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P-TOOL - A SOFTWARE APPLICATION FOR CHOOSING THE TOPOLOGY FOR ACTIVE POWER FILTERS

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Abstract: Energy efficiency is an important dimension of the concept of sustainable development. In electricity, the energy efficiency is tightly connected with the power quality, which is function of harmonic composition, power factor, voltage stability and the balance of the 3 phases. Active power filters (APF) is a modern solution to improve the power quality. This paper presents an overview of the active and hybrid power filter topologies for various applications, and a software application called "P-tool", which is capable to recommend the APF topology to use in specific, user defined, conditions.

Keywords: Energy efficiency, Power quality, active power filter, topology, software application.

1. INTRODUCTION

Due to the rapid technological development, in the past decade we witnessed a great diversification of the "loads" (appliances, industrial equipment etc.) connected to the power grid. The vast majority of these loads are nonlinear and produce important harmonic and reactive regimes, as well as imbalances in three-phase systems, i.e. they affect the power quality (see Tareen et al., 2017). Examples of such situations are quite common and include: adjustable electric drives, electric furnaces, energy transport in DC, conversion of unconventional energies, supply of computer networks, unbalanced three-phase systems with zero charging, and many others.

The effects of nonlinear loads are found in the entire grid: production, transport, and the final conversion of the energy at the receiver. Negative effects are important: reducing capacity to produce active power useful in station; decreasing energy transmission efficiency, reducing the power quality, or even making it unavailable.

Mitigating or eliminating these effects can be achieved in several ways (Singh, 1999; El-Habrook et al, 2000). A simple, inexpensive solution is to use conventional passive filters L+C and/or C. This reduces the content of harmonics and improves the power factor, but operation of the passive filters is discontinuous, they have modest dynamics, and there is a risk of resonance phenomena.

The important and rapid progress in the power semiconductor field, capable of taking on increasing voltages and currents, allow for the development of hard, converters to provide the harmonic and reactive components required for nonlinear loads. On the other hand, the control techniques of the converters have allowed the development of new control systems which take into account the continuous character of the compensation and the dynamic performance, systems called active power filters, APF. Other similar solutions include: APLC - Active power line conditioner; IRPC - Instantaneous reactive power compensator; CAPQ - Conditioner of active power quality (Akagi et al, 2017). This is a second class of solutions for improving the power quality.

Hybrid solutions that use both passive and active filters are also possible and they may lead to the simplification and cost reduction of the resulting systems.

In this context, we have developed the project: ”Knowledge transfer regarding the energy efficiency increase and intelligent power systems", acronym CRESC-INTEL, with the general objective to increase the transfer of technological knowledge and staff with skills between the "Dunarea de Jos" University in Galati and SMEs that operate in the business of electricity and industrial electrical equipment. The project aims at establishing partnerships between the "Dunarea de Jos" University in Galati and economic agents interested in acquiring knowledge, including abilities and competencies to increase the energy efficiency and intelligent power systems in order to obtain a competitive solution, for an intelligent Active Power Filter (APF).

2. CONVERTERS FOR ACTIVE POWER FILTERS

Currently, active filter technology, it carries the following main functions in the grid:

- Harmonics compensation of current;
- Reactive power compensation;
- Neutral current control;
- Secondary functions can also be performed:
    - o Voltage harmonics compensation;
    - o Flicker effect reduction;
    - o Balancing the three-phase voltage system;
    - o Adjusting Output voltages adjusting;
    - o Gaps and voltage drops compensation.

The functions described above can obviously be achieved by generating with the active circuit element a converter placed near the non-linear load the harmonic spectrum and the reagent necessary to it, thus avoiding the absorption from their network and eliminating the negative effects well known. It is about generating harmonic currents with amplitude, frequency and initial phase variable, the choice of the converter is unique, the PWM inverter, which has three degrees of independence in terms of control: modulation, and the initial phase of the command.

