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Harmonics Cancellation in Distribution Systems by Using a Hybrid Four-Branch Star Filtering Topology

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Abstract: This paper presents a new solution for filtering current harmonics in three-phase four-wire networks. The original four-branch star (FBS) filter topology presented in this paper is characterized by a particular layout of single-phase inductances and capacitors, without using any transformer or special electromagnetic device. Via this layout, a power filter, with two different and simultaneous filter resonance frequencies and sequences, is achieved—one frequency for positive-/negative-sequence and another one for zero-sequence components. This filter topology can work either as a passive filter, when only passive components are employed, or as a hybrid filter, when its behavior is improved by integrating a power converter into the filter structure.. The paper analyzes the proposed topology, and derives fundamental concepts about the control of the resulting hybrid power filter. From this analysis, a specific implementation of a three-phase four-wire hybrid power filter is presented as an illustrative application of the filtering An extensive evaluation using simulation designed and experimental results from a DSP-based laboratory prototype is conducted in order to verify and validate the good performance achieved by the proposed FBS passive/hybrid power.
Index Terms: Active power filters, hybrid power filters, passive power filters, power line filters, power system harmonics, reactive power control.

I. INTRODUCTION

International standard regulating current harmonics in distribution networks reflects the importance of the problem originated by current harmonics in terms of power quality reli ability, and continuity of supply, mainly at low-voltage (LV) levels. Current harmonics in distribution grids mostly result from the widespread usage of nonlinear loads. Discharge lamps and power-electronics-based equipments are two frequent examples of nonlinear lo ads in residential, commercial, and industrial facilities. Currents harmonics also have a significant effect on medium-voltage (MV) and LV networks due to the existence of singular loads such as furnace ovens and high power line rectifiers Three-phase three-wire loads generate positive-/negative sequence (pn-seq) current harmonics. These harmonics give rise to resonances, voltage distortion, overheating, and increase in losses, malfunction and premature ageing of electrical equipments, etc. Single-phase nonlinear loads are usually connected between the phase and neutral conductors, and, additionally, originate zero sequence (z-seq) current harmonics typically with 3rd, 9th, and 15th harmonic order. Harmonics with order of multiple of three resulting from several single-phase loads are summed up in the neutral conductor, which can result in a harmonic current in the neutral conductor up to three times higher than in the phase ones. Z-seq harmonic currents, also causing characteristic problems related to pn-seq harmonic currents, can give rise to neutral conductor overload, common mode neutral to earth voltages, increase of phase voltage distortion, and transformers overheating . Shunt-connected current power filters can be classified as Shunt passive power filters (SPPFs) Each one of these shunt filters is designed to offer a very low Impedance path to current harmonics at the tuning frequency. Main advantages of the SPPFs are their simplicity and low cost. However, these advantages are, in fact, shadowed because of the dependence of the filtering characteristic on the grid impedance. Resonance frequency of the SPPF is also modified by parameters tolerance and filter ageing Additionally, the usage of SPPF implies losses at the fundamental grid frequency, and can result in parallel/ series resonances. Shunt active power filters These filters exploit a power-electronics-based power converter working in closed-loop mode as a current source. SAPFs are able to cancel out harmonics and unbalance from the load current, which results in sinusoidal balanced current at fundamental frequency flowing toward the source side. Even though SAPF can filter current harmonics in a very precise form ,their cost is relatively high, which slows down their large scale application in distribution networks Shunt hybrid power filters (SHPFs*)* These filters result from the combination of passive and active power filters taking advantages from both of them SHPF exhibits a fairly good filtering characteristic, which is almost independent of the grid impedance Moreover, the cost of a SHPF is substantially lower than in the case of a SAPF.

