

Importance of Active Filters for Improvement of Power Quality

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ABSTRACT: The Problems due to Harmonics and reactive power losses has been pertaining from the decades. Since many methods are proposed to reduce those above mentioned problems. one of the best method is employing Active Filters for the elimination of Harmonics and compensation of reactive power problems. This paper mainly explains about the new AF technology and different topologies utilizing in the present scenario, economical approach etc for the improvement of power quality. Presently many countries has been using this AF technology, because of its capacity to eliminate the harmonics up to 25th level & more and also size of filter is also reduced.

Keywords: Voltage source inverter, current source inverter ,Active power line conditioners, Harmonics and Reactive power compensation, Active power filters ,power quality .

I INTRODUCTION

The control of ac power using thyristors and the other , semiconductor switches is widely employed to feed the controlled electrical power to electrical loads such as the adjustable speed drives., furnaces , computer supplies etc. such controllers are also used in HvdC Systems & the renewable electric power generation. As non linear loads these solid state converters draw harmonic & reactive power components of current from ac mains. In three phase system they could also cause unbalance and draw excessive neutral currents. The injected Harmonics and reactive power burden unbalance and excessive neutral currents causes low system efficiency and Poor power factor.

They also cause disturbance to other consumers and interference in near by communication networks. Boundless surveys has been carried out to reduce the problems affiliated with electrical power networks having nonlinear loads. customarily passive LC filters were used to debase the Harmonics and capacitors were used to employed to improve the power factor of the ac loads. however passive filters have the enforcement of fixed compensation. large size and

resonance . the elevated austerly of harmonic pollution in power networks has attracted the deliberation of the power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems Such equipment generally know as active filters.(AF). Are also called as active power line conditioners(APLCS),instantaneous reactive power compensators (IRPC's),Active power filter(APF's),and Activepowerquality conditioners(APQC's).In recent years many publications are also appeared on harmonics, reactive power, load balancing and neutral current compensation associated with linear and non linear loads.

This paper mainly covers the state of the art of AF technology the different approaches used, the control topologies, the economical and specialized considerations their selection for specific areas of applications and terminating remarks.

II STATE OF ART

The state of art mostly describes, how the AF technology is represented. AF technology is full fledged for providing compensation for reactive power, harmonics and neutral current in ac networks it has evolved in the past quarter century of development with varying configurations ,control topologies .AF's are also used to terminate the voltage harmonics, to regulate terminal voltage, to inhibit voltage flicker and to advance voltage balance in 3- phase systems. AF's are basically classified into three types, namely two wire, three wire and four wire three phase configurations to meet the requirements of 3- types of non linear loads.

1-phase loads, such as domestic loads such as lights and ovens, TV's, computer power supplies, air conditioners, laser printers, and Xerox machines act as nonlinear and cause power quality problems. Single-phase (two wire) AF's are examined in varying configurations and control topologies to meet the needs of 1-phase nonlinear loads. Starting in 1973, many approaches such as the active series filter , active shunt filter and combination of shunt and series filter have been refined and commercialized also for uninterruptible power supply (UPS)

applications . Both concepts based on a current- source inverter (CSI) with inductive energy storage and a voltage-source inverter (VSI) with capacitive energy storage are used to develop single-phase AF's. Since hefty amounts of ac power are consumed by three- phase loads such as ASD's with solid-state control. Lately, many ASD systems incorporate AF's in their front-end design. A substantial number of publications have reported on three- phase three wire AF's . Active shunt, active series, and combinations of both, named as active power quality conditioners , as well as passive filters combined with active shunt and active series AF's are some typical configurations used. Many control methods such as instantaneous reactive power theory initially developed by Akagi *et al.* , synchronous frame *d-q* theory , synchronous detection method , and notch filter method are used in the development of three-phase AF's.

The problem of excessive neutral current is observed in three-phase four-wire systems, mainly due to nonlinear un- balanced loads, such as computer power supplies, fluorescent lighting, etc. Analyzing the problems of neutral current and unbalanced load currents has been attempted in for four-wire systems. These attempts are of varying nature, like elimination/decrease of neutral current, harmonic com- pensation, compensation of reactive power.