At the three-phase level there are two types of such converters: the inverter supplied in voltage with current output, (figure 1) and inverter supplied in current with voltage output, (figure 2). Analyzing the two schemes more careful, it is concluded that they are actually PWM rectifiers with voltage and current output. In fact, the two converters, with 4 quadrants, can work in both modes, both rectifier and inverter. The rectifier function aims at the accumulation of energy in capacitance C and the inductance L and maintaining the U_C voltage and the I_L current at constant values, by means of an appropriate closed-loop control of the output quantities. The inverter function is based on the energy accumulated in the two circuit elements and by a corresponding command also in a closed loop. In fact, the two regimes are not separate, with a single command that makes the synthesis between the two requests.

The voltage inverter, (figure 1), has some properties that make its use to make the active filters widespread. First, the current output of the inverter is favorable for the compensation of the current harmonics, which have the largest share in the supply networks. On the other hand, in the rectifier mode, the converter has a boost, loading capacity. The storage capacitor, which has an appreciable value, is chosen from standardized products, making any cost-effective value available. Network coupling inductors are small in value and can be easily achieved. Also, the arm structure allows expansion of the high voltage converter in multilevel schemes.

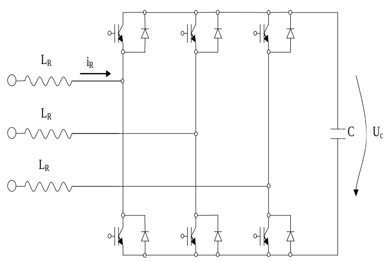

Fig.1. Three phase voltage inverter

The current inverter, (figure 2), has some definite disadvantages. Thus, the accumulation inductance is expensive, which leads to high costs, the product being unique. Also, the schematic requires a major capacitor battery on the network side. If IGBTs are used to make the converter, (figure 2), they must be diode-connected to avoid the lead in the reverse direction. On the other hand, the fitting of two power semiconductors, a diode and IGBT, doubles the power loss in the converter, significantly reducing conversion performance. The switching is also greatly impeded by the current and the presence of large inductances.

For single-phase non-linear loads, one-phase inverter bridges are used, whose schematic is derived from three-phase inverters by removing an arm.

Regarding the power semiconductors used to make the voltage or current inverters are: the maximum power that the inverter must supply, the voltage, the current required in the storage circuit and the maximum switching frequency.

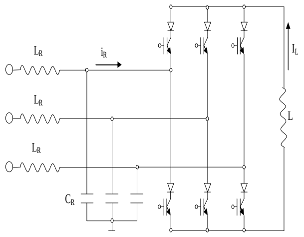

Fig.2. Three-phase current inverter

Depending on the above parameters, there are use:

- Bipolar power transistors BJT;
- MOSFET Power transistors, at low loads and high switching frequencies;
- IGBT transistors at medium switching powers and frequencies;
- GTO transistors at low switching powers and frequencies
- More recent thyristors MCT and IGCT.

3. TOPOLOGIES. ACTIVE FILTERS

The topology of an active power filter is determined by: the parameters to be compensated; the power required for compensation; the adopted compensation control strategy; type of converter used; concrete states of nonlinear load and power network; how to connect the active filter to the so-called PCC, a common coupling point (Dey & Mekhilef, 2015). The topology chosen must be the most appropriate of the required performance and attract minimum costs for the required equipment.

The first topology shown in figure 3 is the shunt one, where the converter is a voltage source inverter with energy storage in the C capacity. Generally, this topology is very advantageous because it can compensate simultaneously both the harmonic components and the reactive component, the filter actively providing the iF current that collects the harmonic current, the reactive current and the active current required to maintain the energy accumulated in the C capacity.

The scheme has the advantage of static switching dimensioning at the value of the compensated current component, obviously less than the total current absorbed by the nonlinear load. Instead, in terms of voltage, the sizing should be made to the maximum level in the circuit, while the storage capacity has an important value (Rosu et al., 2008). The antiparallel bridge bridging scheme allows the use of multi-level and multi-step inverters, thereby partially overcoming the difficulties of making active filters for high voltages. It is the most commonly used option for simultaneous or individual compensation of harmonic currents, reactive power and unbalance of the three-phase absorbed purge system.

