Advanced System for the Control of Work Regime of Railway Electric Drive Equipment

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Abstract: **-** The paper introduces a complex system for the protection of fixed installations in railway electric drives (transformers, feeders, the contact line), based on the fuzzy logic. Thus, a fuzzy controller analyzes the work regime of the equipment and commands the dimming out of abnormal work situations, which generate failures. The system has been tested by means of a Spectrum Digital development board, equipped with a TMS320F2812 and other auxiliary circuits. The research has been financed through a research contract [1].

Key-Words: - Rail transportation electrical systems; Power distribution protection; Fuzzy logic; Microprocessor applications; Protective relaying, Fuzzy sets.

1 Introduction

Although the contact line in electric railway transport (and not only) can be regarded as a line of electric power distribution, it has several (mechanical and electric) characteristics that differ from the usual power systems. Thus, the most common failure regimes are the short circuit in the contact line (L.C.), sub-sectioning (P.S.) or in traction sub-stations (ST), produced by dielectric breakdown of insulators or mechanical failures caused by the pantograph of the electric engine (figure.1).

The sudden growth of currents in the case of short circuits has negative consequences both upon the fixed installations of electric traction (thermal and dynamic effects) and upon other nearby installations (dangerous inductions in the phone networks, in the low voltage grids on pipelines, etc., which can endanger the life of the personnel in the vicinity of the railways.

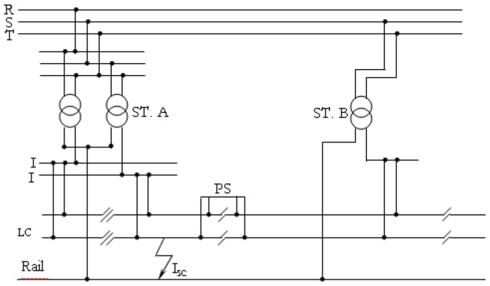


Figure 1. Electric power feeding of railway traction

In the case of single-phase electric railways with the frequency of 50 Hz, the distance between two ST is 50 ÷ 60 km, depending on the profile of the line. For the simple lines, the high value of characteristic impedance (0,47 Ω/km), leads to minimal short circuit currents (at the end of the line), below the maximal load currents.

In the case of short circuits in the vicinity of the ST, the currents reach up to eight times the charge current, and this is why they have to be cut off as quickly as possible. Neither the low current short circuits must be maintained for too long, as they have negative effects upon the installation.

Because of the elements mentioned above, protecting the contact line feeders by maximal current protection is not efficient enough. At present, distance protection is being used, either by di/dt relays or by impedance ones.

The di/dt relays function on the basis of the existing deforming regime existing in the contact line, current regime which should be diminished as much as possible in the future. The elimination of the deforming regime will make the di/dt relay inefficient.

Impedance relays, which are widely used in all power systems, can distinguish between an overload and a short circuit [2]. Because of the configuration of the contact line, the shape of the RX characteristic of the relay in the complex plane should be modified for each traction substation separately, which is difficult to achieve in practice. In order that RX characteristic meets the requirements imposed to the protection system, the complexity and cost increase.[3]

One may notice the incapacity of the usual relays currently applied in railway protection to differentiate between two very similar situations with reference to the value of the current, but which correspond to different situations which require different actions (decisions): overloads and long distance short-circuits. This is due to the fact that the logic of the relay is un-adapted to railway transportation power system, the RX characteristics is not flexible enough.

This considerations lead to the idea that the relay operation logic can be realized using fuzzy logic rules as it is presented in which are more flexible in covering a real situation which cannot be described by means of explicit relations.

AI/Fuzzy expert systems however can overpass this limitation since they have the advantage of fast response and increase accuracy as compared to conventional techniques. [4]

2 The structure of the protection device

In order to secure protection against the abnormal work regimes of the contact lines and transformers, we designed a complex device meant to replace both the maximal current, low voltage relays etc., and the impedance relay. The block diagram of the device is given in figure 2. [1]

