IOP Conf. Series: Materials Science and Engineering **791** (2020) 012034 doi:10.1088/1757-899X/791/1/012034

Elements realization of software-algorithmic system optimization of technological processes based on adaptive methods

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Abstract. The paper examines a possibility to optimize complex technological processes of energy resources transfer and consumption. Notes the importance of unidentified and weakly formalized factors consideration, which influence quality of the described object classes functioning. Suggests use of fuzzy neural networks and controllers on their basis for implementation of technological processes optimization of energy resources transfer and consumption at the expense of its dynamic accuracy forecast improvement. Presents algorithmic realization, that later on configured in the MATLAB simulated environment. Quantitative and qualitative parameters, which characterize fuzzy neural controller's usage quality, were received. Later, software environment elements are being described, which constructed on the basis of the suggested adaptive approach for complex technological processes optimization. Points out a possibility to conduct comparative study, and also simulation modeling implementation by way of presented solutions.
Keywords: optimization of complex technological processes, electrical power systems, electrical energy loss minimization, fuzzy neural networks, accuracy of forecast, elements of a software system.

1. Introduction

Optimization of complex technological processes in electrical power systems (TP EPS), in the most common case, is implemented with the criterion of minimum capacity loss and can be presented as follows:

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$$F_j = \sum_{i=1}^{k} W_i = \sum_{i=1}^{k} \left[\frac{\left(\sqrt{P_i(U)^2 + Q_i(U)^2}\right) \cdot R_{Ei}}{U_i^2} \cdot \left(\frac{1}{\left(1 - \frac{\Delta U_{\% i}}{100}\right)^2} - 1 \right) + \right. \tag{1}$$

$$\left. + \Delta P_{xxi} \cdot T_{pi} \cdot \left(\frac{U_i}{U_{nom\ i}} \right)^2 + \Delta p_{cor\ i} \cdot L_i \cdot k_{Ucor\ i} \right] \rightarrow \min,$$

where W – total losses of electrical power in TP EPS;
ΔR_E, L – equivalent active resistance and length of elements for energy power transmission;
ΔU, % – change of the input voltage value as a percentage of the nominal value;
$\Delta P_{xx\ i}$ – no-load power loss in TP EPS elements;
$T_{p\ i}$ – number of TP EPS hours of work;
$\Delta p_{cor\ i}$ – mean specific losses due to corona in the electrical power transmission elements in TP EPS;
$k_{Ucor\ i}$ – corona loss coefficient.

In addition, the following constrains should be met

$$\begin{cases} \left| P_{int\ i} + P_{out\ i} \right| > 0; \\ \left| Q_{int\ i} + Q_{out\ i} \right| > 0; \\ i = 1, \ldots, k; \end{cases} \tag{2}$$

where $P_{int\ i}$, $Q_{int\ i}$ – values of internal real and reactive power flow of elements in TP EPS;
$P_{out\ i}$, $Q_{out\ i}$ – values of outer real and reactive power flow of elements in TP EPS.

2. Materials and Methods

TP EPS performance indicators optimization is often performed on the basis of the Lagrangian method applied to the expression (1) with constrains (2). Weakness of this solution is an actual neglect of undetermined components, which have strong influence on the electrical power flow distribution [1, 2-7].

Gradient methods with fixed and variable step size are taken as an alternative variant (in particular, on the basis of the Newton-Raphson algorithm).

For TP EPS performance indicators optimization with consideration of unidentified components it is worthwhile to use a modified Newton-Raphson algorithm with fuzzy neuron controllers (FNC) inclusion in its structure [8, 9]. Realization of the mentioned approach have sequence of steps, which presented in the algorithm shown in Figure 1 [9].

