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CONTROL SYSTEM OF THE FILTER-COMPENSATING DEVICE WITH THE SECOND-ORDER FUZZY REGULATOR

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In this article the expediency of using the fuzzy controller, as part of an additional control loop of the compensator control system in terms of the level of commutation overvoltages and amplitudes of the higher harmonics of the supply network current, is shown. The use of fuzzy controller makes it possible, in the process of reactive power compensation, to reduce the generation of higher harmonics of the current to the network, without exceeding the established level of switching overvoltages. The principles of control of the filter compensating device for the powerful sounding pulses generator using the second order fuzzy regulator are considered. The use of a fuzzy second-order regulator will enable the controlled parameters to be adjusted with the given accuracy. References 8, figures 5, table 1.

Key words: multi-functional compensators, control system, fuzzy logic controller.

Introduction. At present, various options for constructing devices for compensating inactive network power are proposed in [1,6,7], however, a narrow specialization and orientation toward a specific type of distortion of the power network indicate the advisability of an integrated approach to solving the problem of improving the quality of electricity and meeting its standards. A promising direction is the creation of multifunctional devices that perform the functions of a network asymmetry compensator, a stabilizer, an active filter and a reactive power compensator [2,8]. Currently two-channel compensator had been developed and it is based on the principle of a two-channel structure in the power circuit. The power circuit of the device is the compensated controlled rectifier that consists of the low and the high frequency channels. The power circuit is shown in [4, 8]. The control system of compensator is based on modern power theories, fuzzy logic and forecast control ideas. Control algorithms of dual channel compensator and control software in real time are considered in [4,5,8]. In this article it is necessary to prove the expediency of using the second-order fuzzy regulator, as part of an additional control loop of the compensator control system in terms of the level of commutation overvoltages and amplitudes of the higher harmonics of the supply network current.

Compensators control principles. Matlab-model of a two-channel semiconductor compensator with digital forecasted control system is shown in Fig. 1. Matlab-model of a two-channel semiconductor compensator includes gate group GG of the low frequency channel with active-inductive load, the voltage inverter - SAF, the digital processing block DPB, the capacitive C with the diode group VD and the pulses distribution block PDB. A load of compensator is the powerful sounding pulses generator, described in [4, 8].

Using a given model, the dependence of the level of commutation overvoltages, as well as the level of the amplitude of an single harmonics of the mains current, on the relative voltage on the storage capacitor were investigated. The graphical dependencies obtained by means of the simulation, as well as their analysis, confirmed the theoretical conclusions about the presence of a range in which further increase of the voltage value on the storage capacitor Uc is not advisable, in order to reduce the values of single harmonics of the mains current, of the set overvoltage limit Upmax, which must be taken into account when tuning the parameters of the fuzzy controller. Recommended level of overvoltage restriction is 0.98 of the amplitude value of the voltage on the secondary winding of the low-frequency channel transformer. The interrelation between the amplitudes of the higher harmonics of the line current I_{Gi} and the level of overvoltages Up on storage capacitor appear as the initial data for the synthesis of the fuzzy controller. Fuzzy controller controls the amplitude level of selected harmonic of mains current k_i and establishes it to the bounden value. This can be received by varying the level of capacitor voltage of the inverter Uc by control signal Uc_ref of the extra control loop.

The initial data for the synthesis of the second-order fuzzy controller is the experimental data, presented in the form of a table of reference points (Table). The table of control points has *n* rows and *m* columns. To each row and column, when forming incoming linguistic variables, there will be a triangular term with a vertex that determines the values of the input parameter of the corresponding row and column.

Thus, the linguistic variables describing the second-order fuzzy regulator will look like this:

- input *k* (k_i - the amplitude level of selected harmonic) and its range K = { K1, K 2, …, Kn};
- input *u* (Uc - the voltage value on the storage capacitor) and its range U = { U1, U 2, …, U m};

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- input *p* (Up - the level of commutation overvoltages) and its range P = { P 1, P 2, …, P m};
- output *r* ($U_{c\ ref}$ - the control signal) and its range R = { R 1, R 2, …, R q}.