This cost reduction is mainly due to the low power rate of the power converter used in SHPF SPPF are conventionally based on simple resonant cells, and have only one resonance frequency, being designed to predominantly drain current away at such resonance frequency Therefore, it is necessary to install as many individual *LC* filters as characteristic current harmonics should to be canceled out. SPPF are not typically applied to cancel the third-order current harmonic, the highest among the z-seq current harmonics. If an SPPF was tuned at the third harmonic, the resonance frequency of the *LC* resonant cell would be very close to the fundamental frequency, typically 50/60 Hz. As a consequence, the current absorbed by the filter at the fundamental frequency, for a reasonable quality factor, would be around the current drained at the third harmonic, which would make this filtering solution economically unviable Some of the techniques commonly applied to cancel z-seq current harmonics in electrical networks are as Shunt zig-zag reactors these kinds of reactors present very low impedance to the z-seq current components. Passive LC power filters with a very high-quality factor the bandwidth of these passive filters is drastically reduced with the aim of reducing the maximum current absorbed at the fundamental frequency. However, they are easily detuned because of parameter tolerance, aging, and influence of the network. Third-harmonic blocking power *filters* in series with the neutral conductor These filters act as high impedance blocks to the third-harmonic current. This high impedance limits current flowing through the neutral conductor but deteriorates the phase to neutral voltage .Active and hybrid filters These filters are based on power converters, sometimes using particular transformer configurations. Power converters allow controlling the filtering characteristic, making this kind of filter very suitable to efficiently cancel out z-seq current harmonics. This paper presents an interesting solution for filtering current harmonics in three-phase four-wire networks. The proposed filter is based on a four-branch star (FBS) topology characterized by a particular layout of single-phase inductors and capacitors ,without using any transformer or special electromagnetic device. Via this layout, a power filter, with two different and simultaneous resonance frequencies and sequences, is achieved, i.e., one frequency for pn-seq and another one for z-seq components. The resonant cells constituting the branches of the FBS filter are designed to drain away either one or several pn-seq components among the 5th-, 7th-, 11th-, and 13th-order harmonics plus either one or several z-seq components among the 3rd, 9th,and 15th current harmonics . The FBS filter topology can work either in passive mode ,when only passive components are employed, or in hybrid mode, when a power converter is integrated into the FBS structure to improve its filtering performance In the following, the FBS topology is introduced and some of its most interesting variants are highlighted. A three-phase four wire hybrid power filter is chosen as a preferred implementation of the FBS topology, being analyzed and evaluated by both Simulation and experiments. The general structure of the shunt power filter topology proposed in this paper is shown in Fig. 1. The pn-seq and the z-seq voltage components of the three-phase network that the filter is connected to are also represented in Fig. 1. The FBS topology consists of three phase branches with three identical single-phase impedances *Zf* and one neutral branch with a fourth single-phase impedance *Zn.*

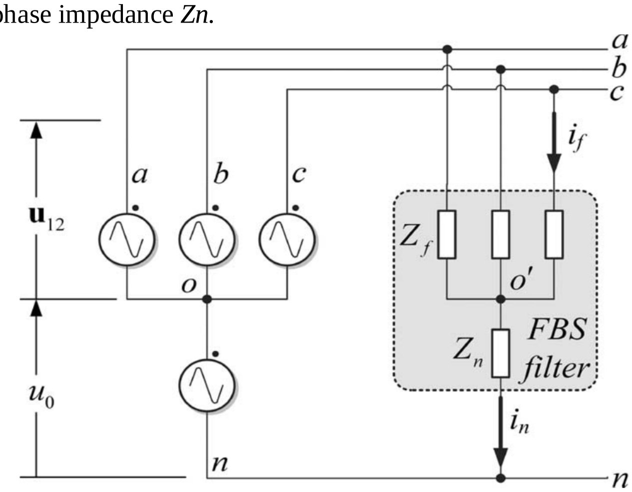

Fig. 1. 1FBS power filter with generic branch impedances

In Fig. 1, the FBS power filter is connected to a generic three-phase network in which pn-seq voltage components**u**12 =[*uao, ubo, uco*] and z-seq voltage components *u*0 have been represented separately for the sake of clarifying the superposition analysis presented in the following. When only pn-seq components are considered in the circuit of Fig. 1, i.e., when it is assumed that *u*0 = 0, the center nodes at the source and filter sides (*o–o*) are virtually connected, and hence, *voo* = 0. Therefore, the pn-seq impedance of the FBS power filter at a particular frequency *Z*12 is given by the given by the following quotient of pharos Z12 =U12/I12=Ufo/If=Ufo/If=Zf , with f = {a, b, c} where U12 and I12 are the pn-seq voltage and current phasors

II. FBS POWER FILTER TOPOLOGY

The single-phase impedances constituting the branches of FBS power filter are resonant cells, which could have several resonance frequencies. Connection of these resonant cells according to FBS topology gives rise to two groups of resonance frequencies, i.e., one group for the pn-seq components and another one for the z-seq components. This implies that the shunt passive power filter with FBS topology is able to perform selective filtering of current harmonics by setting up low-impedance paths to explicit current components with specific frequencies and sequences. Even though the resonant cells composing the FBS filter branches can be really complex in some particular applications ,a reasonably good filtering characteristic is obtained in practice when such resonant cells have a single resonance frequency. Simple *LC* resonant cells will be considered in this introduction of the FBS power filter.