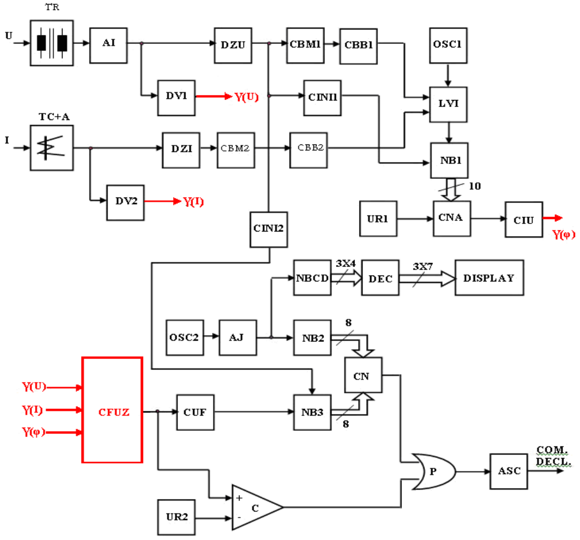


Figure 2. The block diagram of the protection device

The voltage of the power circuit is converted to a reduced value, accepted by the electronic circuit, by means of a group of instrument transformers TR, thus achieving, at the same time, galvanic separation of the power circuit using the insulation amplifier AI, which works with unitary amplification factor. At the output of the insulation amplifier AI we obtained an alternating voltage with a maximal amplitude of 10 V, fed both to a peak detector DV1 and to a device meant to detect the passage through zero of the voltage wave, DZU .

At the output of the peak detector DV1 we obtained signal V(U), whose value is proportional to the value of the voltage in the power circuit. Signal V(U) is fed to one of the analogue inputs of the fuzzy microcontroller. The voltage wave zero passage detector, marked DZU, is meant to generate an impulse at each such passage. The impulse obtained at the output of this block is fed on the one hand to a monostable switch circuit CBM1, in order to obtain a square impulse with a well determined shape and duration, and on the other hand, to an initialization circuit, CINI1. The signal at the output of the monostable switch circuit CBM1 is fed to the bistable switch circuit CBB1, triggering the switch of its output at each impulse received. The bistable switch circuit CBB1 is meant to trigger the determination the phase shift between the voltage and the current in the power circuit by means of a validation/inhibition logic (block LVI) of the access of some square impulses generated by the oscillator OSC 1 and fed to the asynchronous binary counter NB1.

The value of the current in the power circuit is converted by the ensemble current translator – amplifier TC+A into a voltage signal V(I) whose amplitude is 10V, which is fed to the peak detector DV2. At the output of the peak detector we obtain signal V(I), which is fed to one of the analogue inputs of the fuzzy controller. The current signal is also fed to a zero passage detector of the signal corresponding to the current, DZI, which commands a monostable switch circuit, CBM2, and a bistable switch circuit CBB2, both having similar functions with those on the branch corresponding to the voltage wave. The bistable switch circuit CBB2 is meant to stop the phase shift determination process, and it acts in this sense through the validation/inhibition logic.

As shown before, we input to the fuzzy microcontroller three analogue signals V(U), V(I) and V(φ), having values ranging between (0…5) V, whose values depend on the voltage, current and phase shift in the power grid. According to the value of the three signals and using the original processing program implemented on the fuzzy controller under the form of processing rules, at its analogue output we obtained a continuous voltage ranging in the domain (0…5)V. Its value is higher when the regime on the contact line approaches the failure regime, respectively when it is under failure regime and it is directly proportional to the seriousness of the failure.

What has to be done is to disconnect the contact line in a time interval that is inversely proportional to the seriousness of the failure. At the same time, it is necessary to keep on feeding the contact line in the situation of short term failures (caused for instance by atmospheric overcharges).

Meeting these requirements can be achieved by a programmable time delay circuit. This is made of a voltage – frequency converter connected to the output of the fuzzy controller, where a square signal is obtained, whose frequency is directly proportional to the voltage given by the fuzzy controller. These square impulses are then fed to a binary counter NB3, which shows – during one counting period – a value which is directly proportional to the voltage at the output of the fuzzy microcontroller. Counter NB3 is set on 8 binary ranks. Its outputs are fed to the input of a numeric comparator, CN. At the other inputs of the numeric comparator we apply the outputs of another binary comparator NB2, that is meant to memorize a value pre-established by the user. This value is input to the counter by means of the adjusting block AJ, respectively of the tact oscillator OSC2. The impulses fed to binary counter NB2 are simultaneously fed to a decimal code counter NBCD, whose outputs are connected to a decoding system DEC and then to a 7-segment display, marked DISPLAY. In this way, the user has a permanent control over the value given by binary counter NB2. This value represents the very threshold that triggers the main contact line feeding interrupter. Numeric comparator CN signals the situation when the numeric value in counter NB3 becomes equal to the threshold value in counter NB2. It is necessary to enable the modification of the threshold value for the main interrupter, according to the various normal functioning regimes established by the concrete practical situation and which have to be dealt with accordingly. The threshold is established by the users, according to the experience accumulated in time.