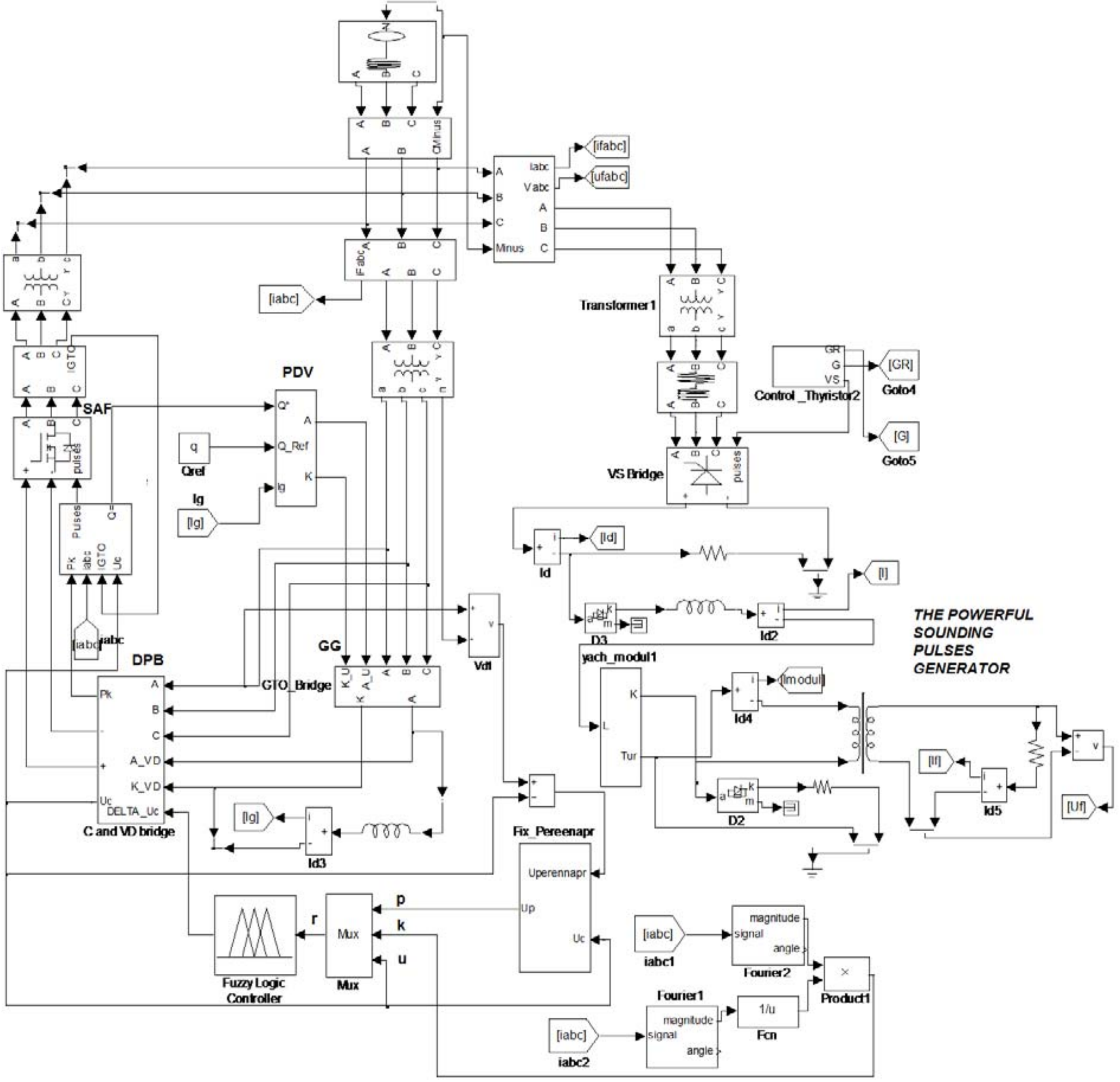


Fig. 1

Inputs *u* and *p* Input *k*	u_{U1}, p_{P1}	u_{U2}, p_{P2}	…	u_{Uj}, p_{Pj}	…	u_{Um}, p_{Pm}
k_{K1}	$r_{11} = R^C_1$	$r_{11} = R^C_1$	…	r_{1j}	…	$r_{1m} = R^C_{m-1}$
k_{K2}	$r_{21} = R^C_1$ and R^C_2	$r_{22} = R^C_2$ and R^C_3	…	r_{2j}	…	$r_{2m} = R^C_{m-1}$ and R^C_m
…	…	…	…	…	…	…
k_{Ki}	r_{i1}	r_{i2}	…	r_{ij}	…	r_{im}
…	…	…	…	…	…	…
k_{Kn}	$r_{n1} = R^C_m$	$r_{n2} = R^C_m$	…	r_{nj}	…	$r_{nm} = R^C_{m-1}$ and R^C_m

The number of product rules N that need to be described is

$$N = m \cdot n. \qquad (1)$$

If the desired value r lies between the centers of gravity of terms R_g и R_{g+1}, then in the context of the production rule $r = R_g$ the result will be less than desired, and with $r = R_{g+1}$ – more than desired. Therefore, production rules are created with a double consecvet of this type

$$\text{IF } k=\mathrm{K_i} \quad \text{AND} \quad u=\mathrm{U_j} \quad \text{AND} \quad p=\mathrm{P_j} \quad \text{then} \quad r=\mathrm{R}^{C_1}{}_{g} \quad \text{AND} \quad r=\mathrm{R}^{C_2}{}_{g+1}.$$

Determination of the degree of truth C_k is carried out in a mathematical package and is described in more detail in [5]. Thus, if the desired value coincides with one of the centers of gravity of terms, then in the consequent of the production rule for a given output, this term is indicated. If the desired value does not coincide with any of the centers of gravity of terms, then in the productive rule consequent for the given output two terms with necessary degrees of belonging are indicated. Since the fuzzy controller synthesis algorithm does not depend on the number of inputs and the sequence of development of product rules, the static characteristic in all directions will have the same properties [9]. Outputs in the fuzzy controller are independent, so this algorithm can be used regardless of the number of outputs.

