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Development of Control Algorithm for Adaptive Leakage Current Protection Devices' using Fuzzy Logic

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Abstract

New approaches and technology of development adaptive to voltage oscillation leakage current protection systems used in isolated neutral system are proposed. The control algorithm of protection device developed using fuzzy logic, which allows adapting of protection devices' thresholds to network parameters changing. Linear integrated and square-law integrated criteria of protection device's threshold adaption for network parameters changing are developed and proved. The model and structure of automatic thresholds adaption system are developed, based on the fuzzy controller.

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Keywords: Leakage current; Fuzzy logic; Adaptive; Control algorithm

1. Introduction

To ensure safe operation of isolated neutral system and electrical equipment in the mining industry, leakage currents protecting devices are widely used [1]. Considerable voltage oscillations observed in mining's power network during operation (-30 % to +20 % from nominal value) because of limited capacity of quarry's networks, that essentially exceeds admissible standards of norm [2]. Thus, oscillations could have a stepwise character associated with switching on – switching off of various electric equipment, or monotonic character associated with smooth changing of loading, and also harmonic character during fluctuations of loading or at periodic switching on – switching off processes of equipment. Application of variable frequency electric drive in mining is also accompanied by voltage oscillation of electric grid. Nevertheless protection device's thresholds remain invariable

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that leads to decreasing of safety level during overvoltage and to malfunctions during under voltage. The leakage currents protection devices aren't used in 6 kV cable power transmission lines which used for electrical supply of digging machines and cabled in open-cast mines and coal pits, because of insufficient response time of existing devices.

Existing leakage currents protection devices is inefficient due to the complexity of the physical phenomena associated with leakage currents. Existing devices do not carry out automatic adapting of thresholds depending on the voltage oscillation in the controllable network nor depending on the single-phase and diphasic short circuits, both of which lead to increasing of the admissible current. In underground electrical supply networks, lengths of protected lines occasionally changes: such uncontrollable changes of parameters lead to decreasing of leakage current protection devices' efficiency. Protection device should possess adaptive properties [3] which allow changing it according to network's characteristics. We have developed an algorithm to control such adaptive leakage current protection system, using fuzzy controller. Proposed control algorithm will provide protection devices with the aforementioned adaptive properties.

2. Development of control algorithm

We have created a model of isolated neutral system using Matlab 7.01 (Fig. 1), in order to develop control algorithm and to measure the features of such network and obtain necessary data [4].

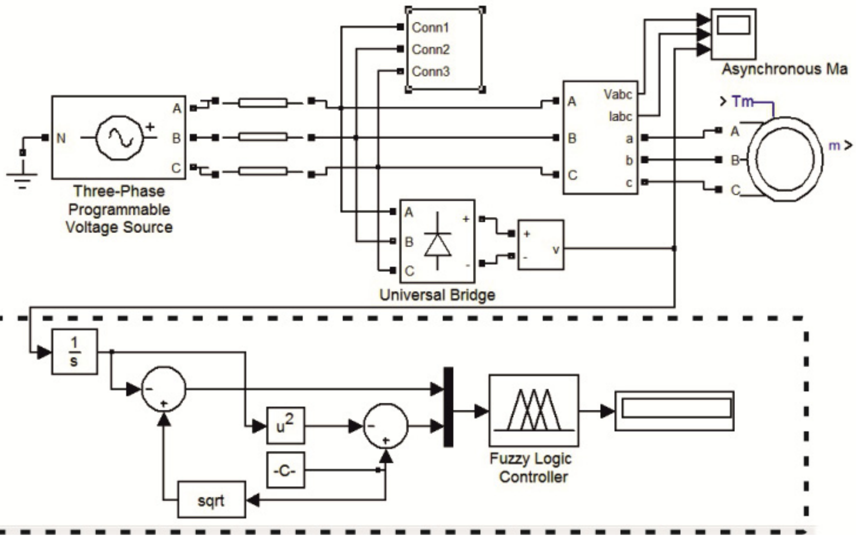

Fig. 1. Model of an isolated neutral system.

In the model stepwise, linear and harmonic changes of voltage are provided. Experiment data of the processes' features received by modelling from output of the scheme 6V. The scheme 6V used as the sensor of leakage current protection device and provides fast response time at the controllable network's voltage oscillation.

For automatic adaption of protection device's thresholds during voltage oscillation it's necessary to determine response criteria. If we choose voltage amplitude changing as response criterion, it will significantly complicate practical realization of system and reduce noise stability that will lead to malfunctions.