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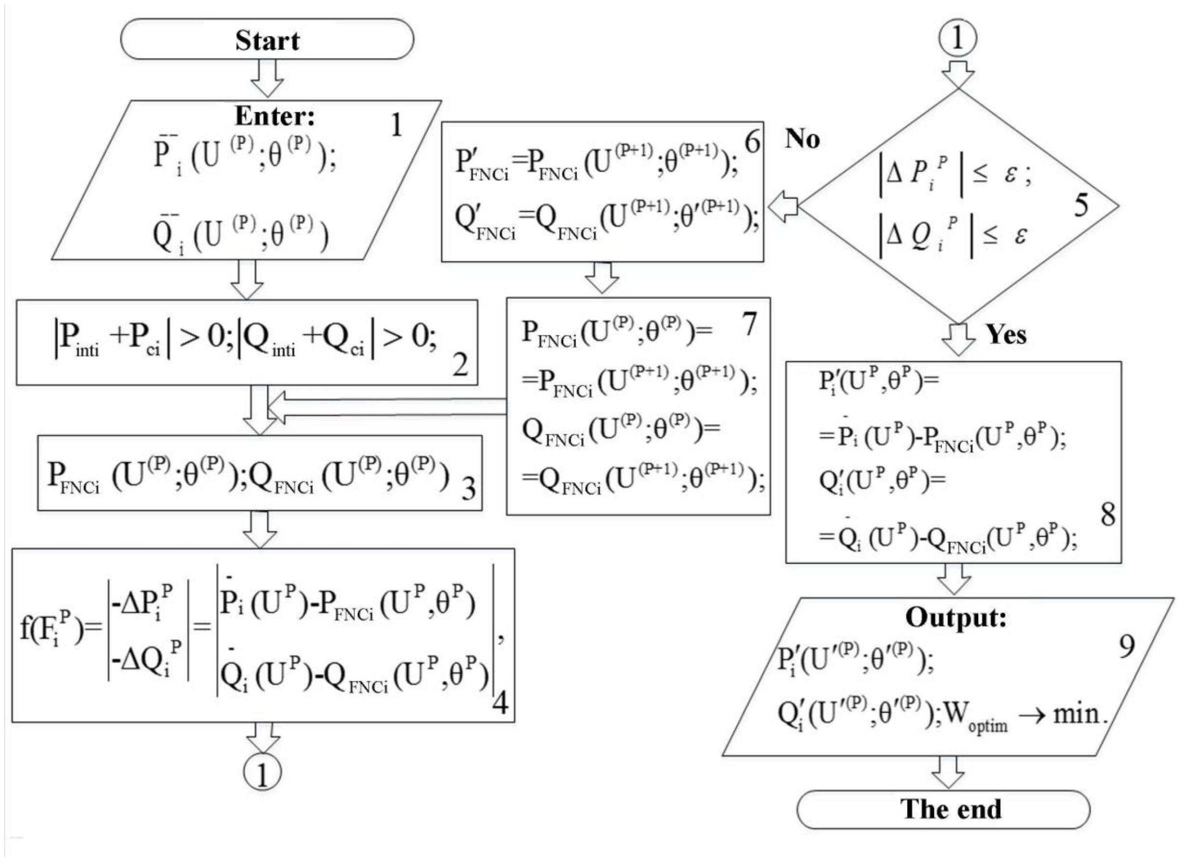

Figure 1. Modified Newton-Raphson algorithm for TP EPS optimization with FNC inclusion

Figure 1 presents the following notations:

$P_{FNCi}(U^{(P)};\theta^{(P)})$, $Q_{FNCi}(U^{(P)};\theta^{(P)})$ – forecast of real and reactive power with use of FNC;

$f(F^P)$ – unbalanced vector on n - th iteration;

$\bar{P}(U^P), \bar{Q}(U^P)$ – assignment of real and reactive power in the nodal of TP EPS;

ΔP^P, ΔQ^P – real and reactive power residuals;

P'_{FNCi}, Q'_{FNCi} – adjusted vectors of real and reactive power;

$U^{(P+1)}, \theta^{(P+1)}$ – voltage amplitude and phase lag during the iterations.

Table 1 presents comparative study results of TP EPS control system functioning using modified Newton-Raphson algorithm, shown in figure 1. Realization implemented within the ANFIS structure of MATLAB software system framework.

