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CHOOSING THE MAIN ELEMENTS OF AN ACTIVE POWER FILTER WITH FAP-TOOL APPLICATION

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Abstract: This paper presents the electronic application FAP-tool, which includes the following applications: P-tool, C-tool, M-tool and Daq-tool developed within the project "Knowledge Transfer Regarding the Energy Efficiency Increase and Intelligent Power Systems" (acronym CRESC-INTEL). The FAP-tool application allows the user as the technicians and/or engineers to introduce the data from the analyzed electrical system where is necessary to connect the Active Power Filter. With the FAP-tool application they get recommendations on the following aspects: topology of the Active Power Filter that can be used, the control method that provides the best results, the values of the passive elements to ensure the connection to the grid and the appropriate control board. All those data are returned as a list of the components which may be used.

Keywords: energy efficiency, power quality, active power filter, electronic application.

1. INTRODUCTION

Power quality is a very important objective in the electric power system. Maintaining the quality of electricity within the standards has lately been more complicated, due to the technological developments that have diversified the types of electricity consumers. Most of these consumers are nonlinear, generate harmonics, create unbalances, and consume reactive power.

To reduce the problems caused by nonlinear loads, the Active Power Filter is the most suitable equipment to be used. They are voltage and controlled sources which allow the compensation of all deficiencies that may arise in the electrical grid.

From the point of view of the power circuit configuration, the active filters are divided as follows (Gurguiatu, 2016):

- Series Active Filters;
- Parallel Active Filters;
- Hybrid Active Filters.

The use of one of these topologies depends on the nature of the problems in the electrical system.

The control of active power filters is performed with several command methods encountered in the literature (Bălănuță, 2012):

- The control method developed on the basis of the instantaneous powers principle (PQ);
- The control method developed on the basis of the synchronous algorithm principle (DQ);
- The control method developed based on the indirect control principle;
- The control method developed on the basis of the current synchronization principle with the positive voltage sequence component:
  - The control method developed on the basis of the band-stop Filter principle (BSF);
  - The control method developed on the basis of the low-pass Filter principle (LPF);
  - The control method developed on the principle of maximum.

Each of these control methods is distinct in its own way, with impressive results in case of correct choice of the control strategy for compensation (Bălănuță, 2012).

Choosing the right topology and the control method for sizing the Active Power Filter that can provide the best results has always been a challenging issue.

Due to the project "*Knowledge Transfer Regarding the Energy Efficiency Increase and Intelligent Power Systems*" (acronym CRESC-INTEL) which aims to increase the transfer of technological knowledge and personnel between "Dunărea de Jos" University of Galati and businesses companies in the field of electricity, to increase the energy efficiency by intelligent power systems, in order to obtain a competitive, technical and economical solution for an intelligent system of the Active Power Filter, it was possible to implement the FAP-tool application, that allows the optimal determination of the topology based on the applications previously developed in this project: P-tool, C-tool, M-tool and Daq-tool.

The *C-tool application* - is capable to indicate the right elements available for the construction of the L, LC and LCL filters, included in the APFs structure (Bălănuță, et al., 2019). The *P-tool application* - is capable to recommend the APF topology to use in specific, user defined, conditions (Gurguiatu, et al., 2018). The *M-tool application* - is capable to indicate the most appropriated control strategy in certain conditions (Gurguiatu, et al., 2019). The *Daq-tool application* - is capable to assist designers in selecting the appropriate control system for the APF, starting from a set of specific requirements (Bălănuță, et al., 2019).

2. SIZING THE PASSIVE ELEMENTS OF THE ACTIVE POWER FILTER

This chapter presents the calculus formulas for sizing the passive elements required in the construction of the passive filter used to connect the Active Power Filter to the grid.

2.1. L type filter

The calculus of the filter L_{FA} is determined in (Moran, et al., 1995) based on the fact that for a given frequency, the slope of the current through the active power filter - i_{FA} must be lower than that of the triangular carrier signal, which characterizes the switching frequency. The slope of the carrier signal is determined by:

$$\chi = 4 \cdot \varepsilon \cdot f_s \quad (1)$$

where ε represents the amplitude of the triangular signal and f_s - switching frequency.