We know from the automatic control theory that integrated assessments of quality give the complex characteristics, which directly proportional to energy consumption in the majority of technical systems, that corresponds to controllable network's voltage oscillation. Owing to the linear integrated assessments are applied to monotonous dynamic processes, such criteria are effective at linear and stepwise character of the voltage oscillation. Square-law integrated assessments are applied to oscillatory processes; these criteria are effective at harmonic character of the voltage oscillation.

Therefore the linear integrated and square-law integrated criteria were chosen as response criteria of automatic threshold adaption system, which combined application, will allow reacting to all types of voltage oscillations of the controllable network and will provide a high noise stability of protection system.

To form the fuzzy inference systems' rule base it is necessary to predefine input and output linguistic variables [5]. It is obvious that as one of input linguistic variables it is necessary to use β_1 - «linear integrated criterion», and as the second input linguistic variable β_2 - «square-law integrated criterion». As an output linguistic variable we will use the protection device's threshold γ - « threshold ».

As a term set of the first input variable we will use a term set T_1= {N20, N15, N10-8, N7-5, AZ, P5-7, P8-10, P15, P20, P25, P30}. As a term set of the second input variable we will use a term set T_2= {AZ, P6-7, P8-9, P10, P (-15+15), P (-20+20), P (-25), P (-30)}. As a term set of an output variable we will use a term set T_3= {N30, N25, N20, N15, N10-8, N7-6, AZ, P6-7, P8-10, P15, P20, P25, P30}.

Taking account made specifications the considered information about leakage current protection device's threshold changing could be presented in the form of 17 rules of the fuzzy products as follows (Mamdhani fuzzy inference system)[6]:

Rule_1: If β_1 is P30 γ is N30;
Rule_2: If β_1 is P25, γ is N25;
Rule_3: If β_1 is P20, γ is N20;
Rule_4: If β_1 is P15, γ is N15;
Rule_5: If β_1 is P8-10, γ is N10-8;
Rule_6: If β_1 is N7-5, γ is P6-7;
Rule_7: If β_1 is N10-8, γ is P8-10;
Rule_8: If β_1 is N20, γ is P20;
Rule_9: If β_1 is AZ and β_2 is P6-7, γ is P6-7;
Rule_10: If β_1 is AZ and β_2 is P8-9, γ is P8-10;
Rule_11: If β_1 is AZ and β_2 is P (-15+15), γ is P15;
Rule_12: If β_1 is AZ and β_2 is P (-20+20), γ is P20;
Rule_13: If β_1 is AZ and β_2 is P (-25), γ is P25;
Rule_14: If β_1 is AZ and β_2 is P (-30,) γ is P30;
Rule_15: If β_1 is AZ and β_2 is AZ, γ is AZ;
Rule_16: If β_1 is P5-7, γ is N7-6;
Rule_17: If β_1 is N15, γ is P15;

The whole process of fuzzy modelling is implemented using Fuzzy Logic Toolbox software Matlab7.0.1. Then all necessary stages of the fuzzy modelling are realised by editor of the fuzzy inference system FIS. Basic settings of the fuzzy inference are specified such as: a method of fuzzy logic And (And method) "min" - value , a method of fuzzy logic OR (Or method) "max" - value , an implication method (Implication) "min" - value, an aggregation method (Aggregation) "max" – value and a method of defuzzification (Defuzzification) "centroid" – value [7].

The next step of a fuzzy modelling is determination of input and output parameters' membership functions [8]. Taking account the results received by imitating modelling, it is known that values of the first linguistic variable β_1 «linear integrated criterion» vary within from -(minus) 206 to 310 that corresponds to voltage oscillations from -30 % to +20 % from rating value. The received membership function of the first input variable is shown in Fig. 2 (a), on an axis of ordinates membership function is shown, on an axis of abscises - linear integrated criterion [9] is presented. Values of the second linguistic variable β_2 - «square-law integrated criterion» vary within from 0 to 3376 that corresponds to voltage oscillations from -30 % to +20 % from the nominal value at 5 Hz frequency. Corresponding to terms of the second linguistic variable membership function is presented on Fig. 2(b).

