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Harmonic Compensation in Power System using Active Power Filters

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Abstract

The advent of power electronics and computerized equipment in recent decades has brought enhanced efficiency and improved system but at the same time also created harmonics and waveform distortion to the power system network. With high harmonic contents present in the supply network, a higher equipment component failure rate or undesirable tripping of sensitive device might be experienced. This paper presents a combined system of active and passive filters. Passive filters have been most commonly used to limit the flow of harmonic currents in distribution systems. Their performance is limited to a few harmonics, and they can introduce resonance in the power system. Active filter introduces current or voltage components, which cancel the harmonic components of the nonlinear loads or supply lines, respectively.

Keywords: *Harmonics, Passive Filter, Shunt and Series Active Filter, PWM Technique, Multilevel Inverters*

1. Introduction

Harmonic Interference in power system which are produced by harmonic producing load such as diode or thyristor converter or cycloconverters have been serious problem to solve. Passive filters consisting of a bank of tuned LC filters and/ or a high pass filter have been broadly used to suppress harmonics because of low initial cost and high efficiency. But Passive filter suffers with a major disadvantage that parallel resonance between a source and filter causes amplification of harmonic currents on the source side at specific frequencies. Also these filters fall into series resonance with source so that voltage distortion produces excessive harmonic currents flowing through this filter.

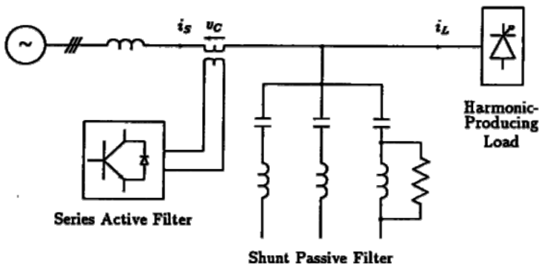

Fig 1. Combination of series active and shunt passive filter

With progresses in power electronics devices, active filters consisting of voltage or current source PWM inverters have been studied and put into practical use because they have the ability to overcome the disadvantages caused by passive filters. However the difficulties faced with active filters are difficult construction of large rated current source with rapid current response and its initial cost and running cost are high fig 1 shows a combination of active filter and shunt passive filter, shunt passive filter connected in parallel with load suppresses the harmonic current produced by the load, whereas the active filter connected acts as a harmonic isolator between the source and the load

This paper presents a combined system of active and passive filter which when connected with power system, passive filters suppresses the harmonics produced by the load, whereas the active filter improves the filtering characteristics of passive filter. Many active filter topologies are introduced and many of them are already in existence.

2. Active and Passive Filters

The simplest method of harmonic filtering is with passive filters. They use reactive storage components, namely capacitors and inductors. Among the more commonly used passive filters are the shunt-tuned LC filters and the shunt low-pass LC filters. They have some advantages such as simplicity, reliability, efficiency, and cost. Among the main disadvantages are the resonances introduced into the ac supply; the filter effectiveness, which is a function of the overall system configuration; and the tuning and possible detuning issues. These drawbacks are overcome with the use of active power filters. Most of the active power filter topologies use voltage source converters, which have a voltage source at the dc bus, usually a capacitor, as an energy storage device. This topology, converts a dc voltage into an ac voltage by appropriately gating the power semiconductor switches. Although a single pulse for each half cycle can be applied to synthesize an ac voltage, for most applications requiring dynamic performance, pulse width modulation (PWM)

PWM techniques applied to a voltage source inverter consist of chopping the dc bus voltage to produce an ac voltage of an arbitrary waveform. There are a large number of PWM techniques available to synthesize sinusoidal patterns or any arbitrary pattern. With PWM techniques, the ac output of the filter can be controlled as a current or voltage source device. Figure 2 shows the way PWM works by means of one of the simplest and most common techniques: the triangular carrier technique. It forces the output voltage v_a over a switching cycle, defined by the carrier period of v_{car}, to be equal to the average amplitude of the modulating wave v_a^{ref}. The resulting voltages for a sinusoidal modulation wave contain a sinusoidal fundamental component $v_{a(1)}$ and harmonics of unwanted components. These unwanted components can be minimized using a frequency carrier as high as possible, but this depends on the maximum switching frequency of the semiconductors (IGBTs, GTOs, or IGCTs).