The example of fuzzy controller rule synthesis. Lower voltage limit on the storage capacitor, which is chosen from the condition of ensuring the permissible value of the harmonic current factor of the supply network, is equal to twice the amplitude value of the linear voltage on the secondary winding of the rectifier transformer. It is recommended to maintain the voltage on the storage capacitor at level 2.6 from the amplitude value of the voltage on the secondary winding of the low-frequency channel transformer. Terms of linguistic variable output parameter of fuzzy controller are shown in Fig. 2. Let consider the synthesis of the production rule for a variable k = k1, u = u1. Let according to the table of control points, the required output value r1 is 2,38. Nearest terms are V1 and V2.

To identify the base and additional consecutive factors, the center of gravity of the linguistic variable with active terms V1 and V2 with C = 1 equals $r_\Sigma=(2{,}3+2{,}4)/2=2{,}35$.

As $v_r > v_\Sigma$, then the basic consequent is v = V2, additional consequent is v = V1. The degree of truth of the basic consequent is 1. The degree of truth of the additional consequent C is determined from the graph presented in [5] depending on the relative value of the output value according to the formula

$$r^*=1-(2{,}38-2{,}35)/(2{,}4-2{,}35)=0{,}94. \tag{2}$$

According to the graph presented in [5], it can be found the value of the truth of the additional consequent C = 0.68.

The production rule will have the form: IF k = K1 AND u = U1 then v = V1 $^{0.68}$ AND v = V2.