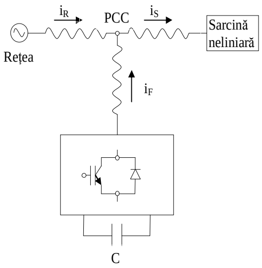

Fig.3. Shunt active power filter with voltage source inverter

The second topology, (figure 4) is also a shunt scheme which, however, uses a current-carrying inverter with energy accumulation in the inductance L and the PCC injection of the compensated current iF. Generally, the topology has the same properties as the previous scheme, but also preserves all the drawbacks of the inverter type. The presence of considerable inductance L leads to the emergence of large switching overvoltages, high conversion losses, and the need for large capacitor batteries parallel to the network. Furthermore, multilevel or multistage schemes for active filtres at high voltages can not be used.

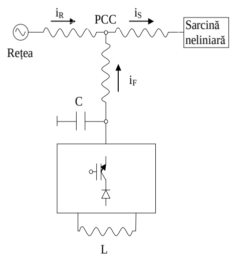

Fig.4. Shunt active power filter current source inverter

To compensate voltage harmonics, the variants in figure 5 and figure 6 connect the nonlinear load through the adapter transformer "m". The scheme generate the v_F voltage necessary to offset the voltage harmonics on the line and adjust the final voltage to the grid or load. The advantages and disadvantages previously described for shunt connection are also conserved when the series is connected, which, given the need for the adaptation transformer, makes these schemes rarely used.

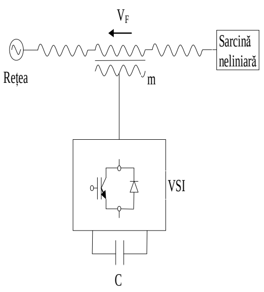

Fig.5. Series FAP - voltage source inverter

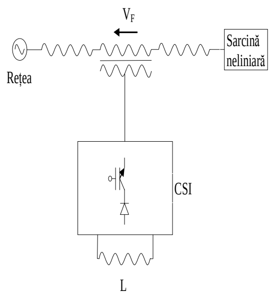

Fig.6. Series FAP -current source inverter

By using the above schemes, hybrid constructs can be configured to achieve additional functions. For example, figure 7 shows the structure of a unified active power conditioner composed of a series active filter, (figure 5), and a shunt, (figure 3), both using power-operated inverters, DC being the common C capacity.

The structure is complex and the performances offered are adequate. In addition to compensating for current and voltage harmonics and reactive power, the structure also has a different function, adjusting the output voltage and active power transmitted on the line, making the so-called Unified Power Flow Control (UPFC) flexible transmission systems current.

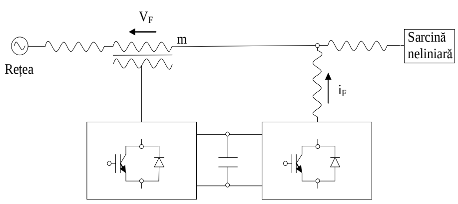

Fig.7. Hybrid active power filter, UPFC

Another hybrid variant is shown in Fig. 8. It is composed of a series active power filter and a shunt passive filter, the second one being provided for the compensation of lower-order harmonics.

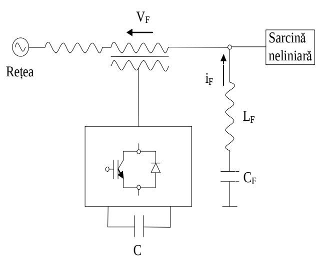

Fig.8. Hybrid filter, active series and shunt passive

An interesting case is that of unbalanced nonlinear loads for which it is desired to compensate current harmonics and reactive power, balancing the three-phase current absorbed and avoiding the overload of the null conductor. A solution is shown in Fig. 9. It consists of a shunt active filter to the power-operated inverter, connecting the load to the grid through 4 wires, so with a neutral conductor, and connecting it to a midpoint formed by sectioning the storage capacity into two identical capacitors. The advantages of the topology in shunt with the voltage-injected inverter, but also the disadvantage of closing the neutral current through the storage capacities C/2, which entails the need for high power capacitors. On the other hand, this limits the scope of the topology to small powers.