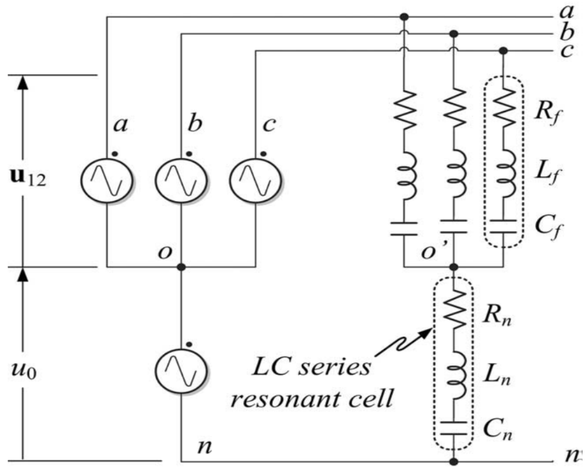

Fig. 1.2 FBS power filter based on simple series *LC* resonant cells.

the FBS topology presented in this paper is suitable for working as a shunt passive power filter simultaneously draining off pn-seq current harmonics at frequency f12and z-seq current harmonics at frequency f0It is worth to remark that currents drained by the pn-seq circuit and the z-seq circuit are independent. It is a useful characteristic in the case where the z-seq resonance frequency is set near to the fundamental grid frequency, e.g., f0 = 150 Hz for a 50-Hz grid. Under such operating conditions, the z-seq circuit would absorb no current at fundamental frequency for a balanced grid voltage. It should also be pointed out that, for given values for *Rf* and *Rn* different from zero, impedance at the resonance frequency for the z-seq component is higher than for the pn-seq component. Hence, filtering capability of pn-seq circuit is comparatively higher than for z-seq one. As previously mentioned, the FBS power filter provides these filtering characteristics without using either transformers or special electromagnetic devices, which results in lower cost and higher modularity than in other existing commercial solutions Several filter variants can be derived from the generic FBS filter structure of Fig.1. 2. Some of these particular structures of the FBS power filter are shown in Fig1.3 and presented in the following. In these power filters, the number of freedom degrees for setting the resonance frequencies and quality factors is reduced in the pursuit of achieving a simpler and more economical implementation while at the same time keeping a satisfactory harmonic cancellation characteristic Fig 1.3(a) shows a particular configuration of the FBS passive power filter suitable for those applications where the z-seq resonance frequency f0 is lower than the pn-seq resonance frequency f12In this FBS implementation, the phase-branch impedances are constituted by series *LC* resonant cells, and the neutral branch impedance consists only of a single-phase inductance *Ln*. Resistances *Rf* and *Rn* have been intentionally omitted inFig.1 .3(a) since they are not of interest for calculating the resonance frequencies. Fig. 4(b) shows another configuration of the FBS passive power filter suitable for those applications where the z-seq resonance frequency f0 is higher than the pn-seq resonance frequency$f$12. In this case, the phase branches are series *LC* resonant cells, and the neutral branch is constituted by a capacitor *Cn*. Fig. 4(c) shows a specific implementation of the FBS power filter destined to both compensation of reactive power at the fundamental grid frequency and cancellation of z-seq current harmonics at frequency f0. In this case, phase branches are constituted by a capacitors bank, and the inductance is connected to the neutral branch Fig. 4(d) shows a dual implementation to one that is shown in Fig. 4(c). In this case, the phase branches consist of three single-phase inductances, and the neutral branch is constituted by a single capacitor