For other rules, calculations are carried out similarly.

The surface of the static characteristic is shown in Fig. 3.

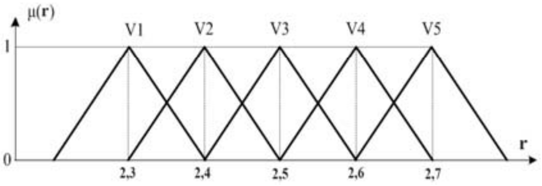


Fig. 2

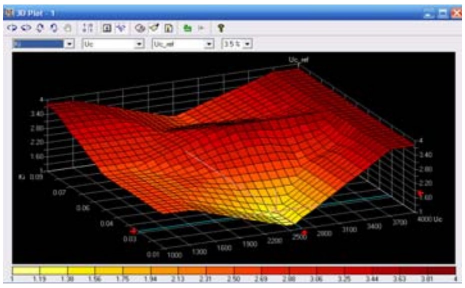
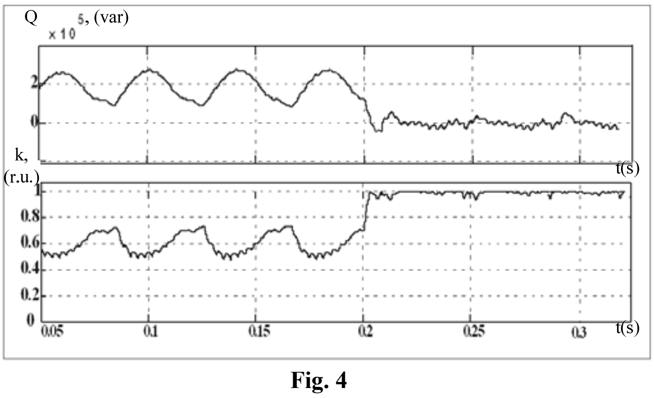


Fig. 3

Simulation results. Energy characteristics of generator including reactive power Q and a power factor *k* when the compensator is connected are shown in Fig. 4. Fig. 5 demonstrates changing of the current harmonics amplitudes Im that are generated by the generator to the mains supply. The proposed control system provides maintaining the load factor with the compensator not lower than 0.98 and reducing the amplitudes of higher harmonics of the power supply current by 50-60% of the initial value, which proves the efficiency of using the second-order fuzzy controller. When using the proposed fuzzy controller amplitude of commutation overvoltage pulse does not exceed 0.96 of the amplitude value of the voltage on the secondary winding of the low-frequency channel transformer.



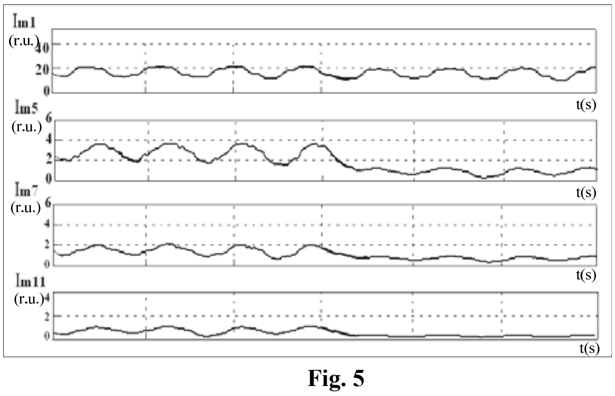


Fig. 4 Fig. 5

Conclusions. The simulation results confirmed the effectiveness of the proposed multi-loop control system of compensators for powerful sounding pulses generators. The obtained results are completed for use in the development of the structure of a microprocessor control and regulation system for the filter-compensating device for powerful sounding pulses generators, the creation of real-time control algorithms and their program realization.

1. Asiminoaei L., Lascu C., Blaabjerg F., Boldea I. Performance Improvement of Shunt Active Power Filter With Dual Parallel Topology. *IEEE Transactions on Power Electronics.* 2007. Vol. 22. No 1. Pp. 247-259.