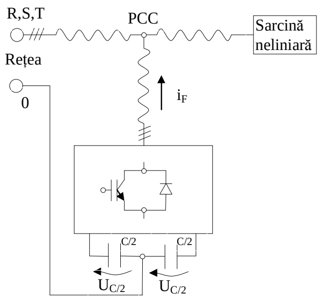

Fig.9. Shunt active power filter with 4 wires and median point on capacity

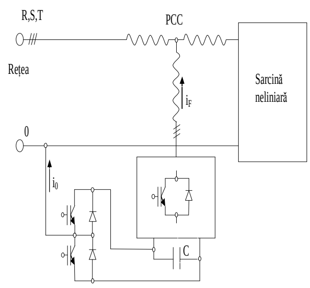

Fig.10. Shunt active power filter with 4-wire and 4-pole

In Fig. 11 is a classic series diagram consisting of three single-phase inverters with power supply and network connection via adapters transformers. Practically, the active filter is decomposed into three independent single-phase filters, ensuring more reliable operation and simpler operation. In the diagram is presented only one active power filter for the simplicity of the diagram but it is mentioned that there are three active power filter each one having his own capacity.

Active filter and shunt passive filter (figure 12). The active filter is used to remove only some of the low current harmonics, while the passive filter manages to eliminate most of the harmonic current on the load. The main drawback of this configuration is that iot is not suitable for variable load conditions because the passive filter can only be adjusted for a predetermined harmonic composition.

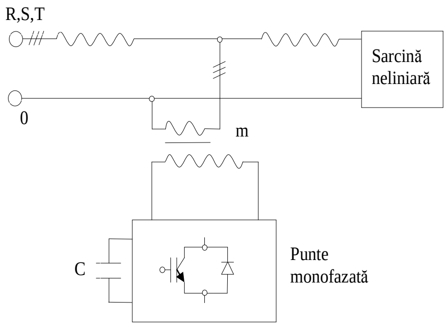

Fig.11. Active power filter series with 3 single-phase inverters

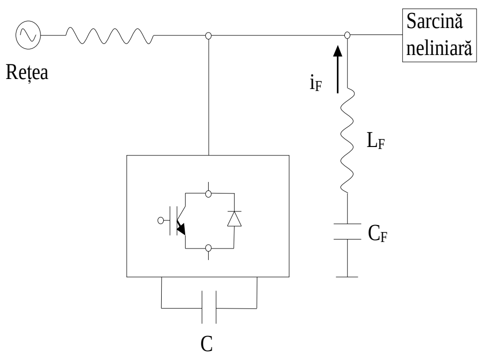

Fig.12. Shunt active power filter and shunt passive power filter

Serial active filter with shunt passive filter (Figure 13) is a combination recommended for medium or high voltage applications because low voltage is obtained on the active filter. Passive filter voltage drop is important in this configuration, which allows a low voltage drop on the active filter.

Under these conditions, an active filter can be used for a lower voltage level (Epure & Rosu, 2010), which reduces costs. It should also be remembered that, at high voltage levels, the cost of semiconductor equipment is very important.

4. CHOOSING THE TOPOLOGY OF ACTIVE POWER FILTERS

To determine the topology of the active power filter, the power and voltage level and the potential compensation parameters with the active filter shall be considered. Table 1 presents the main topologies used with a single compensated parameter and those with several parameters, covering all possible combinations of parameters.