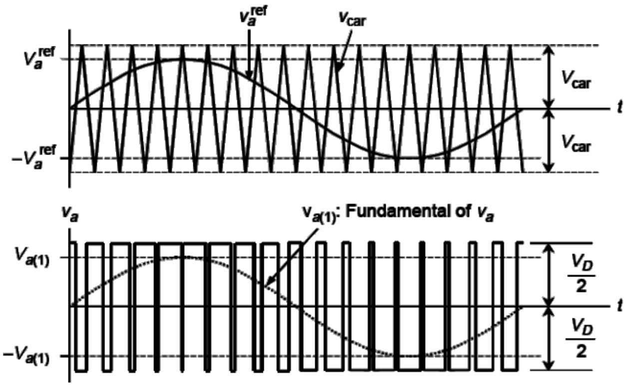

Fig. 2 PWM Carrier technique (Triangular Carrier)

The modulation strategy shown in Figure 2 uses a triangular carrier, which is one of many strategies applied today to control power inverters. Depending on the application (machine drives, PWM rectifiers, or active power filters), some modulation strategies are more suitable than others. The modulation techniques not only allow controlling the inverters as voltage sources but also as current sources. Figure 3 shows the compensating current generated for a shunt active power filter using three different modulation techniques for current-source inverters. These three techniques are periodical sampling (PS), hysteresis band (HB), and triangular carrier (TC). The PS method switches the power transistors of the active filter during the transitions of a square wave clock of fixed frequency: the sampling frequency. The HB method switches the transistors when the error exceeds a fixed magnitude: the hysteresis band. The TC method compares the output current error with a fixed amplitude and fixed triangular wave: the triangular carrier. Figure 3 shows that the HB method is the best for this particular waveform and application because it follows more accurately the current reference of the filter. When sinusoidal waves are required, the TC method has been demonstrated to be better.

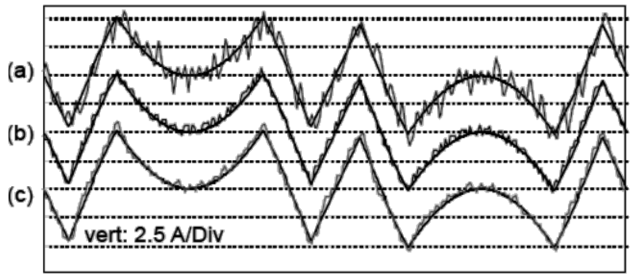

Fig. 3 Current waveforms obtained using different modulation techniques for an active power filter(a) PS method, (b) HB method, (c) TC method.

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type). These filters can also be combined with passive filters to create hybrid power filters.

3. Shunt Active Filters

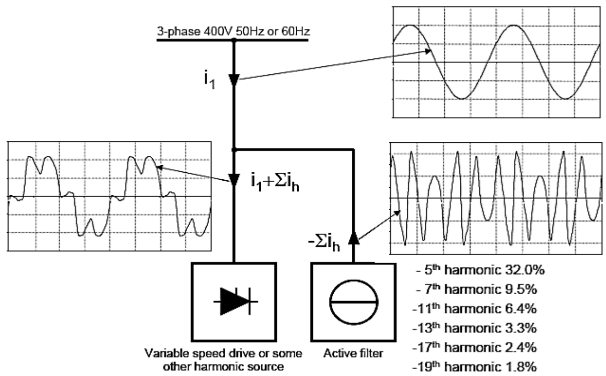

Fig. 4 Effect of connection of active filter parallel to harmonic producing load

Non Linear loads like variable speed drives, Uninterrupted Power supplies and all kind of rectifiers draw a non-sinusoidal current from the network. Therefore they can be considered to be harmonic current source. Shunt Active filters works as a current source which, when properly designed and controlled, produces harmonic currents having opposite phase then those harmonic currents produced by non linear loads. When such a shunt active filter is connected in parallel with a non linear load its harmonic currents are compensated and the network is loaded with almost fundamental current only.

Connecting this active filter parallel with the load the harmonics are compensated and the network is loaded by almost fundamental current only as shown in fig 3. It should be noted that the output current of active filter has a continuous spectrum of all harmonics due to the accuracy of control system Figure 4 shows the connection of a shunt active power filter

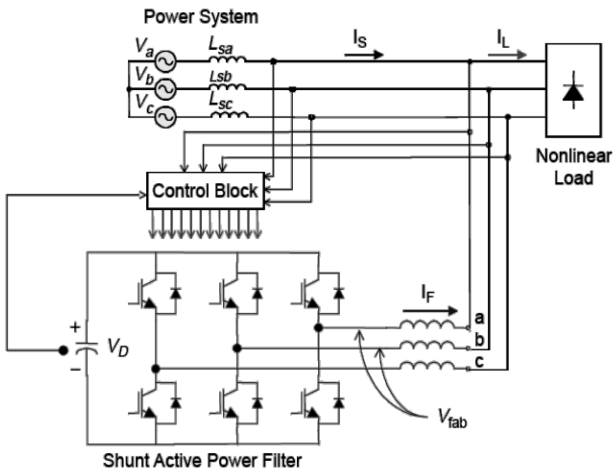

Fig 4 Connection of Shunt Active Filter

The following results show a comparison between PWM and multilevel converter methodologies. These results have been obtained using a software called PSIM, which have been corroborated with real experimental results. The fig 5 compares the current quality obtained with a shunt active power filter implemented with a PWM converter working at 10 kHz switching frequency, and with the four stage converter. Both the figures show the load current (a three-phase diode rectifier), the source current, and the filter current