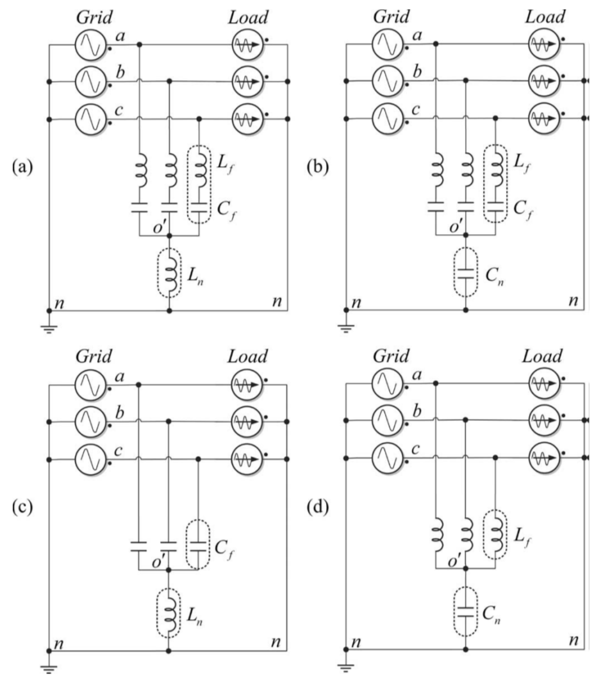

Fig.1.3. Some specific implementations of the FBS power filter suitable for some applications

The neutral-branch impedance in all proposed structures could be substituted by an *LC* resonant cell in order to reduce constraints in setting the resonance frequencies and the quality factors of the FBS power filter. Likewise, resonant cells in phases and neutral branches could be constituted by more complex networks to obtain multiple resonance frequencies using only one FBS power filter.

III. LITRAUTRE SURVEY

The oldest forms of electronic filters are passive analog linear filters, constructed using only resistors and capacitors or resistors and inductors. These are known as RC and RL single-pole filters respectively. More complex multi pole LC filters have also existed for many years, and their operation is well understood. Hybrid filters are also possible, typically involving a combination of analog amplifiers with mechanical resonators or delay lines. Other devices such as CCD delay lines have also been used as discrete-time filters. With the availability of digital signal processing, active digital filters have become common. Passive implementations of linear filters are based on combinations of resistors (R), inductors (L) and capacitors (C). These types are collectively known as passive filters, because they do not depend upon an external power supply and/or they do not contain active components such as transistors Inductors block high-frequency signals and conduct low-frequency signals, while capacitors do the reverse. A filter in which the signal passes through an inductor, or in which a capacitor provides a path to ground, presents less attenuation to low-frequency signals than high-frequency signals and is therefore a low-pass filter. If the signal passes through a capacitor, or has a path to ground through an inductor, then the filter presents less attenuation to high-frequency signals than low-frequency signals and therefore is a high-pass filter. Resistors on their own have no frequency-selective properties, but are added to inductors and capacitors to determine the time-constants of the circuit, and therefore the frequencies to which it responds. The inductors and capacitors are the reactive elements of the filter. The number of elements determines the order of the filter. In this context, an LC tuned circuit being used in a band-pass or band-stop filter is considered a single element even though it consists of two components. At high frequencies (above about 100 megahertz), sometimes the inductors consist of single loops or strips of sheet metal, and the capacitors consist of adjacent strips of metal. These inductive or capacitive pieces of metal are called stubs. The simplest passive filters, RC and RL filters, include only one reactive element, except hybrid LC filter which is characterized by inductance and capacitance integrated in one element .An L filter consists of two reactive elements, one in series and one in parallel. Three-element filters can have a 'T' or 'π' topology and in either geometries, a low-pass, high-pass, band-pass, or band-stop characteristic is possible. The components can be chosen symmetric or not, depending on the required frequency characteristics. The high-pass T filter in the illustration ,has a very low impedance at high frequencies, and a very high impedance at low frequencies. That means that it can be inserted in a transmission line, resulting in the high frequencies being passed and low frequencies being reflected.