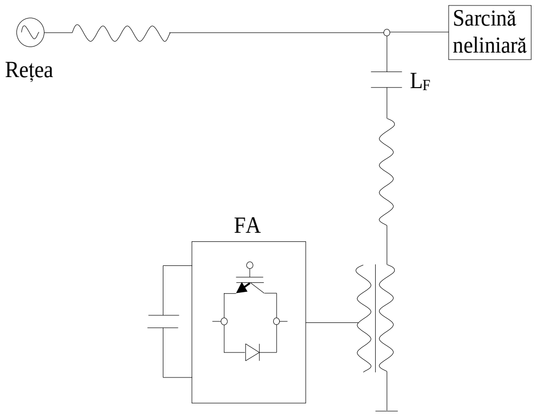

Fig.13. Active power filter in series with shunt passive filter

The performance of the possible applications is marked with 1 to 3 stars, the larger number indicating the most favorable topology for the application. Such a choice ensures the best performance and, at the same time, acceptable costs.

To balance the currents of a three-phase load is recommended shunt power filters with three or four wires fig 9 and 10. Compensating the current through the null conductor also requires a shunt active filter. Depending on the magnitude of the imbalance and the null current, it is possible to provide active filters dedicated to these compensations, or to take over the function of the harmonic power filter. By summing all four compensations, it is very likely that the power required by the filter will get very high. This leads to increased power losses in the converter, its oversize and even the impossibility of making the active filter due to the current and voltage limitations of the semiconductor power devices. From the above, it results that for the current compensation the correct solution is the hybrid filter active-series and passive-shunt, as a result of significant cost reductions.

In what concerns the type of inverter, due to the favorable properties shown above, the voltage-fed converter is preferred (see figure 1).

The structure shown above allows reactive current compensation, but also the three-phase load imbalance and the current through the neutral conductor.

Table 1

Application	Active filter		Hybrid filter	
	Series	Shunt	Active series and passive shunt	Active series and active shunt
1. Harmonic current		**	***	*
2. Reactive current		***	**	*
3. Balance the load		*		
4. Null current		**	*	
5. Harmonic voltages	***		**	*
6. Voltage regulation	***	*	**	*
7. Voltage balancing	***		**	*
8. Flicker	**	***		*
9. Voltage drops and gaps	***	*	**	*
10. Harmonic and reactive currents		***	**	*
11. Harmonics and reactive currents, load balancing		**		*
12. Harmonics and null currents, reactive, load balancing		*		
13. Harmonic voltage, voltage regulation	**			*
14. Harmonic voltage, voltage regulation, Flicker, drops, gaps	**			*
15. Harmonics currents and voltages			**	*
16. Reactive and harmonic current, harmonic voltage, voltage regulation			*	**
17. Balancing and voltage adjustment	**		*	
18. Reactive current, load balancing		*		
19. Null reactive current, load balancing		*		
20. Harmonic current, reactive, voltage balancing		**	*	
21. Harmonic current, load balancing		*		
22. Harmonic null current, balancing voltages		*	**	

Summing up all four compensations: Voltage compensation. Voltage compensation has as its object the harmonic voltages, the regulation and balancing of the voltages in the PCC, as well as the flicker, the short-term falls and gaps in voltages. Typical for such compensations would be the active filter series, Fig. 5 and 6. Table 1 confirms the choice above, regardless of the application groups. Typically, the above applications do not require high power, which is why they are deployed simultaneously.

Voltage and current Compensation. There are applications that require compensation of voltages and currents as well. The ideal solution, the separate compensation of currents and voltages, is a hybrid structure consisting of a series active and a shunt active filter, Fig.7, known as UPFC. Such a structure responds very well to the requirements, but the costs are appreciable. Such solution is considered when the structure is also used for other purposes, such as controlling power flows, adjusting voltages. For conventional applications, individual currents and voltages are compensated in agreement with the above.

5. P-TOOL APPLICATION

In "Knowledge transfer regarding the energy efficiency increase and intelligent power systems", acronym CRESC-INTEL project it was developed an software application called P-tool. The main aim of P-tool is to give the possibility to all the technicians to rapidly choose the right topology starting from the power quality indicator which must be improved. The P-tool application can be also used to rapidly choose the right topology considering the place where the active power filter it will be used.