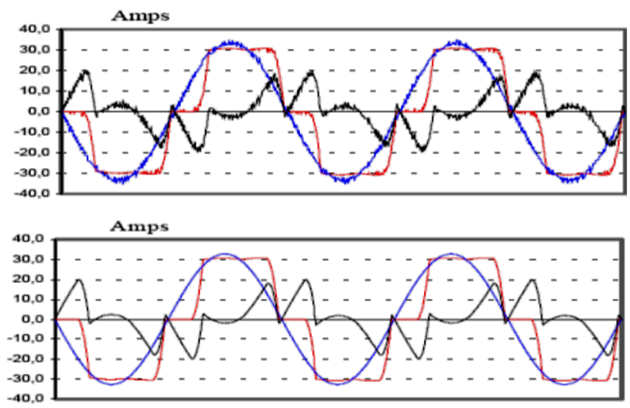

Fig 5 Active Power Filter Waveform (a)PWM Technique, (b)Multilevel Technique

4. Series Active Filter

Series active power filters were introduced to operate mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series-connected filter protects the system from an inadequate supply-voltage quality. This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the ac supply and for low-power applications and represents an economically attractive alternative to UPS, since no energy storage (battery) is necessary and the overall rating of the components is smaller. The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. In many cases, series active filters work as hybrid topologies with passive LC filters. If passive LC filters are connected in parallel to the load, the series active power filter operates as a harmonic isolator, forcing the load current harmonics to circulate mainly through the passive filter rather than the power distribution system. The main advantage of this scheme is that the rated power of the series active filter is a small fraction of the load kVA rating, typically 5%. However, the apparent power rating of the series active power filter may increase in case of voltage compensation. Fig 6 shows how the series filter works to compensate the voltage harmonics on the load side.

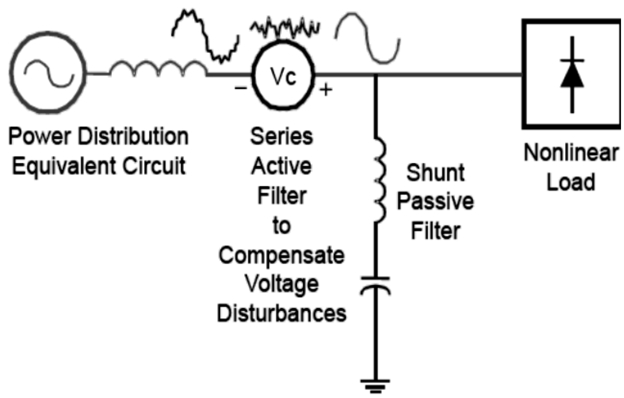

Fig 6 Series Filter compensating voltage harmonics

An interesting combination topology is shown in Fig 6. The shunt active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology has been called the Unified Power Quality conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter, and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power, and load current unbalances. In addition, it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses.

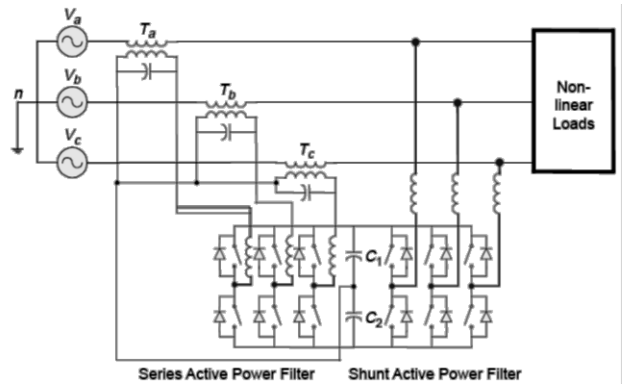

Fig 7. Unified Power Quality Conditioner

5. Multilevel Converters

Multi-stage converters work more like amplitude modulation rather than pulse modulation, and this fact makes the outputs of the converter very much cleaner. This way of operation allows almost perfect currents, and very good voltage waveforms, eliminating most of the undesirable harmonics and even better. The bridges of each converter work at a very low switching frequency, which gives the possibility to work with low speed semiconductors, and to generate low switching frequency losses. Three-level inverters are becoming very popular