A extreme volume of work is reported on the data related to the tracking and measurement of the various quantities, such as real power, reactive power, etc., in the presence of harmonics in the supply systems with nonlinear loads. These concepts are quite relevant to extract the control signals for AF's and for the improvement of instruments to measure conventional and newly defined quantities in the presence of harmonics and unbalance. For measuring the performance of AF's, it is important to develop good measuring systems, and these new concepts have given a new growth to instrumentation technology in this field.

The problems of reactive power and unbalance of load were identified long ago, and they became worse in the presence of nonlinear loads. Many paper publications report on solid-state compensators for voltage flicker, reactive power, and balancing the nonlinear reactive loads, such as arc furnace, traction loads, etc. Many more terminologies, such as static var compensators, static flicker compensators, static var generators, etc., have been used in the literature.

One of the important factors in advancing the AF technology is the advent of fast self-commutating solid-state devices called power electronic devices. In the initial stages, thyristors, bipolar junction transistors (BJT's)

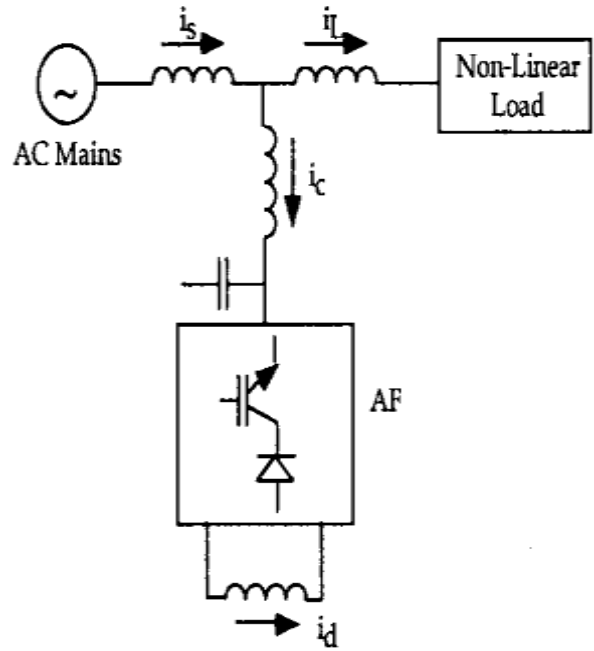


Fig 1 current –fed -type

and power MOSFET's were used for AF fabrication; coming after, static induction thyristors (SIT's) and gate-turn-off thyristors (GTO's) were employed to develop AF's. With the introduction of insulated gate bipolar transistors (IGBT's), the AF technology got a real boost and, at present, they are considered as ideal power electronic devices for AF's. The advanced sensor technology has also contributed to the enhanced performance of the AF. The possibility of Hall-effect sensors and isolation amplifiers at reasonable cost and with adequate ratings has improved the AF performance.

The next important discovery in AF improvement has resulted from the microelectronics revolution. Starting from the use of discrete analog and digital components , the progression has been to microprocessors, microcontrollers , and digital signal processors (DSP's) . Now, it is possible to develop complex algorithms on-line for the control of the AF at reasonable amount. This improvement has made it possible to use different control algorithms such as, proportional integral (PI) , variable-structure control , fuzzy logic, and neural nets for improving the dynamic and steady-state performance of the AF. With these improvements, the AF's are capable of providing fast corrective action, even with dynamically changing nonlinear loads. Moreover, these AF's are found to compensate quite a sum of higher order harmonics

(typically up to the 25th).

III. CONFIGURATIONS

AF's can be classified based on type of converter, topology, and the number of phases. The type of converter can be either CSI or VSI bridge structure. The topology can be shunt, series, or a combination of both. The third classification is based on the number of phases, such as two-wire (single phase) and three- or four-wire three-phase systems. The three classifications were clearly explained with necessary diagrams as shown below.