The maximum current slope i_{FA}, for the active filter is characterized by:

$$\frac{di_{FA}}{dt} = \frac{0.5 \cdot U_{cc} + U_{sm}}{L_{FA}} \quad (2)$$

where

$$L_{FA} = \frac{0.5 \cdot U_{cc} + U_{sm}}{4 \cdot \varepsilon \cdot f_s} \quad (3)$$

In equation (3) U_{cc} is the voltage from the DC line and U_{sm} – the maximum value of the power supply voltage.

2.2. L-C filter

To define the *L-C* filter it is necessary to determine the value of the *L* filter given by (3) and to calculate the filtering capacity using (4).

$$C = \frac{1}{(2 \cdot \pi \cdot f_c)^2 \cdot L} \quad (4)$$

2.3. L-C-L filter

The size of the *L-C-L* filter is achieved by: calculation of the inductance L_{FA} (3), calculation of the filtering capacity C (4) and calculation of the value of the resistance related to the filter (6) (Hojabri & Hojabri, 2015) (Tavakoli Bina & Pashajavid, 2009):

$$L_1 = (4 \div 6) L_2 \quad (5)$$

$$R_d = 3 \cdot \frac{1}{2\pi f_{ref} C} \tag{6}$$

Taking into account that the highest range of the compensating harmonics is 40 and applying a constant of 1.25 to fc_{max}, a minimum limit of 2.5 kHz and a maximum of 3 kHz result for the resonant frequency. At the same time, if the total inductance L_d = 4.5 mH and f_{res} is dependent on k and C, the following constraints will result (Tavakoli Bina & Pashajavid, 2009):

$$\begin{cases} 2500 \le f_{res} \le 3000 \\ f_{res} = \frac{1}{2 \cdot \pi} \cdot \frac{(k+1)}{\sqrt{0.0045} \cdot \sqrt{k \cdot C}} = 2.37 \frac{(k+1)}{\sqrt{k \cdot C}} \end{cases} \tag{7}$$

3. FAP-TOOL APPLICATION

Within the project "*Knowledge Transfer Regarding the Energy Efficiency Increase and Intelligent Power Systems*" (acronym CRESC-INTEL) an electronic application called the FAP-tool has been developed. The main objective of this application is to allow qualified and unqualified persons to determine quickly the most efficient topology and control methods for an Active Power Filter, to calculate the passive elements that are components of the filter, to choose the passive elements and the acquisition systems that match from the lists proposed by the application.

3.1. FAP-tool

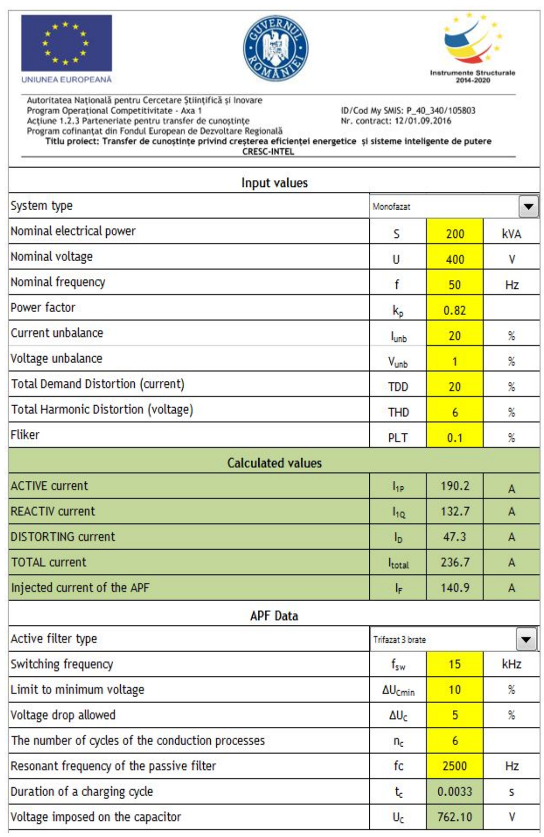
Figure 1 shows the main window of the FAP-tool electronic application, in which the data from the analyzed electrical system are introduced by selecting the type of electrical distribution system to which the Active Power Filter is to be connected. Also, in this page the type of Active Power Filter which is to be implemented is selected introducing the data about the Active Power Filter.