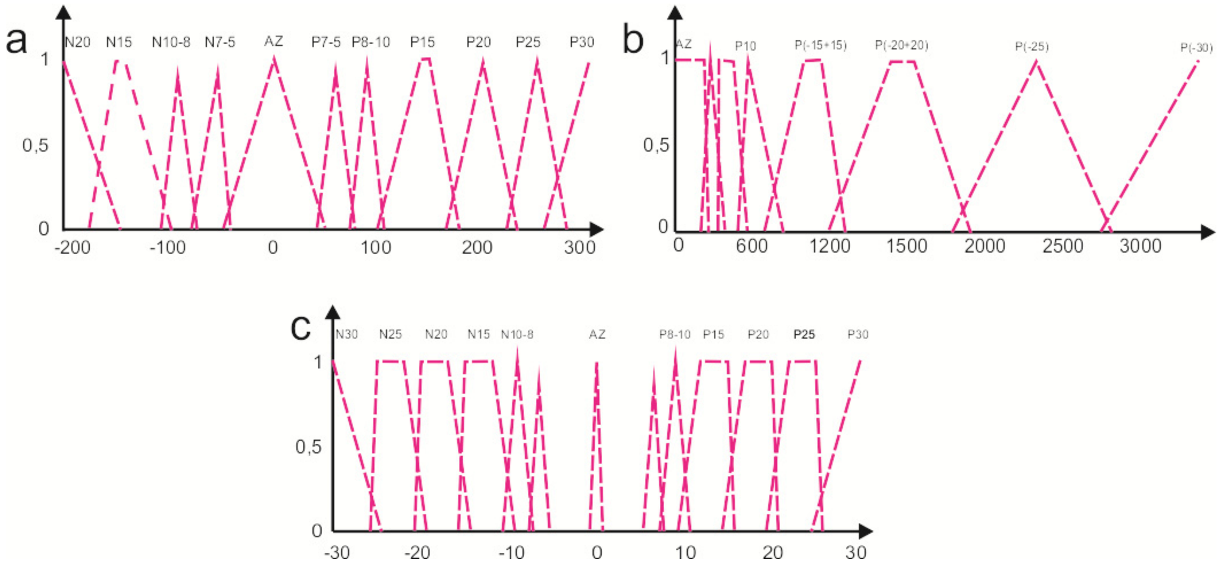

Fig. 2. (a) the membership function «linear integrated criterion»; (b) the membership function «quadratic integrated criterion»;(c) the membership function «threshold».

The output variable vary within from -30 % to + 20 %. Corresponding to terms of the output linguistic variable membership function is presented on Fig. 2(c).

All membership functions and terms were received taking account the dead zone, which vary within from – 5 % to + 5 % of voltage oscillation from rating value [10]. The dead zone was imposed to don't sway additional transient processes at small voltage oscillations in system and to avoid decreasing of safety level.

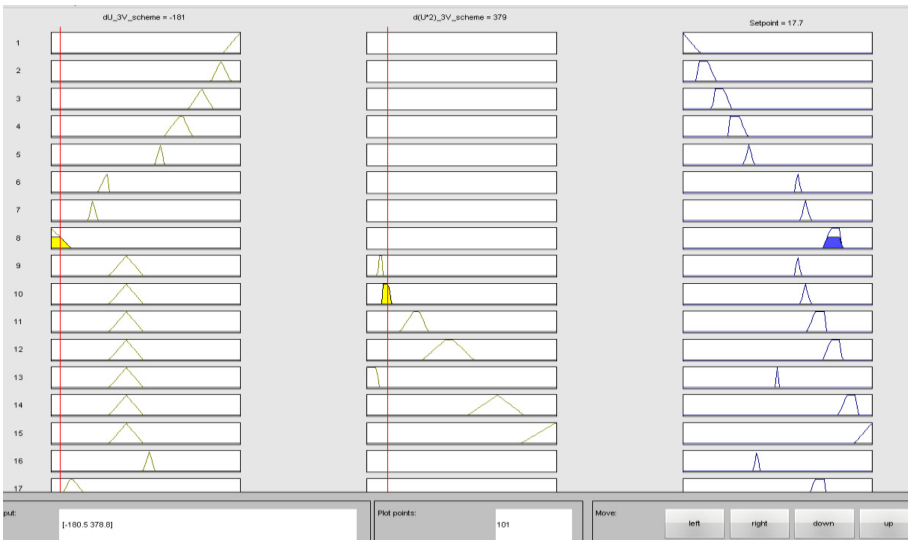

Fig. 3. the Browser of fuzzy rules system.

The next stage is to record the previously developed fuzzy production rules in the editor of the fuzzy inference by program Rule Editor, which is editor of the fuzzy inference. Editor of the fuzzy inference possesses the fuzzy rules system and the fuzzy inference system's surface browsing possibility (Fig. 3, Fig. 4).