Likewise, for the illustrated low-pass π filter, the circuit can be connected to a transmission line, transmitting low frequencies and reflecting high frequencies. Using m-derived filter sections with correct termination impedances, the input impedance can be reasonably constant in the pass band.. Multiple element filters are usually constructed as a ladder network. These can be seen as a continuation of the L T and π designs of filters. More elements are needed when it is desired to improve some parameter of the filter such as stop-band rejection or slope of transition from pass-band to stop-band Active filters are implemented using a combination of passive and active (amplifying) components, and require an outside power source. Operational amplifiers are frequently used in active filter designs. These can have high Q factor, and can achieve resonance without the use of inductors. However, their upper frequency limit is limited by the bandwidth of the amplifiers4. Digital signal processing allows the inexpensive construction of a wide variety of filters. The signal is sampled and an analog turns the signal into a stream of numbers. A computer program running on a CPU or a specialized DSP (or less often running on a hardware implementation of the algorithm) calculates an output number stream. This output can be converted to a signal by passing it through a digital-to-analog converter. There are problems with noise introduced by the conversions, but these can be controlled and limited for many useful filters. Due to the sampling involved, the input signal must be of limited frequency content or aliasing will occur. In the late 1930s, engineers realized that small mechanical systems made of rigid materials such as quartz would acoustically resonate at radio frequencies, i.e. from audible frequencies (sound) up to several hundred megahertz. Some early resonators were made of steel, but quartz quickly became favored. The biggest advantage of quartz is that it is piezoelectric. This means that quartz resonators can directly convert their own mechanical motion into electrical signals. Quartz also has a very low coefficient of thermal expansion which means that quartz resonators can produce stable frequencies over a wide temperature range. Quartz crystal filters have much higher quality factors than LCR filters. When higher stabilities are required, the crystals and their driving circuits may be mounted in a "crystal oven" to control the temperature. For very narrow band filters, sometimes several crystals are operated in series .Engineers realized that a large number of crystals could be collapsed into a single component, by mounting comb-shaped evaporations of metal on a quartz crystal. In this scheme, a "tapped delay line" reinforces the desired frequencies as the sound waves flow across the surface of the quartz crystal. The tapped delay line has become a general scheme of making high-*Q* filters in many different ways. SAW (surface acoustic wave)
Filters are electromechanical devices commonly used in radio frequency applications. Electrical signals are converted to a mechanical wave in a device constructed of a piezoelectric crystal or ceramic; this wave is delayed as it propagates across the device, before being converted back to an electrical signal by further electrodes. The delayed outputs are recombined to produce a direct analog implementation of a finite impulse response filter. This hybrid filtering technique is also found in an analog sampled filter. SAW filters are limited to frequencies up to 3 GHz. The filters were developed by Professor Ted Paige and others. BAW bulk acoustic wave
filters are electromechanical devices. BAW filters can implement ladder or lattice filters. BAW filters typically operate at frequencies from around 2 to around 16 GHz, and may be smaller or thinner than equivalent SAW filters. Two main variants of BAW filters are making their way into devices: thin-film bulk acoustic resonator or FBAR and solid mounted bulk acoustic resonators. Another method of filtering, at microwave frequencies from 800 MHz to about 5 GHz, is to use a synthetic single crystalyttrium iron garnet sphere made of a chemicalcombination of yttrium and iron (YIGF, or yttrium iron garnet filter). The garnet sits on a strip of metal driven by a transistor, and a small loop antenna touches the top of the sphere. An electromagnet changes the frequency that the garnet will pass. The advantage of this method is that the garnet can be tuned over a very wide frequency by varying the strength of the magnetic field. For even higher frequencies and greater precision, the vibrations of atoms must be used.

Atomic clocks use cesium masers as ultra-high *Q* filters to stabilize their primary oscillators. Another method, used at high, fixed frequencies with very weak radio signals, is to use a ruby maser tapped delay line10. Historically, linear analog filter design has evolved through three major approaches. The oldest designs are simple circuits where the main design criterion was the Q factor of the circuit. This reflected the radio receiver application of filtering as Q was a measure of the frequency selectivity of a tuning circuit. From the 1920s filters began to be designed from the image point of view, mostly being driven by the requirements of telecommunications. After World War II the dominant methodology was network synthesis. The higher mathematics used originally required extensive tables of polynomial coefficient values to be published but modern computer resources have made that unnecessary. Low order filters can be designed by directly applying basic circuit laws such as Kirchhoff's laws to obtain the transfer function. This kind of analysis is usually only carried out for simple filters of 1st or 2nd order.. This approach analyses the filter sections from the point of view of the filter being in an infinite chain of identical sections. It has the advantages of simplicity of approach and the ability to easily extend to higher orders. It has the disadvantage that accuracy of predicted responses relies on filter terminations in the image impedance, which is usually not the case.[

The network synthesis approach starts with a required transfer function and then expresses that as a polynomial equation of the input impedance of the filter. The actual element values of the filter are obtained by continued-fraction or partial-fraction expansions of this polynomial. Unlike the image method, there is no need for impedance matching networks at the terminations as the effects of the terminating resistors are included in the analysis from the start sources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. Digital filters may be more expensive than an equivalent analog filter due to their increased complexity, but they make practical many designs that are impractical or impossible as analog filters. When used in the context of real-time analog systems, digital filters sometimes have problematic latency the difference in time between the input and the response due to the associated analog-to-digital and digital-to-analog conversions and anti-aliasing filters, or due to other delays in their implementation. Digital filters are commonplace and an essential element of everyday electronics such as radios, cell phones, and AV receivers. A variety of mathematical techniques may be employed to analyze the behavior of a given digital filter. Many of these analysis techniques may also be employed in designs, and often form the basis of a filter specification. Typically, one characterizes filters by calculating how they will respond to a simple input such as an impulse. One can then extend this information to compute the filter's response to more complex signals.