A. Converter-Based Classification

There are two types of converters used in the development of AF's. Fig. 1 shows the current-fed pulse width modulation (PWM) inverter bridge. It functioned as a non sinusoidal current source to meet the harmonic current requirement of the nonlinear load. A diode is used in series with the self commutating device (IGBT) for reverse voltage blocking. However, GTO-based configurations do not need the series diode, but they have restricted frequency of switching. They

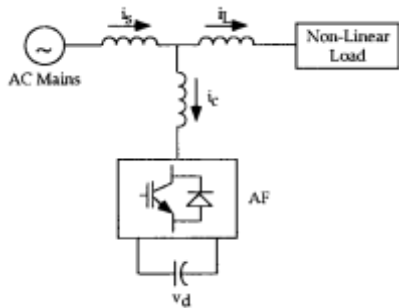


Fig. 2. Voltage-fed-type AF.

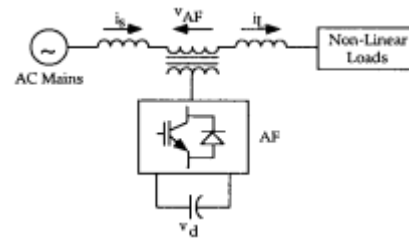


Fig. 3. Series-type AF.

are considered sufficiently trust worthy, but have higher losses and require higher values of parallel ac power capacitors. Moreover, they cannot be used in multilevel or multistep modes to improve performance in higher ratings.

The other type of converter used as an AF is a voltage-fed PWM inverter structure, as shown in Fig. 2. It has a self-supporting dc voltage bus with a large dc capacitor. It has become more dominant, since it is lighter, cheaper, and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies. It is more popular in UPS-based applications, because in the presence of mains, the same inverter bridge can be used as an AF to suppress harmonics of critical nonlinear loads.

B. Topology-Based Classification

AF's can be classified based on the topology used as series or shunt filters and unified power quality conditioners use a combination of both. Combinations of active series and passive shunt filtering are known as hybrid filters. Fig. 2 is an example of an active shunt filter, which is mostly used to suppress current harmonics, reactive power compensation (also known as STATCOM), and balancing unbalanced currents. It is mainly used at the load end, because current harmonics are injected by nonlinear loads. It injects equal compensating currents, opposite in phase, to cancel harmonics and/or reactive components of the nonlinear load current at the point of connection. It can also be used as a static var generator (STATCON) in the power system network for stabilizing and improving the voltage profile.

Fig. 3 shows the basic block of a stand-alone active series filter. It is connected before the load in series with the mains,

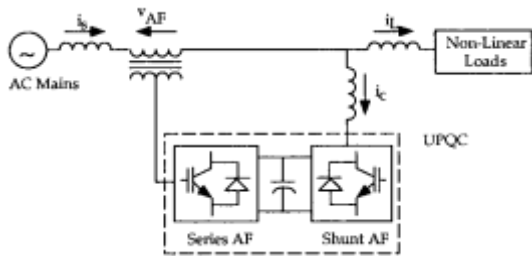


Fig. 4. Unified power quality conditioner as universal AF.

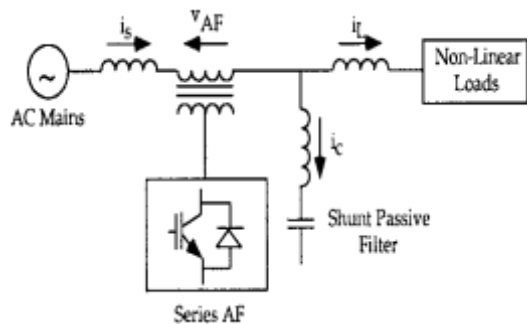


Fig. 5. Hybrid filter as a combination of active series and passive shunt filters.

using a matching transformer, to eliminate voltage harmonics, and to balance and regulate the terminal voltage of the load or line. It has been used to decrease negative-sequence voltage and regulate the voltage on three-phase systems. It can be installed by electric utilities to reduce voltage harmonics and to damp out harmonic propagation caused by resonance with line impedances and passive shunt compensators.