The data corresponding to the measured electrical parameters are introduced into the yellow cells to be easily recognized by the user. In the presented example the input data are:

- Nominal electrical power: S (kVA): 200 – represents the nominal power of the non-linear load;
- Nominal voltage: U (V) 400 – represents the grid voltage in CCP (Common coupling point);
- Nominal frequency: f (Hz) 50 – represents the nominal frequency of the electrical grid;
- Power factor: k_p 0.82 – represents the power factor of the non-linear load in the CCP.
- Current unbalance: I_{unb}(%) 20 – represents the current unbalance, due to the non-linear load;
- Voltage unbalance: V_{unb}(%) 1 – represents the measured voltage unbalance, due to the nonlinear load;
- Total Demand Distortion (current): TDD (%) 20 – represents the harmonic level on the measured current, due to non-linear load;
- Total Harmonic Distortion (voltage): THD (%) 6 – represents the harmonic level on the measured voltage, due to non-linear load;
- Flicker: PLT(%) 0.1 – represents the measured flickers.

APF data:

- Switching frequency: f_{sw}(kHz) – 15;
- Limit to minimum voltage: ΔU_{Cmin}(%) – 10;
- Voltage drop allowed: ΔU_C(%) – 5;
- The number of cycles of the conduction processes: n_c – 6;
- Resonant frequency of the passive filter: f_c(Hz) – 2500.



Input values			
System type	Monofazat		
Nominal electrical power	S	200	kVA
Nominal voltage	U	400	V
Nominal frequency	f	50	Hz
Power factor	k_p	0.82	
Current unbalance	I_{unb}	20	%
Voltage unbalance	V_{unb}	1	%
Total Demand Distortion (current)	TDD	20	%
Total Harmonic Distortion (voltage)	THD	6	%
Fliker	PLT	0.1	%
Calculated values			
ACTIVE current	I_{1P}	190.2	A
REACTIV current	I_{1Q}	132.7	A
DISTORTING current	I_D	47.3	A
TOTAL current	I_{total}	236.7	A
Injected current of the APF	I_F	140.9	A
APF Data			
Active filter type	Trifazat 3 brate		
Switching frequency	f_{sw}	15	kHz
Limit to minimum voltage	ΔU_{Cmin}	10	%
Voltage drop allowed	ΔU_C	5	%
The number of cycles of the conduction processes	n_c	6	
Resonant frequency of the passive filter	fc	2500	Hz
Duration of a charging cycle	t_c	0.0033	s
Voltage imposed on the capacitor	U_c	762.10	V

Fig.1. FAP-tool application interface

Fig.2 presents the second main window of the electronic application FAP-tool, where a series of results is briefly presented, called "Minimum results obtained" which can be classified into four categories:

- Recommended filter topology, where information about the type of Active Power Filter that can be used is presented;
- Recommended control method - here is the information about the control method which shows the best results for minimizing electricity quality problems;
- Connection and storage elements - the calculated values of the passive elements required for the construction of the filter are presented;
- The control panels show the number of input and output signals.

In our case the recommendations made by the FAP-tool are the following:

- Recommended filter topology: Shunt;
- Recommended command method: Sec_Poz.

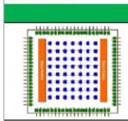
Minimum results obtained							
Recommended Filter Topology				Active filter: Shunt			
Issue/Issues of the system				Active filter		Hybrid filter	
Harmonic currents, reactive and load balancing				Series	Shunt	Active series and passive derivation	Active series and active derivation
				-	**	-	*
Recommended command method				Sec_Poz			
Command method	PQ Instantaneous power	DQ Synchronous algorithm	CI Indirect control	SCP_FSB Separation of polluting components - Filter stops the band	SCP_FTJ Separation of polluting components - Filter passes down	MAX Maximum	Sec-Poz Positive Sequence
Ratings obtained based on previous results	**	***	***	**	**	***	****
Connection and storage elements							
Passive connection filter in CCP				L	Lff	0.28	mH
				LC	Lsf	0.28	mH
					C	14.53	uF
				L	Lff	0.22	mH
				LCLR	C	18.16	uF
					Lsf	0.06	mH
					R	10.52	Ω
					Pr	5071.67	W
Storage capacity					C_{min}	11.21	mF
Control board							
Minimum requirements for the control board							
	Nr AI	Nr AO	Nr DIO	FPGA			
				Flip-Flops	Slice LUT	Block RAMs	
	10	4	6	14750	23979	180	