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Table 1. Comparative study of based on fuzzy neural network models realizations.

FNN learning algorithm – Sugeno (hybrid)					FNN learning algorithm – Mamdani (hybrid)		
Input membership term types (configuration $3\times3\times3$)							
	term	trapmf	psigmf	dsigmf	trapmf	psigmf	dsigmf
Estimated prameters	ε_n	0.271	0.228	0.228	0.152	0.061	0,056
	r	0.981	0.989	0.987	0.972	0.989	0,974
	$\varepsilon_{\%}$	3.145	2.012	2.005	3.478	2.054	2,159
Nuber of training epochs		500	6	6	500	30	27
Learning time, sec.		67.46	1.03	1,05	67.44	4.27	3.85
FNN learning algorithm – Sugeno (hybrid)					FNN learning algorithm – Mamdani (hybrid)		
Input membership term types (configuration $6\times3\times3$)							
	term	trapmf	psigmf	dsigmf	trapmf	psigmf	dsigmf
Estimated prameters	ε_n	0.090	0.053	0.061	0.087	0.028	0,032
	r	0.980	0.987	0.988	0.979	0.987	0,988
	$\varepsilon_{\%}$	2.954	1.903	1.985	2.903	1.874	1,889
Number of training epochs		500	16	17	200	40	33
Learning time, sec.		68,74	2.33	2.48	27.01	5.47	4.68
FNN learning algorithm – Sugeno (hybrid)					FNN learning algorithm – Mamdani (hybrid)		
Input membership term types (configuration $9\times3\times3$)							
Estimated parameters	term	trapmf	psigmf	dsigmf	trapmf	psigmf	dsigmf
	ε_n	0.021	0.012	0.012	0.073	0.011	0,013
	r	0.983	0.991	0.993	0.985	0.997	0,994
	$\varepsilon_{\%}$	2.901	1.853	1.751	2.101	1.609	1,645
Number of training epochs		500	51	53	100	38	34
Learning time, sec.		69,41	7.03	7.36	13.88	5.24	4.69
Processor type - Intel Core i3-7350 – Core Processor (4.2 GHz)							

Best results from the analyzed sample demonstrated FNN realization on the basis of Mamdani algorithm using input terms configuration and membership function - psigmf. figure 2 presents results of fuzzy neural network training in the context of this variant realization. Test sample deviations from the exit results is an indication of high accuracy functioning of given system.

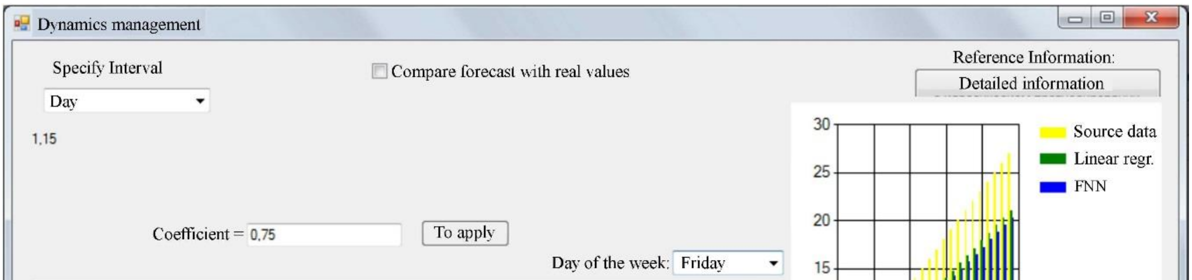
Figure 2. Fuzzy neural network training using an input membership term function of psigmf type.

3. Results

Received during functioning of mentioned TP EPS algorithm optimization results are realized in the form of software system elements [9]. User, in addition, is provided with a possibility to perform both on-line (up to 1 day) and medium-term parameters control (weekly, monthly variations) of technological cycle of conversion, transfer and consumption of energy resources. To construct necessary dependences, one should choose a period of interest, that needs analysis of power flow in TP EPS. Realized software system also allows to conduct collaborative calculations for normative method of energy resources distribution and perform comparative study with system functioning based on FNC.