Fig. 4 shows a unified power quality conditioner (also known as a universal AF), which is a combination of active shunt and active series filters. The dc-link storage element (either inductor or dc-bus capacitor) is shared between two current-source or voltage-source bridges operating as active series and active shunt compensators. It is used in single-phase as well as three-phase configurations. It is considered an ideal AF which eliminates voltage and current harmonics and is capable of giving clean power to critical and harmonic-area loads, such as computers, medical equipment, etc. It can balance and regulate terminal voltage and eliminate negative-sequence currents. Its main drawbacks are its large cost and control complexity because of the large number of solid-state devices involved. Fig. 5 shows the hybrid filter, which is a blend of an active series filter and passive shunt filter. It is quite known than others because the solid-state or power electronic devices used in the active

series part can be of reduced size and cost and a major part of the hybrid filter is made of the passive shunt $L-C$ filter used to suppress lower order harmonics. It has the capability of decreasing voltage and current harmonics at a reasonable cost. There are many more hybrid configurations but for the sake of brevity, they are not discussed here; however, details can be found in the respective references.

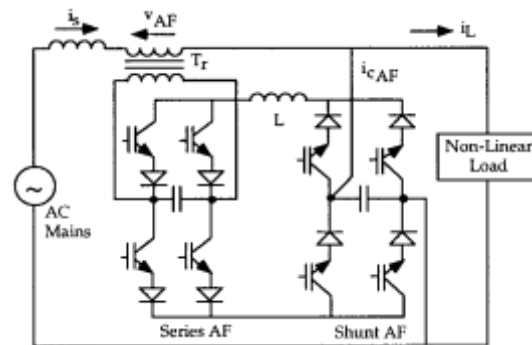


Fig. 6. Two-wire series AF with current-source converter.

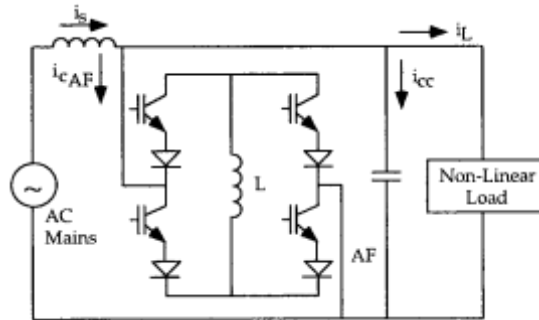


Fig. 7. Two-Wire shunt AF with current-source converter.

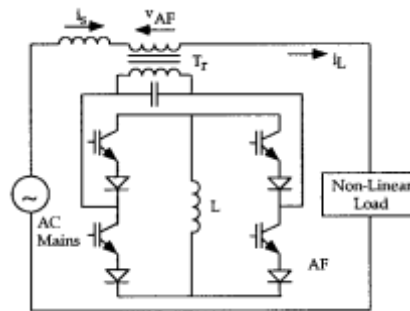


Fig. 8. Two-wire unified power quality conditioner with current-source converter.

C. Supply-System-Based Classification

This categorization of AF's is based on the supply and/or the load system having single-phase (two wire) and three-phase (three wire or four wire) systems. There are many nonlinear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase nonlinear loads are without neutral, such as ASD's, fed from three-wire supply systems. There are many nonlinear single-phase loads distributed on four-wire three-phase supply systems, such as computers, commercial lighting, etc. Hence, AF's may also be classified accordingly as two-wire, three-wire, and four-wire types.

1) *Two-Wire AF's*: Two-wire (single phase) AF's are used in all three modes as active series, active shunt, and a combination of both as unified line conditioners. Both converter configurations, current-source PWM bridge, with inductive energy storage element and voltage-source PWM bridge with capacitive dc-bus energy storage elements, are used to form two-wire AF circuits. In some cases, active filtering is included in the power conversion stage to improve input characteristics at the supply end.

