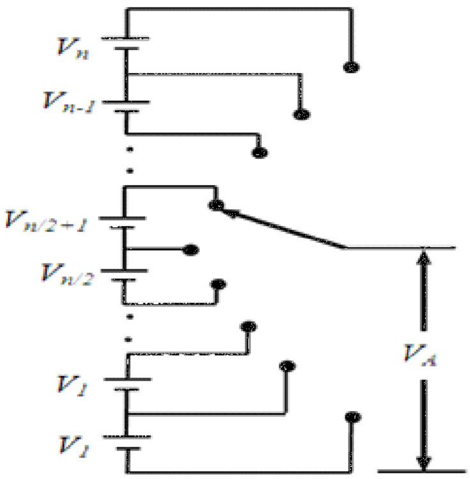

Fig. 2.8: One phase leg of n-level inverter

3. CONCLUSION

After reviewing issues related to the harmonics in power system, this chapter discusses different configurations of filters used to compensate the harmonic distortion in power supply. The conventional type of filters were shunt /series passive filters connected at PCC which provide a low/high impedance path to the harmonics generated, but they have drawbacks such as fixed compensation, resonance, bulky size, high no load losses etc. For a complete compensation of distortions, active power filters were invented and implemented. Many efficient control algorithms are available in literature for the control of three-phase active filters. An effective option namely combination of passive and active filters called hybrid filter is implemented. This chapter surveys various configurations and control algorithms of active filter and hybrid filter, proposed and tested by different authors. Their merits and demerits are briefly touched upon. As per different authors, still there is scope for improvement of hybrid filter performance especially under dynamic conditions of the load.

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