The first interface for the P-tool application is presented in figure 14.

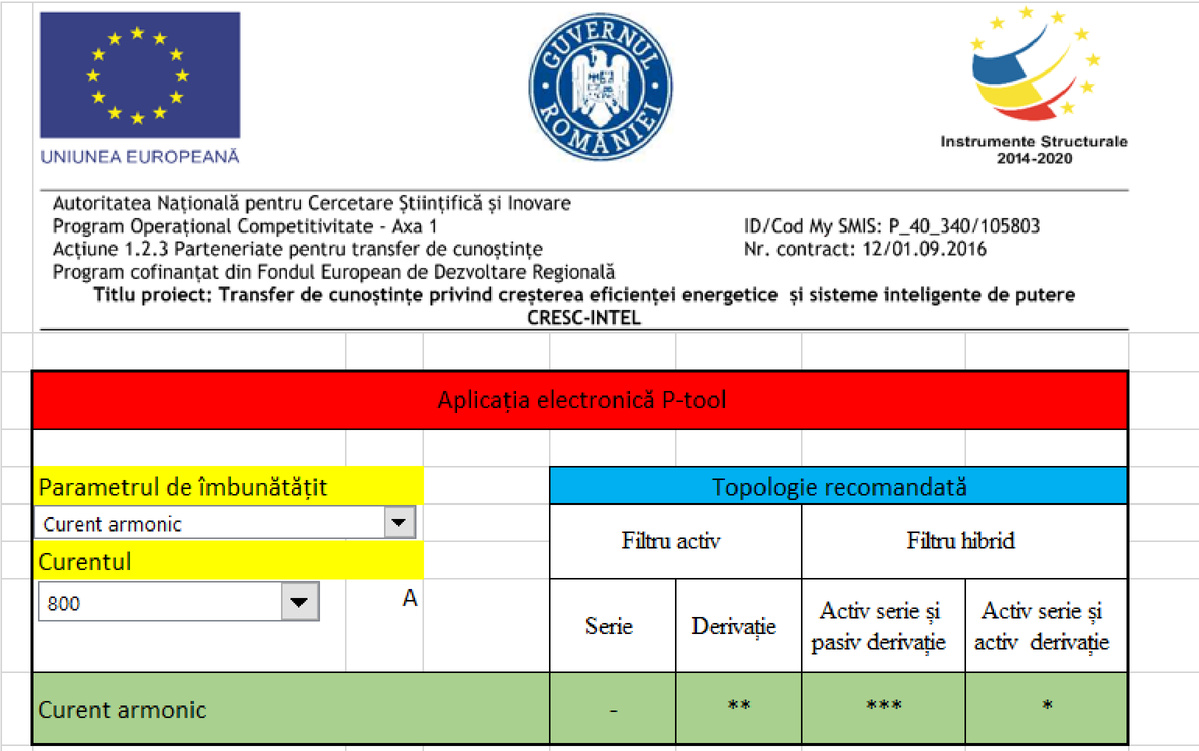

Fig.14. Interface of P-tool application

În the P-tool application it can be seen on the red cell the name of the application in Romanian language ”Aplicația electronică P-tool” which mean the electronic application P-tool. Also it can be observed that on the yellow cell there are two parameters which can be choose: „Parametrul de îmbunătățit” – the power quality indicator who have to be improved by the new FAP and ”Curentul” which is the current of the new FAP. On the blue cell it is obtained as result the topology which can be used in the new FAP labeled with stars. The biggest number of stars mean the most appropriate topology. There are indicated two main topology: „Filtru active” – Active filter and „Filtru hybrid” - Hybrid filter each one with two possible topology: „Serie” – series and ”derivație” – shunt for the active filter and „Activ serie și pasiv derivație” – Active series and passive shunt respectively ”Activ serie și activ derivație” – Active series and shunt active.