Figs. 6–8 show three configurations of active series, active shunt, and a combination of both with current-source bridge, using inductive storage elements. Similar configurations, based on a VSI bridge, may be obtained by considering only two wires (phase and neutral) at each stage of Figs. 2–4. In the case of a series AF with voltage-fed converter, sometimes the transformer is removed and load is shunted with passive $L-C$ components. The series AF is normally used to eliminate the

voltage harmonics, spikes, sags, notches, etc., while the shunt AF is used to suppress current harmonics and compensation of reactive power.

2) *Three-Wire AF's*: Three-phase three-wire nonlinear loads, such as ASD's, are major applications of solid-state power converters and, lately, many ASD's, etc., incorporate AF's in their front-end design. A large number of publications have appeared on three-wire AF's with different configurations. All the configurations shown in Figs. 1–5 are developed, in three-wire AF's, with three wires on the ac side and two wires on the dc side. Active shunt AF's are developed in the current-fed type (Fig. 1) or voltage-fed type with single-stage (Fig. 2) or multistep/multilevel and multi series configurations. Active shunt AF's are also designed with three single-phase AF's with isolation transformers for proper voltage matching, independent phase control, and reliable compensation with unbalanced systems. Active series filters are developed for stand-alone mode (Fig. 3) or hybrid mode with passive shunt filters (Fig. 5). The latter (hybrid) has become popular to decrease in the size of power devices and cost of the overall system. A combination of active series and active shunt is used for unified power quality conditioners (Fig. 4) and universal filters.

3) *Four-Wire AF's*: A large number of single-phase loads may be supplied from three-phase mains with neutral conductor. They cause excessive neutral current, harmonic and reactive power burden, and unbalance. To reduce these problems, four-wire AF's have been attempted. They have been developed as: 1) active shunt mode with current feed and voltage feed; 2) active series mode; and 3) hybrid form with active series and passive shunt mode. Figs. 9–11 show three typical configurations of shunt AF's. The first configuration of a four-wire shunt AF is known as the capacitor midpoint type, used in smaller ratings. Here, the entire neutral current flows through dc-bus capacitors which are of a large value. Fig. 10 shows another configuration known as the four-pole switch type, in which the fourth pole is used to stabilize the neutral of the AF. The three single-phase bridge configuration, shown in Fig. 11, is quite common and this version allows the proper voltage

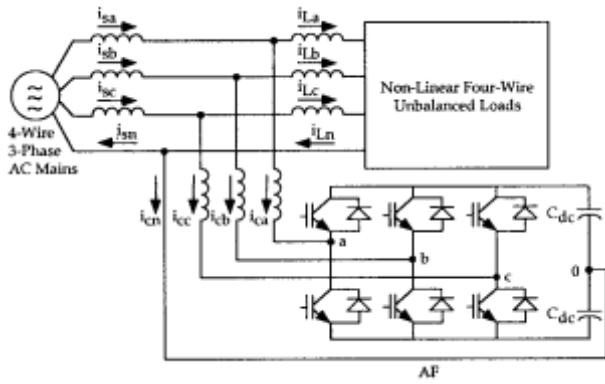


Fig. 9. Capacitor midpoint four-wire shunt AF.

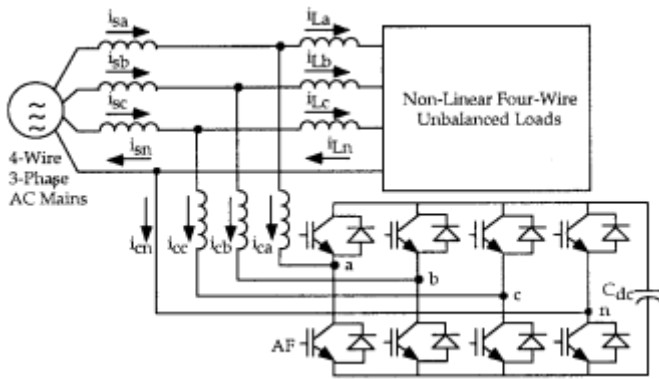


Fig. 10. Four-pole four-wire shunt AF.

matching for solid-state devices and enhances the reliability of the AF system. A detailed comparison of the features of these three configurations (Figs. 9–11).