Fig.2. FAP-tool application interface

After introducing the input data the FAP-tool application allows to the user to obtain a wide report, being composed of the following subcategories:

- General information;
- Recommended active/hybrid filter topology information;
- Grid connection information and energy storage capacity;
- Information about the ordering method;
- Control board information.

3.2. *Report*

This subsection presents information about the input data (introduced by the user and the calculated ones), as well as the results obtained in general, based on the input data.

In Fig.3 the data introduced by the user is presented in the first window, as well as those about the currents circulating through the system. Finally these are calculated values.

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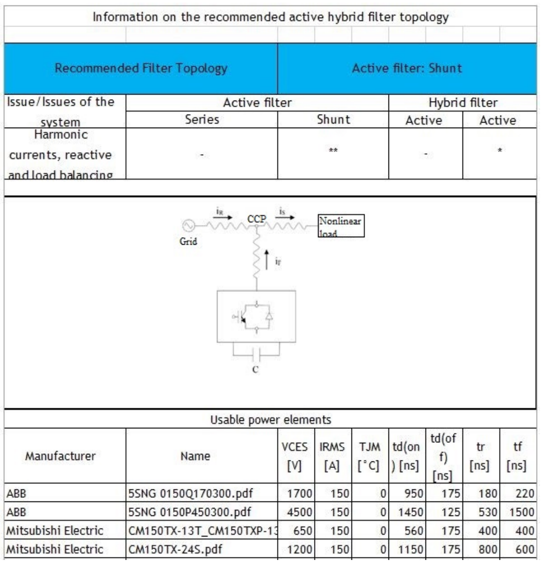
Titlu proiect: Transfer de cunoștințe privind creșterea eficienței energetice și sisteme inteligente de putere CRESC-INTEL

REPORT			
General information			
Nominal electrical power	S	200	kVA
Nominal voltage	U	400	V
Nominal frequency	f	50	Hz
Power factor	kp	0.82	
Current unbalance	Iunb	20	%
Voltage unbalance	Vunb	1	%
Total Demand Distortion (current)	TDD	20	%
Total Harmonic Distortion (voltage)	THD	6	%
Fliker	PLT	0.1	%
ACTIVE current	I1P	190.183	A
REACTIV current	I1Q	132.749	A
DISTORTING current	ID	47.3427	A
TOTAL current	Itotal	236.714	A
Injected current of the APF	IF	140.938	A
Switching frequency	fsw	15	kHz
Limit to minimum voltage	ΔUCmin	10	%
Voltage drop allowed	ΔUC	5	%
The number of cycles of the conduction processes	nc	6	
Resonant frequency of the passive filter	fc	2500	Hz
Duration of a charging cycle	tc	0.00333	s
Voltage imposed on the capacitor	UC	762.102	V

Fig.3. The first page of the Report window

Fig.4 presents the information about the recommended active filter topology which can be used in the electrical system described by the input variables. In addition, a list of possible static power devices is provided.

Fig.5 presents the connection types of passive elements that can be used to connect the Active Power Filter to the system, as well as the calculated values of these elements. There are three types of filtration: *L*, *L-C* and *L-C-L*. Thus, the user can choose to implement one type of passive connection filter out of the three available, depending on the nature of the application.