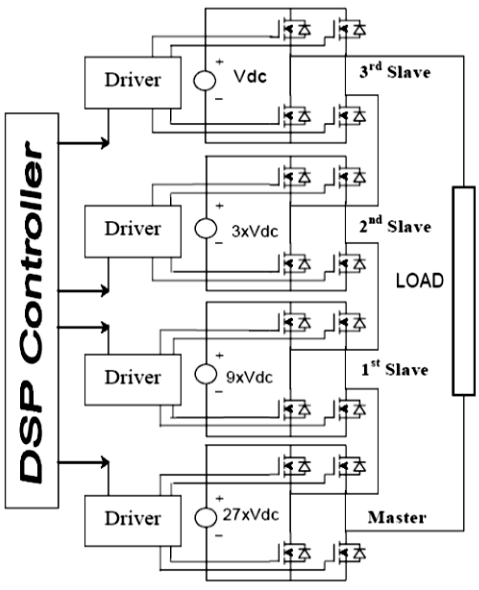

Fig.8 Main Components of a four stage multi converter

today for most inverter applications, such as machine drives and power factor compensators. The advantage of multilevel converters is that they can reduce the harmonic content generated by the active filter because they can produce more levels of voltage than conventional converters (more than two levels). This feature helps to reduce the harmonics generated by the filter itself. Another advantage is that they can reduce the voltage or current ratings of the semiconductors and the switching frequency requirements. The more levels the multilevel inverter has, the better is the quality of voltage generated because more steps of voltage can be created. The figure 8 displays the main components of a four-stage converter. The figure only shows one of the three phases of the complete system. As can be seen, the dc power supplies of the four converters are isolated, and the dc supplies are scaled with levels of voltage in power of three.

The scaling of voltages in power of three allows having, with only four converters, 81 different levels of voltage 40 levels of positive values, 40 levels of negative values, and zero. The converter located at the bottom of the figure has the bigger voltage, and will be called Master. The rest of the modules will be the Slaves. The Master works at the lower switching frequency, which is an additional advantage of this topology. With 81 levels of voltage, a four-stage converter can follow a sinusoidal waveform in a very precise way, as shown in figure 9. It can control the load voltage as an AM device (Amplitude Modulation). The figure 9 shows different levels of amplitude, which are obtained through the control of the gates of the power transistors in each one of the four converters.

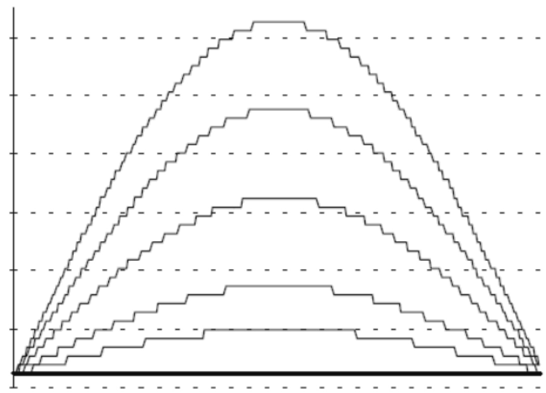

Fig 9. Voltage AM using four stage converter

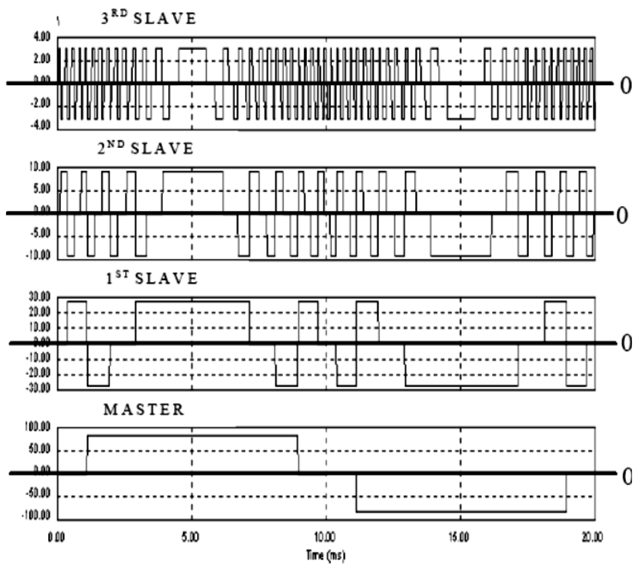

Fig.10 Voltage modulation in each converter

Conclusion

After discussing about various types of filters shunt and series their location , behavior and their harmonic reduction technique, we can infer that in comparison to conventional passive LC filters, active power filters offer very fast control response and more flexibility in defining the required control tasks for particular applications. If the objective is to reduce the network perturbations due to distorted load currents, the shunt connection is more appropriate. If the problem is to protect the consumer from supply-voltage disturbances, the series-connection is most preferable. The combination of the two topologies gives a solution for both problems simultaneously. With the new semiconductor devices and topologies coming inthe near future, active power filters will increase their ability to keep the power distribution systems clean and free of dangerous perturbations. However, at the same time, electronic equipment will become more and more sensitive to power quality disturbances. Active power filters are typically based on GTOs or IGBTs, voltage source PWM converters, connected to medium- and low-voltage distribution systems in shunt, series, or both topologies at the same time.

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