2. Dixon J., del Valle Y., Orchard M., Ortúzar M., L. Morán L. Maffrand C. A Full Compensating System for General Loads, Based on a Combination of Thyristor Binary Compensator and a PWM-IGBT Active Power Filter. *IEEE Trans. Industrial Electronics.* 2003. Vol. 50. No 5. Pp. 982-989.

3. Domnin I.F., Levon E.A., Varvyanskaya V.V. Fuzzy logic based control system of converter for powerful sounding pulses generator. *Bulletin of NTU KhPI.* 2014. No 47. Pp. 22–27.

4. Domnin I.F., Kaida E.A. Synthesis of the second-order fuzzy regulator for the control system of the filter-compensating device. *Bulletin of NTU KhPI.* Series: Radiophysics and ionosphere. 2017. No 42 (948). Pp. 17–22. (Rus)

5. Kim S., Enjeti P.N. A New Hybrid Active Power Filter (APF) Topology. *IEEE Transactions on Power Electronics.* 2002. Vol. 17. No 1. Pp. 48-54.

6. Kwak S., Kim T. An Integrated Current Source Inverter With Reactive and Harmonic Power Compensators. *IEEE Transactions on Power Electronics.* 2009. Vol. 24. No 2. Pp. 348-357.

7. Levon O.O. Semiconductordual two-channel regulated compensator of inactive components of the total power: Ph.Dr. tech. sci. diss.: 05.09.12. NTU KhPI. Kharkiv. 2015. 200 p. (Rus)

8. Soloviev K.A., Muravieva E.A. The reference model for a process control system based on a fuzzy controller of the second order. *Modern problems of science and education in technical high school*: sat. materials of II International scientific-practical conf. Sterlitamak. 2015. Pp. 61–66. (Rus)

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СИСТЕМА КЕРУВАННЯ ФІЛЬТРОКОМПЕНСУЮЧИМ ПРИСТРОЄМ З FUZZY-РЕГУЛЯТОРОМ ДРУГОГО ПОРЯДКУ

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Показано доцільність використання нечіткого регулятора у складі додаткового контура регулювання системи керування компенсатором за рівнем комутаційних перенапруг і амплітуд вищих гармонік струму мережі живлення, застосування якого дає можливість у процесі компенсації реактивної потужності зменшити генерацію в мережу вищих гармонік струму, не перевищуючи при цьому встановлений рівень комутаційних перенапруг. Розглянуто принципи керування фільтрокомпенсуючим пристроєм для формування потужних зондуючих імпульсів з використанням нечіткого регулятора другого порядку, застосування якого дає змогу регулювати контрольовані параметри з заданою точністю. Бібл. 8, рис. 5, табл. 1.

Ключові слова: багатофункціональні компенсатори, система керування, нечіткий логічний регулятор.

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СИСТЕМА УПРАВЛЕНИЯ ФИЛЬТРОКОМПЕНСИРУЮЩИМ УСТРОЙСТВОМ С FUZZY-РЕГУЛЯТОРОМ ВТОРОГО ПОРЯДКА

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В статье показана целесообразность использования fuzzy-регулятора в составе дополнительного контура регулирования системы управления компенсатором по уровню коммутационных перенапряжений и амплитуд высших гармоник тока питающей сети, применение которого дает возможность в процессе компенсации реактивной мощности уменьшить генерирование в сеть высших гармоник тока, не превышая при этом установленный уровень коммутационных перенапряжений. Рассмотрены принципы управления фильтрокомпенсирующим устройством для формирователя мощных зондирующих импульсов с использованием нечеткого регулятора второго порядка, применение которого даст возможность регулировать контролируемые параметры с заданной точностью. Библ. 8, рис. 5, табл. 1.

Ключевые слова: многофункциональные компенсаторы, система управления, нечеткий логический регулятор.

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