IV. PROPOSED SCHEME

A previously presented FBS passive power filter can offer a fairly good behavior when applied to cancel out current harmonics in three-phase four-wire systems under optimal operating conditions. However, the filtering characteristic of the FBS passive power filter is affected by typical problems of any passive filter, i.e., its filtering capability depends on the value of the grid impedance; when there exists risk of resonance, retuning is necessary due to ageing and tolerances. A solution to overcome drawbacks associated with passive filters consists of integrating a power converter into the filter structure. This filtering system is known as a hybrid power filters A properly designed and well-controlled power converter can generate any voltage–current relationship at its output, obviously provided that it works inside its operative range. Therefore, such power converter could be understood a sa "virtual impedance" integrated into the original structure of the passive filter. This virtual impedance improves the behavior of the original passive filter by increasing its capability for draining off current harmonics at frequencies different from the resonance ones, compensating drifts in the passive filter parameters, and damping oscillations due to resonance phenomena. Conventional three-phase three-wire hybrid filters are used to integrate a three-leg full-bridge voltage-source inverter (VSI)(without neutral connection) to improve the filter characteristic for pn-seq current harmonics. Different implementations of FBS hybrid power filters can be achieved depending on both the complexity of the branch impedances and the topology of the VSI. Fig.3.1 shows a specific implementation of a three-phase four-wire FBS hybrid power filter that results from integrating a four-terminal VSI four-leg ,three-leg with neutral connection, three single-phase wye connected with neutral connection into the FBS passive power filter structure shown in Fig.1.2 The phase branches are constituted by *LC* resonant cells, and the neutral branch is constituted by an inductor. Resonance frequencies *f*12 and *f*0 for the pn-seq and z-seq respectively. Resistances of the branches have been intentionally omitted in Fig. 3.1 to simplify the diagram.

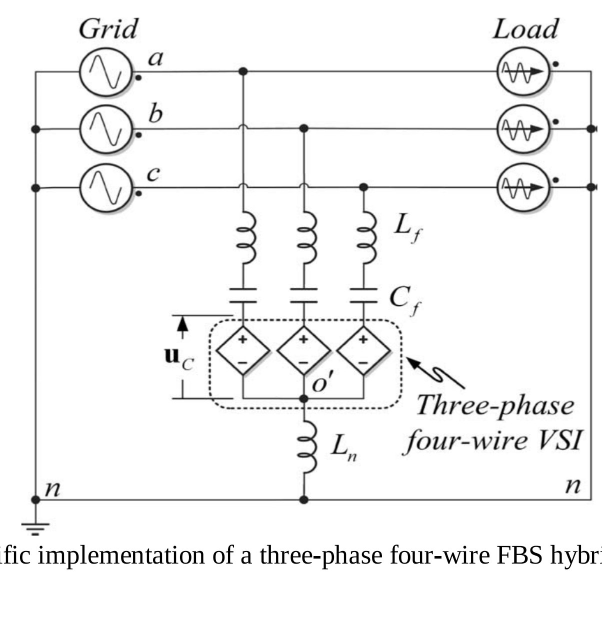

Fig. 3.1Specific implementation of a three-phase four-wire FBS hybrid power filter

The VSI of Fig3.1 can simultaneously synthesize both pn-seq and z-seq voltages at its output that makes it suitable for improving both the pn-seq and the z-seq passive filter characteristics at the same time. Based on this fact, this paper proposes the FBS hybrid power filter of Fig3.1 as an effective solution for canceling out the most characteristic pn-seq current harmonics, i.e., the 5th, 7th-,and 11th-order harmonics, together with the z-seq third-order current harmonic. It is worth noting that the higher the voltage range for the VSI, the higher the controllability and the better the response of the FBS hybrid power filter, but the more expensive the implementation. It should also be highlighted that the power converter of the FBS hybrid power filter is generally much smaller and inexpensive than the power converter of a conventional active power filter. This is mainly due to the fact that the power converter in an FBS hybrid power filter ideally does not generate any voltage at fundamental frequency since the grid voltage at fundamental frequency drops across the capacitors of the *LC* resonant cells. Therefore, this power converter is exclusively devoted to generate only those harmonic voltages that are necessary to inject the desired harmonic currents into the grid. Hence, the dc-link voltage of the power converter in an FBS hybrid power filter can be significantly reduced in relation to the conventional SAPF—around 90% lower It should also be naturally understood that the performance of the FBS hybrid power filter is also directly related to the implemented control algorithm. Even though this paper aims only to present the main characteristics of the FBS topology,