IV. CONTROL TECHNIQUES

Control strategy is the heart of the AF and is implemented in three stages. In the first stage, the essential voltage and current signals are sensed using power transformers (PT's), CT's, Hall-effect sensors, and isolation amplifiers to gather accurate system information. In the second stage, compensating commands in terms of current or voltage levels are based on control methods and AF configurations. In the third stage of control, the gating signals for the solid-state devices of the AF are generated using PWM, hysteresis, sliding-mode, or fuzzy-logic-based control techniques. The control of the AF's is realized using discrete analog and digital devices or advanced microelectronic devices, such as single-chip microcomputers, DSP's, etc.

A. Signal Conditioning

For the purpose of implementation of the control algorithm, several instantaneous voltage and current signals are required. These signals are also useful to monitor, measure, and record various performance indexes, such as total harmonic distortion (THD), power factor, active and reactive power, crest factor, etc. The typical voltage signals are ac terminal voltages, dc-bus voltage of the AF, and voltages across series elements. The current signals to be sensed are load currents, supply currents, compensating currents, and dc-link current of the

AF. Voltage signals are sensed using either PT's or Hall-effect voltage sensors or isolation amplifiers. Current signals are sensed using CT's and/or Hall-effect current sensors. The voltage and current signals are sometimes filtered to avoid noise problems. The filters are either hardware based (analog) or software based (digital) with either low-pass, high-pass, or band pass characteristics.

B. Development of Compensating Signals

Development of compensating signals either in terms of voltages or currents is the important part of AF control and affects their rating and transient, as well as steady-state performance. The control strategies to generate compensation commands are based on frequency-domain or time-domain correction techniques.

1) *Compensation in Frequency Domain:* Control led approach in the frequency domain is based on the Fourier analysis [FIT analysis] of the distorted voltage or current signals to extract compensating commands. Using the Fourier transformation, the compensating harmonic components are separated from the harmonic-polluted signals and combined to generate compensating commands. The device switching frequency of the AF is kept generally more than twice the highest compensating harmonic frequency for effective compensation. The on-line application of Fourier transform (solution of a set of nonlinear equations) is a cumbersome computation and results in a large response time.

2) *Compensation in Time Domain:* Control methods of the AF's in the time domain are based on instantaneous derivation of compensating commands in the form of either voltage or current signals from distorted and harmonic-polluted voltage or current signals. There is a large number of control methods in the time domain, which are known as instantaneous "p-q" theory, synchronous d-q reference frame method, synchronous detection method, flux-based controller, notch filter method, P-I controller, sliding-mode controller.