Graph of the collaborative analysis results for normative (classic) process of energy resources control and FNN system is shown in figure 3. It can be seen that in the presented block of software system was also realized a function «Compare control forecast with real values», which gives a possibility in graphical format to compute combined graphs of forecast control samples and real values for the same periods.

Interface of the developed software elements contains interrelated forms, first of which has an area for automatic or manual fill-out of user`s information.



Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
22	45	46	51	1	26	31	47
23	47	48	53	2	27	32	49
0	18,82135	19,69235	24,04735	1,40635	12,53335	16,88835	20,56335
1	8,88421245	9,70528945	13,81067445	1,66060745	7,41875645	11,52414145	10,52636645
2	6,006540218...	6,808297017...	10,81708101...	1,275005083...	5,923408746...	9,932192741...	7,610053816...
3	5,860881064...	6,655160945...	10,62656035...	1,609776967...	5,828709184...	9,800108590...	7,449440826...

Figure 3. Collaborative analysis bloc of real and controlled measures for on-line and medium-term periods.

Upon completion of the corresponding data bases generation appears an option to fill-out parameter settings both classic method and realization on the basis of FNN (FNC) figure 4. It is worth noting, that the considered approach framework gives a possibility to analyze data not only in the context of power but also transferred electricity volume.

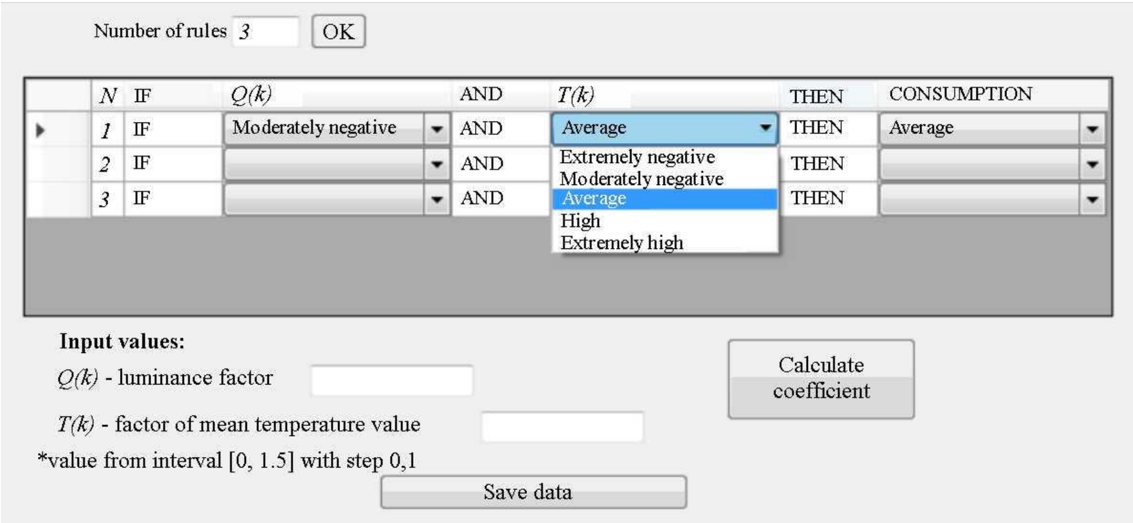


Figure 4. Generation of the functioning rules for FNN (FNC).

In the software system elements is also organized an option to preview reference data about algorithms [10], which are used to control flow of energy resources in TP EPS [11-14].

The developed solution also provides input data validity check at different stages, among them, for the data bases in the previous periods. So, before TP EPS optimization algorithm begins to work there is a check for correctness and completeness of the input data, which can be updated when necessary.

The developed interface of the software system is user friendly both for automatic and for manual mode use, and that was confirmed by the testing results.