As a graphical presentation in Fig. 15 there are presented the result. The graphical representation can be reded like this: Considering that in a certain point of the grid it is necessary to reduce the harmonic current and if the rms current is below 800A the recommended topology are: 1. Hybrid filter with Active series and passive shunt; 2. Active filter with shunt solution; 3. Hybrid filter with active series and shunt active.

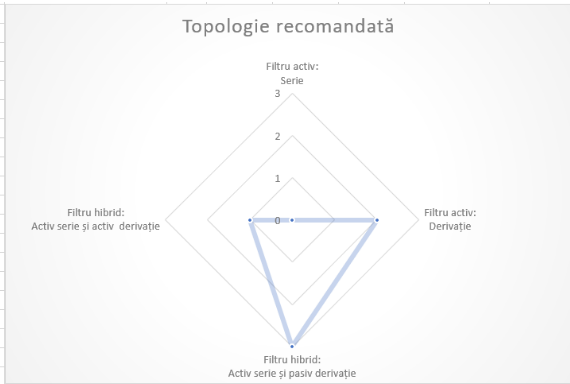

Fig.15. Graphic presentation of the results

Also, the three diagrams are presented further in the P-tool application. The diagram for the three proposed topologies as shown in Fig. 16 ordered accordingly with the numbers of stars.

In this moment the technicians know that there are three possible topologies which it can be used in solving the problem regarding the reduction of the harmonic current. The best choice is Hybrid filter with Active series and passive shunt. Analyzing the other constraint the technician can have the right decision concerning the topology to use in realization of the new solution.

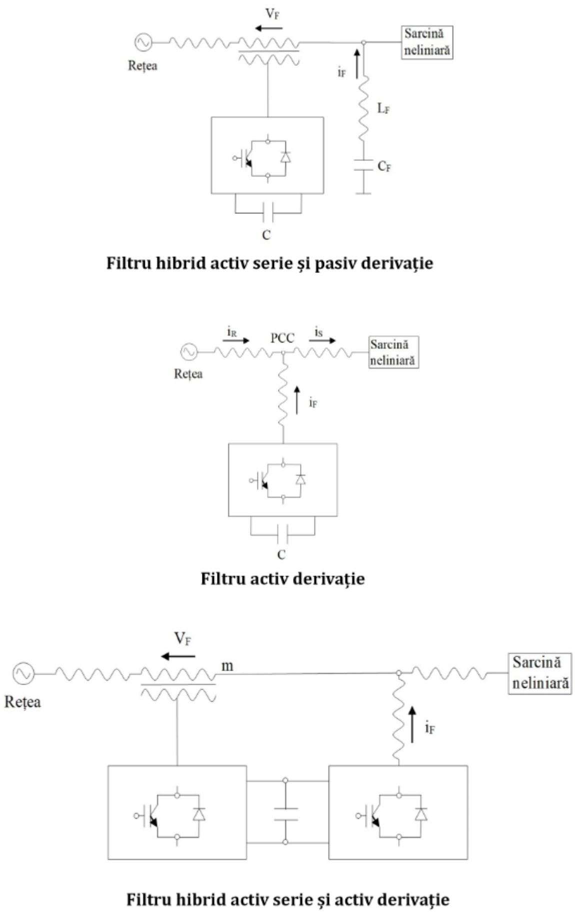

Fig.16. Recommended APF topologies

6. CONCLUSIONS

Starting from the PWM voltage and current inverters, the series and shunt topologies of active power filters can be conceived, adapted to the particularities of nonlinear loads and grids. Practically at least one topology is available that can compensate for the harmonic, the reactive and the three-phase imbalance. Moreover, voltage drops and even flicker may be diminished. Also, topologies, given the inverters and the semiconductor devices used, provide a dynamic performance compensation.

In this paper it was presented the most important topologies appropriate which can be used in improving the power quality indicators.

Also, it was presented shortly the P-tool application, an instrument useful for the technicians who want to provide solution for certain improvement in energy efficiency related to grid.

7. ACKNOWLEDGMENT

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