Information on the recommended active hybrid filter topology				
Recommended Filter Topology		Active filter: Shunt		
Issue/Issues of the system	Active filter		Hybrid filter	
	Series	Shunt	Active	Active
Harmonic currents, reactive and load balancing	-	**	-	*

Manufacturer	Name	VCES [V]	IRMS [A]	TJM [°C]	td(on) [ns]	td(off) [ns]	tr [ns]	tf [ns]
ABB	5SNG 0150Q170300.pdf	1700	150	0	950	175	180	220
ABB	5SNG 0150P450300.pdf	4500	150	0	1450	125	530	1500
Mitsubishi Electric	CM150TX-13T_CM150TXP-13	650	150	0	560	175	400	400
Mitsubishi Electric	CM150TX-24S.pdf	1200	150	0	1150	175	800	600

Fig.4. Page two of the Report window

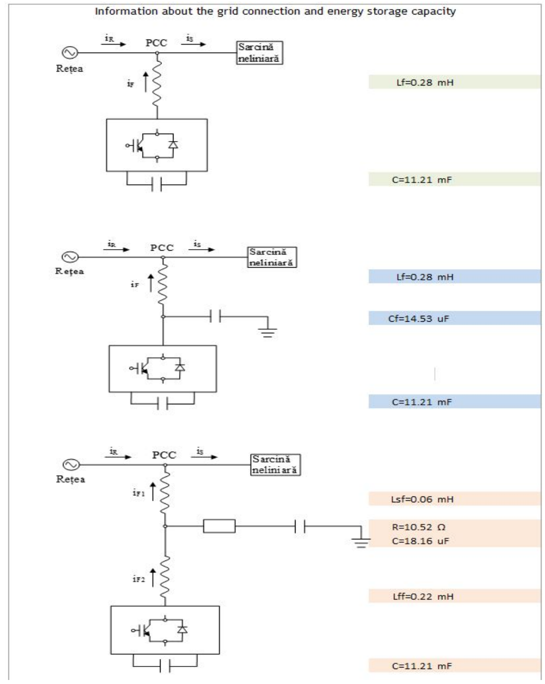
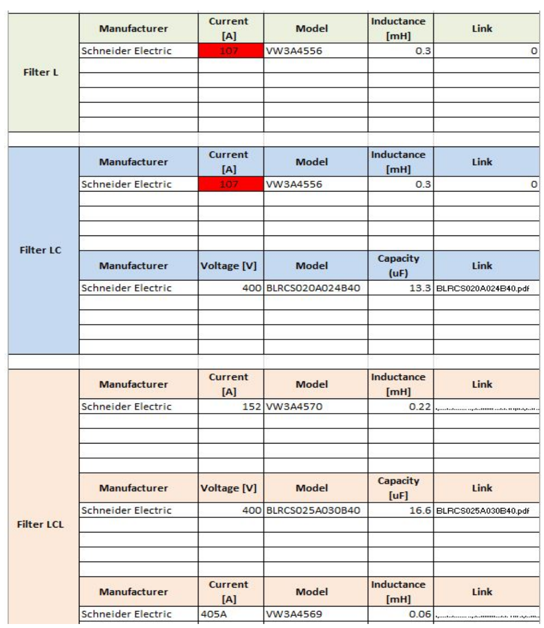


Fig.5. Page three of the Report window

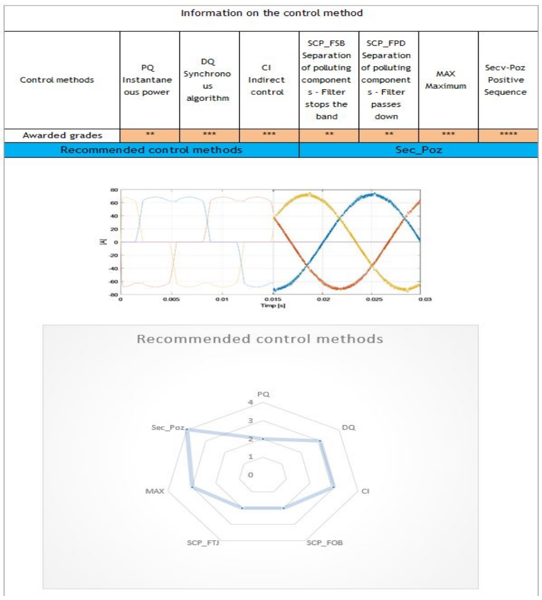
Fig.6 presents the fourth page of the Report. It contains a list of passive components, made by various manufacturers which can be used in equipping the Active Power Filter for the connection to the network or for storing the energy needed to the filter. The values of the passive components are determined in Fig. 5.