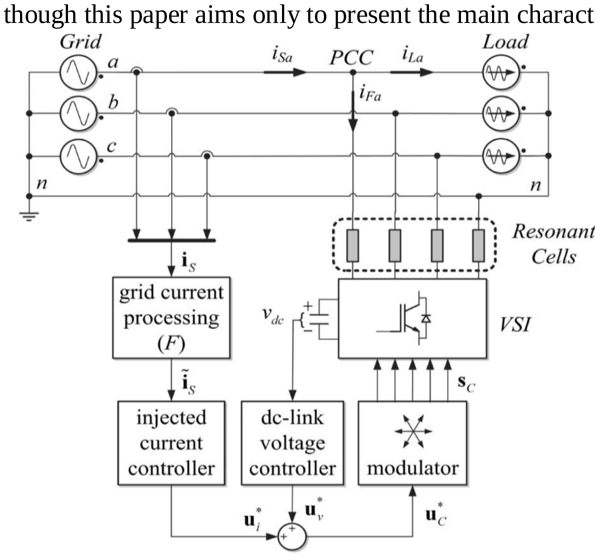

Fig 3.2 Control diagram of the FBS hybrid power filter.

The control system of the FBS hybrid power filter is constituted by the four main blocks shown in Fig. 3.2,namely: 1) the grid current processing block (*F*), which is in-charge of selecting current harmonics to be filtered from the controlled grid current ; 2) the injected current controller, which sets a reference voltage for the VSI in order to cancel out the selected current harmonics; 3) the dc-link voltage controller, which modifies the original reference voltage of the VSI by adding an extra term in order to keep the dc-link voltage at its nominal value; and 4) the modulator, which generates the switching signals of the VSI from the final reference voltage of the VSI The resonant cells of the FBS hybrid power filter of Fig3.2offers very low impedance to pn-seq and z-seq currents at the tuning frequencies $f12$ and $f0$, respectively. Therefore, a low dc link voltage only about 10% of the grid voltage is necessary in the VSI to inject into the grid significant levels of harmonic currents at frequencies $f12$ and $f0$. However, impedance offered by the resonant circuits grows as frequency goes far away from the resonance ones. As a positive consequence, the current ripple injected by the FBS hybrid power filter into the grid at the switching frequency is very low. However, this also implies that the FBS hybrid power filter can only compensate a limited range of the pn-seq and z-seq current harmonics. For this reason, the grid current processing block (*F*) extracts those individual frequencies that are suitable to be filtered from the grid current by using any signal filtering technique. As previously mentioned the harmonics compensation range can be extended by increasing the dc-link voltage level, which increases the VSI rating, and consequently, its cost. Currents signals at the input of the current processing block can be sensed either upstream or downstream of the point of common coupling (PCC) between the FBS power filter and the grid. The transfer function of the control system depends on both the current sensing point and the type of injected current controller This current controller can work on either synchronous or static reference frames using either conventional synchronous PI or stationary resonant controllers, respectively. The dc-link voltage controller generates a reference voltage in phase with the current at the fundamental grid frequency flowing through the VSI. Interaction of both voltage and current generates an exchange of active power between VSI and the grid intended to keep the energy stored into the dc-link stored energy and so the dc-link voltage close to its nominal value .Since the aim of this paper is to only introduce the FBS topology and some of its main applications, the control diagram of Fig3.2 is implemented by using light algorithms,. Hence, the grid current processing block (*F*) consists off three very narrow notch filters (NFs)one per phase canceling out the fundamental frequency component the current harmonics to be compensated by the filter. The injected current controller was implemented by a simple proportional regulator per phase

V. CONCLUSION

A new filter based on the FBS topology was presented in this paper. Analysis, simulations, and experiments conducted in this paper proved the FBS power filter topology as an effective and economical solution for current conditioning in three-phase four- wire networks. Connection of resonant cells according to FBS topology results in independent low-impedance paths for both pn- and z-seq components at specific frequencies, which allows performing selective filtering of current harmonics in both the phases and the neutral conductor of a three-phase four-wire system. The FBS power filter topology can operate in either passive or hybrid mode. In this second mode, a very simple VSI with a dc-link voltage around 10% of the grid line voltage extends further filtering capability of the passive network as well as it avoids overloads and unexpected resonances. A three-phase four-wire hybrid power filter was presented in this paper as an attractive application of the FBS filtering topology. The proposed solution allows low cost implementation of the neutral current conditioning functionality in a conventional wye-connected three-phase passive filter.