So, the result of a fuzzy inference received at particular values of input variables is shown on Fig. 3. The first input variable's value is equal to 181 (first column), and the second input variable's value is equal to 379 (second column). Corresponding to such values of input variables value of the threshold is equal to 17,7 % from rating value. Corresponding sub-condition with number 8 was used in a rule of fuzzy production. This rule is considered to as active and it is applied in current process of the fuzzy inference.

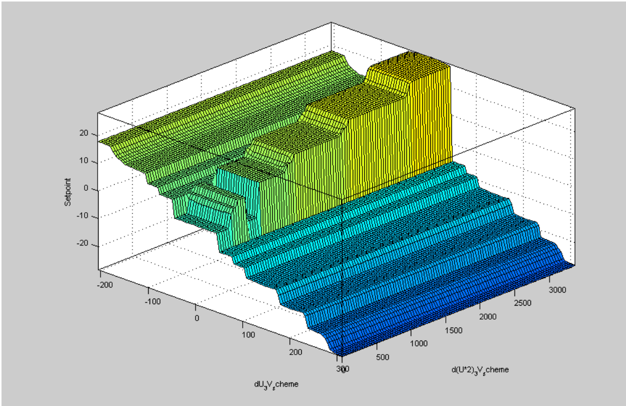

Fig. 4. the Browser of fuzzy inference surface.

The received output-input variables diagram (Fig. 4.) corresponds to values of the first input variable and second input variable - 100 (voltage oscillations vary within from -8 % to -10 %, which corresponds to the 5th rule of the fuzzy production).

The special «fis» file was created based on the fuzzy inference system, which is a basis of fuzzy controller's operation. Fuzzy controller based model of protection system was modelled using previously developed model of isolated neutral system and response criteria forming system (response criteria forming system and fuzzy controller were shown on Figure 1 by the dotted line).

Changing of voltage oscillation's character and parameters was done during simulation modelling. The results of the simulation modelling are presented in table 1.

Table 1. Results of the simulation modelling.

U_{ph}, V	voltage oscillation's character	amplitude (in relative units), and other parameters of fluctuation	linear integrated $J_1(t)$	square-law integrated $J_2(t)$	threshold
380	Harmonic	-0,3(-30%), 5Hz	1,09	3376	29,8%
380	Harmonic	-0,15(-15%), 5 Hz	0,305	941	16,1%
380	Harmonic	-0,06(-6%), 5 Hz	0,069	213	6,54%
380	Harmonic	0,06(6%), 5 Hz	0,056	215,97	6,3%
380	Harmonic	0,1(10%), 5 Hz	0,14	482	10,2%
380	Harmonic	0,2(20%) 5 Hz	0,45	1403	19,9%
380	Stepwise	-0,3(-30%)	310,024	860667,8	-29,7%
380	Stepwise	-0,15(-15%)	154,97	454255,6	-16,7%
380	Stepwise	-0,06(-6%)	62,02	187580,45	-6,54%
380	Stepwise	0,06(6%)	-61,95	-187061,5	6,46%
380	Stepwise	0,1(10%)	-103,24	-329341,7	9,5%
380	Stepwise	0,2(20%)	-206,46	-679812,5	18,9%
380	Linear	-0,3(-30%)	310,24	861253,9	-28,25%
380	Linear	-0,15(-15%)	155,01	454472,2	12,34%
380	Linear	-0,06(-6%)	61,01	187472,8	-6,2%

380	Linear	0,06(6%)	-62,01	-194954,1	6,58%
380	Linear	0,1(10%)	-103,2	-329197,8	9,4%
380	Linear	0,2(20%)	-206,41	-679621,2	18,6%

Simulation modelling was carried out with imitation of voltage oscillation's character and parameters vary within from -30 % to +20 % from rating value.

Conclusion

Leakage current protection system was developed based on fuzzy logic, which adaptive to controllable network's voltage oscillation. The linear integrated and square-law integrated criteria were chosen as response criteria of automatic threshold adaption system, which combined application, will allow reacting to all types of controllable network's voltage oscillation and will provide a high noise stability of protection system.

The fuzzy linguistic rule base of adaptive protection system was developed. The fuzzy controller was designed on base of developed rule base. The results of simulation modelling and prototype test have confirmed possibility of feeding in new highly effective leakage current protection to mining industry. Adaptive protection devices could be applied in the mining industry network to protect electric equipment containing frequency-regulated electric drives, and changing of threshold could be adapt to voltage oscillation of frequency invertor.

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