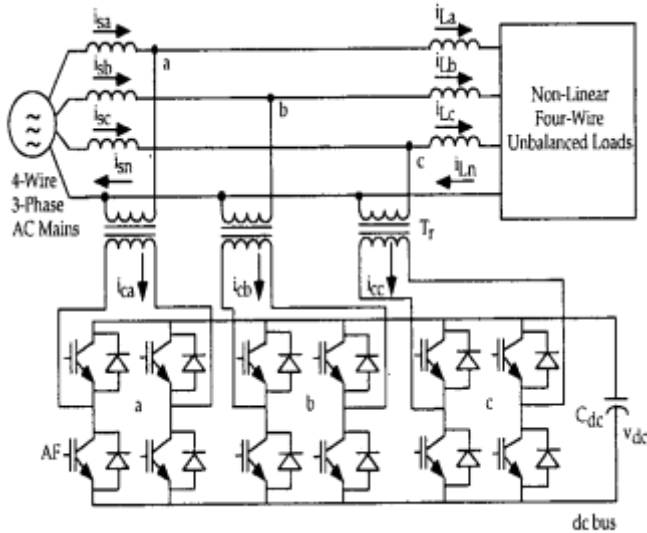


Fig:11 Three bridge four wire shunt

The instantaneous active and reactive power ($p-q$) theory has been widely used and is based on “ $-\beta$ ” transformation of voltage and current signals to derive compensating signals. The instantaneous active and reactive power can be computed in terms of transformed voltage and current signals. From instantaneous active and reactive powers, harmonic active and reactive powers are extracted using low-pass and high-pass filters. From harmonic active and reactive powers, using reverse “ $-\beta$ ” transformation, compensating commands in terms of either currents or voltages are derived. In the synchronous $d-q$ reference frame and flux-based controllers, voltage and current signals are transformed to a synchronously rotating frame, in which fundamental quantities become dc quantities, and then the harmonic compensating commands are extracted. The dc-bus voltage feedback is generally used to achieve a self-supporting dc bus in voltage-fed AF’s. In the notch-filter-based method, the compensating commands are drawn out using notch filters on distorted voltage or current signals. In P-I and sliding-mode controllers, either dc-bus voltage (in a VSI) or dc-bus current (in a CSI) is maintained to the desired value and reference values for the magnitudes of the supply currents are obtained.

V. SELECTION OF COMPONENTS AND ADDITIONAL FEATURES OF AF’S

The selection of components of the AF’s is an important factor to achieve improved performance. The main component of the AF is the solid-state device. In the earlier days, BJT’s followed by MOSFET’s were used in small ratings. Nowadays, the IGBT is an ideal choice up to medium ratings, and GTO’s are used in higher ratings..

The value of this inductor is very crucial in the performance of the AF’s. If a small value of L_{cr} is selected, then large switching ripples are injected into the supply currents, and a large value of L_{cr} does not allow proper tracking of the compensating currents close to the desired values. A best selection of L_{cr} is necessary to obtain good performance of the AF. previously, a passive ripple filter is used at the terminal of the supply system, which compensates for switching harmonics and improves the Total Harmonic Distortion of the supply voltage and current. The design of the passive ripple filter is also important, because source impedance can cause an interaction with its components. The dc-bus capacitor value C_{dc} of the AF’s is another important parameter. With a small value of C_{dc} , large ripples in the steady state and wide fluctuations in the dc-bus voltage under transient conditions are observed. A higher value of C_{dc} reduces ripples and fluctuations in the dc-bus voltage, but increases the cost and size of the system AF’s are used to compensate current and voltage harmonics, but in most cases, they also have more functions, such as reactive power compensation, current and voltage unbalance, neutral current, voltage flicker, voltage spikes, and for voltage regulation. Most of the voltage-related compensations are carried out using series AF’s, while current related compensations (reactive power, current unbalance, etc.) are made using shunt AF’s. Sometimes, the structure similar to AF’s is used exclusively for additional features, such as reactive power compensation, load balancing, voltage regulation and voltage unbalance compensation, etc.

VI. ECONOMICAL & TECHNICAL APPROACHES

Technical literature on the AF’s has been reported since and, in the last two decades, has boomed.

Around 1990, many commercial development projects were completed and put into practice. A number of approaches discussed earlier have been investigated, but could not be developed commercially because of cost and complexity considerations. Initially reported configurations were quite general and the rating of solid-state devices involved was consequential, which resulted in high cost. Due to these reasons, the technology could not be translated to field applications. Later on, the rating of active filtering was reduced by the introduction of supplementary passive filtering, without deteriorating the overall filter performance. Moreover, modern AF's are capable of compensating quite high orders of harmonics (typically, the 25th) dynamically.

VII. CONCLUSION

An boundless use of AF's has been presented to provide a clear awareness on various aspects of the AF to the researchers and engineers working in this field. The consequential increase in the use of solid-state power control results in harmonic pollution above the adequate limits. Utilities are finding it difficult to maintain the power quality at the consumer end, and consumers are paying the penalties indirectly in the form of increased plant downtimes, etc. At present, AF technology is well developed, and many manufacturers are fabricating AF's with large capacities. The utilities in the long run will abet the consumers with nonlinear loads to use the AF's for maintaining the power quality at acceptable levels. A large number of AF configurations are available to compensate harmonic current, reactive power, neutral current, unbalance current, and harmonics. The consumer can select the AF with the required features depends upon the system.

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