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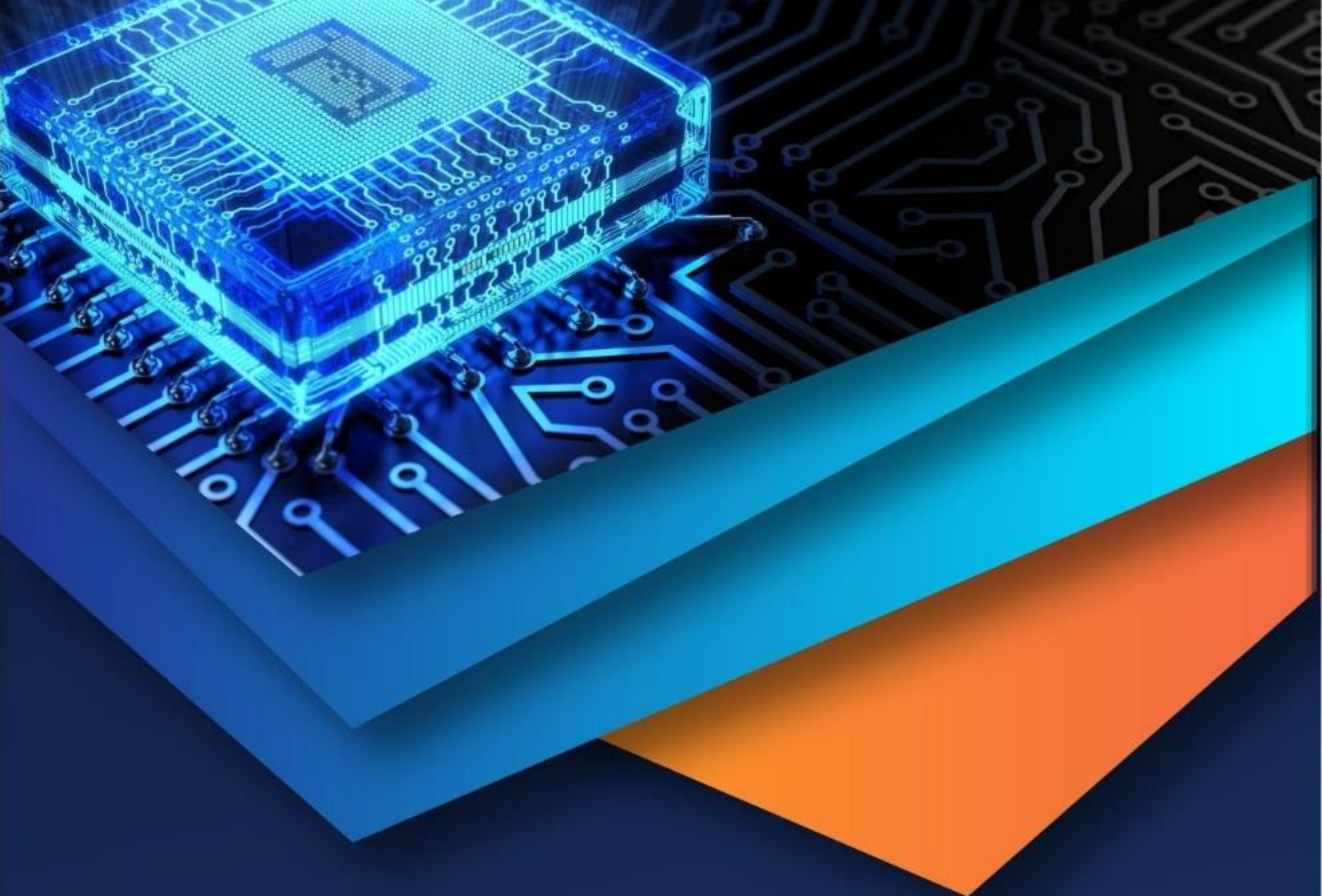

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