Hardware and software tools for modeling and analysis of alternative structures in the control system that handles technological processes of energy resources conversion, transfer and consumption realized by means of the host-program ODP.exe, layout of which is presented in Figure 5 for the modeling subsystem of «Generation/CHP» type [15].

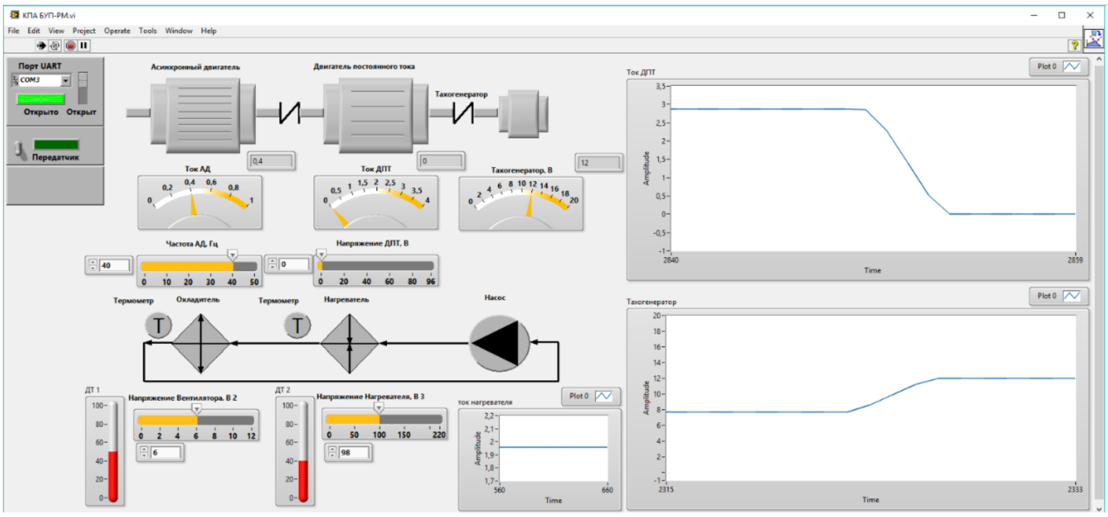


Figure 5. User`s interface for the modeling subsystem of «Generation/CHP» type.

To establish connection to a hardware part there are switch and window to choose a port to communicate by data transmission virtual port. To assign work mode (DAC control) there are sliders and windows for data digital writing. Both dial indicators and oscillogram graphs of transient processes are used for the information output.

Analisis of the TP EPS optimization model functioning using measure of the energy resources loss at its minimum, which has been constructed on the FNC basis, allows to say about its high accuracy characteristics, that are much more accurate than existing classic realizations (around 3-6%), which is proved by the data in figures 6,7.