	Manufacturer	Current [A]	Model	Inductance [mH]	Link
Filter L	Schneider Electric	107	VW3A4556	0.3	0
Filter LC	Manufacturer	Current [A]	Model	Inductance [mH]	Link
	Schneider Electric	107	VW3A4556	0.3	0
	Manufacturer	Voltage [V]	Model	Capacity (uF)	Link
	Schneider Electric	400	BLRCS020A024B40	13.3	BLRCS020A024B40.pdf
Filter LCL	Manufacturer	Current [A]	Model	Inductance [mH]	Link
	Schneider Electric	152	VW3A4570	0.22	
	Manufacturer	Voltage [V]	Model	Capacity [uF]	Link
	Schneider Electric	400	BLRCS025A030B40	16.6	BLRCS025A030B40.pdf
	Manufacturer	Current [A]	Model	Inductance [mH]	Link
	Schneider Electric	405A	VW3A4569	0.06	

Fig.6. Page four of the Report window

The control method which can deliver the best results for the electrical system that is defined by the input values is presented in Fig.7.



Information on the control method

Control methods	PQ Instantaneous power	DQ Synchronous algorithm	CI Indirect control	SCP_FSB Separation of polluting components - Filter stops the band	SCP_FPD Separation of polluting components - Filter passes down	MAX Maximum	Secv-Poz Positive Sequence
Awarded grades	**	***	***	**	**	***	****
Recommended control methods				Sec_Poz			

Fig.7. Page five of the Report window

It is in a graphical form in which the results obtained by the other types of control methods are presented. Thereby, the user knows that there are more control methods for solving the issue, but the control method with the most stars is the best solution

Fig.8 presents the block diagram of the control method recommended by the electronic application FAP-tool.

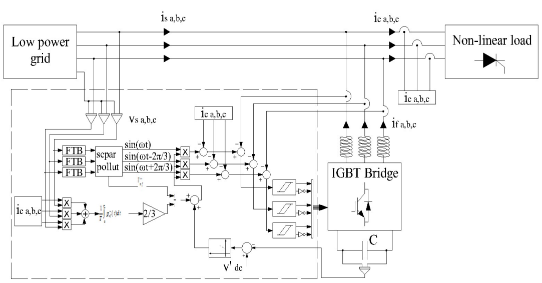
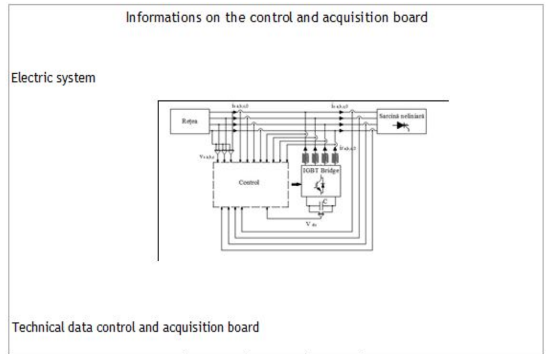


Fig.8. Page six of the Report window

In Fig.9 is presented the block diagram of the electrical system where the Active Power Filters are connected. Also here is provided to the user the list of acquisition boards that can be used to make the Active Power Filter.



Technical data control and acquisition board

Nume	Nr AI	Nr AO	Nr DIO	FPGA		
				Flip-Flops	Slice LUT	Block RAMs kbits
X3-SD	16	16	22	17280	153600	432
X3-SD16	16	16	22	33280	33280	1512
X3-Servo	12	12	22	33280	33280	1512
X3-2M	12	12	22	33280	33280	1512
MicroLabBox (Xilinx® Kintex®-7 X	32	16	48	407600	50950	16020

Fig.9. Page seven of the Report window

After all the input data is introduced into the FAP-tool application, the obtained results will provide the suggestions regarding these four aspects: power elements, passive elements, control strategy, control board in a report.

4. ACKNOWLEDGMENT

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5. CONCLUSION

In this paper, the electronic application FAP-tool was briefly presented. This application comes to support the people who want to design Active Power Filters. Finally it offers the calculus and selection of the components related to the Active Power Filter in the database.

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