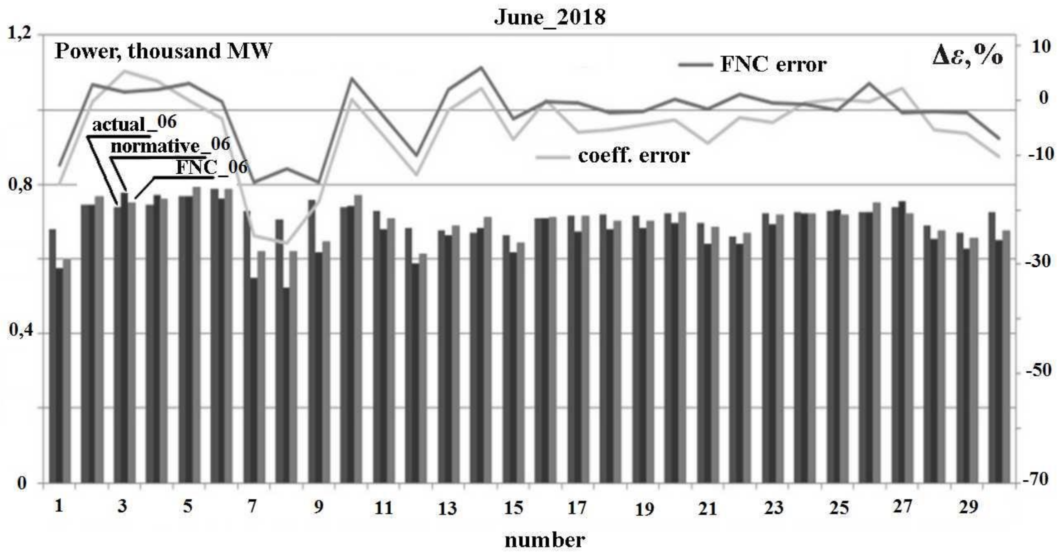


Figure 6. Optimization forecast for the TP EPS load center of Voronezh city (June, 2018): actual, normative, FNC – thousand MW; forecast systems functioning error based on the normative method and FNN usage, %.

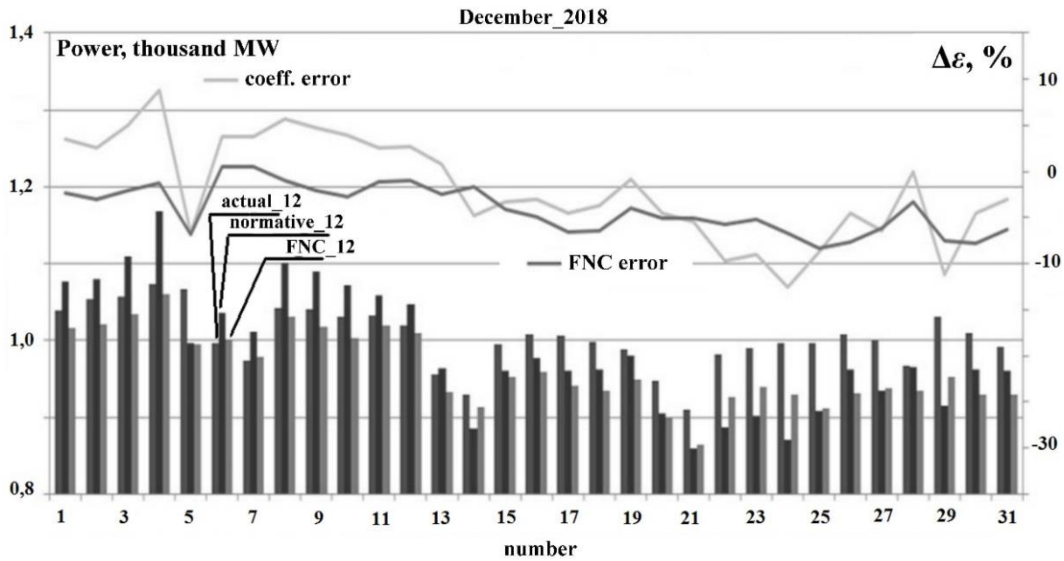


Figure 7. Optimization forecast for the TP EPS load center of Voronezh city (December, 2018): actual, normative, FNC – thousand MW; forecast systems functioning error based on the normative method and FNN usage, %.

4. Conclusion

1. Conducted optimization of complex TP EPS with consideration of weakly formalized factors by using fuzzy neural networks and controllers on their basis. Presented algorithm which allows realization of the control parameters correction in real time mode.

2. Forecast error in on-line and medium-term period is in the range of 1,6% to 3,5%, that allows to say about high potential usage of the described approach in the existing energy load centers (in particular in power generating industry).

3. Developed software system elements for TP EPS optimization allow to carry out automated monitoring and control of load parameters based on evaluation of actual and forecast graphs of power flows distribution dynamics.

4. There is a possibility to organize feedback from TP EPS actuator mechanisms and their optimization on the basis of the performed in advance simulation modeling.

5. Received within the framework of the developed software system elements results of TP EPS Voronezh load center functioning prove reliability of conclusions, with regard to relevance usage of FNN (FNC) as an adaptive structure, which allow to take into consideration weakly formalized and also unidentified factors.

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