It is obvious that the triggering of the contact line main feeding interrupter is done in a time interval that is directly proportional to the threshold value in binary counter NB2, and inversely proportional to the voltage at the analogue output of the fuzzy microcontroller. The main interrupter can be triggered almost instantaneously, if the fuzzy microcontroller outputs a 5V voltage, which corresponds to highly dangerous failure. This value is sensed by comparator C, which permanently compares the output value of the fuzzy controller to a 5V reference voltage, fed by reference source UR2. In case of reaching a regime that triggers the main interrupter, at the output of port P we have logic 1. This signal is power amplified by means of command signal amplifier ASC, which outputs a high enough signal to command the main interrupter.

For a correct functioning, binary counter NB3 has to be periodically reset, so that its value should not reach the threshold value memorized by binary counter NB2, even under a normal functioning regime. This condition is met during each period of the voltage in the grid, by initialization circuit CINI2. This circuit too, uses as time reference the zero passage impulse of the grid voltage. It is preferable to initialize counter NB3 just once during one period, as in this case, the value of counter NB3 depends on two operations of phase determination – corresponding to the two semiperiods – which achieves in this way a high immunity to very short perturbations or incorrect work regimes along the contact line.

All the circuits presented above have been designed built and tested and they worked correctly.

3 The Fuzzy Controller

As mentioned before, in order to offer a complex protection of the contact line in railway electric transport, using mono-phase AC (27,5 [kV], 50 [Hz]) we designed a Fuzzy relay, starting from the practical case of a railway electric traction sub-station [1]. This relay allows a maximal current, overcharge, distance and minimal voltage protection. Although initially we did not take into consideration directional protection (the inverse current circulation between two traction substations), its introduction is not a problem and we consider that the Fuzzy relay can achieve that too.

In literature are cited fuzzy applications in protection of power systems (generally), but this applications are not specific to electric railway transportation [5], [6], and [7] with the consequences mentioned in 1.

As the scale representing the transfer functions that correspond to the processed magnitudes is a percentage one (0 - 100%), we needed to norm the discussion universe, by means of a 1st degree polynomial function.

A. Information on the input magnitudes

We considered the following usual regimes:

Table 1. Input and Output Magnitudes

Variable		Linguistic values	Variation domain	Universe of discourse
Input	Current	normal	50 ÷ 600 [A]	0÷30,8 [%]
		overcharge	600÷800 [A]	25,6÷41 [%]
		short-circuit	800÷2000 [A]	35,9÷100 [%]
	Voltage	short-circuit	16 ÷ 20 [kV]	0÷43,5 [%]
		overcharge	20 ÷ 25 [kV]	26,1÷87 [%]
		normal	25 ÷ 27,5 [kV]	69,6÷100 [%]
	Phase shift	normal	0÷30 [grad]	0÷43,8 [%]
		overcharge	30÷60 [grad]	31,3÷81,3 [%]
		short-circuit	60÷80 [grad]	68,8÷100 [%]
Output	Command	blocked	0 [V]	0 [%]
		high delay	1,66 [V]	33,3 [%]
		low delay	3,33 [V]	66,6 [%]
		instant	5 [V]	100 [%]

In figures 3, 4, 5 are presented the membership functions for the input magnitudes, and in figure 6 is present the output magnitude.

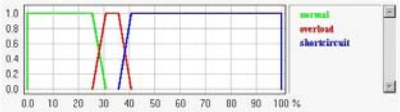


Figure 3. Representation of membership functions for the input magnitude “current”

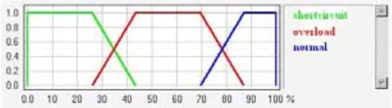


Figure 4. Representation of membership functions for the input magnitude “voltage”

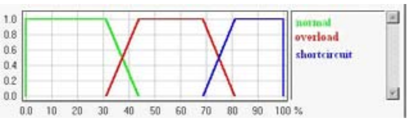


Figure 5. Representation of membership functions for the input magnitude “phase shift”

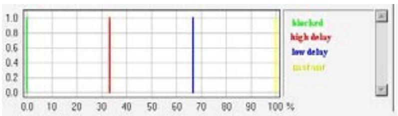


Figure 6. Representation of membership functions for the output magnitude “command”

B. Command rules (inference)

The rules have been established for practical reasons after having checked the reference literature and consulted experts in electric traction and protection installations for electrical systems.

Figure 7 shows the rules base which connecting the fuzzy input variables to the fuzzy output variable, by means of the inference method (max/min). For deffuzification we chose the Singleton weight centers method due to its major advantage, namely the short processing time, a stringent condition for the real time functioning of the Fuzzy controller with a function of relay. For this reason, for the practical application under analysis we established Singleton-type membership functions corresponding to the linguistic term “command” of the output magnitude. Using the max-min inference method alongside with the defuzzification method is widely spread in practice and has lead to outstanding performances of the regulation systems.

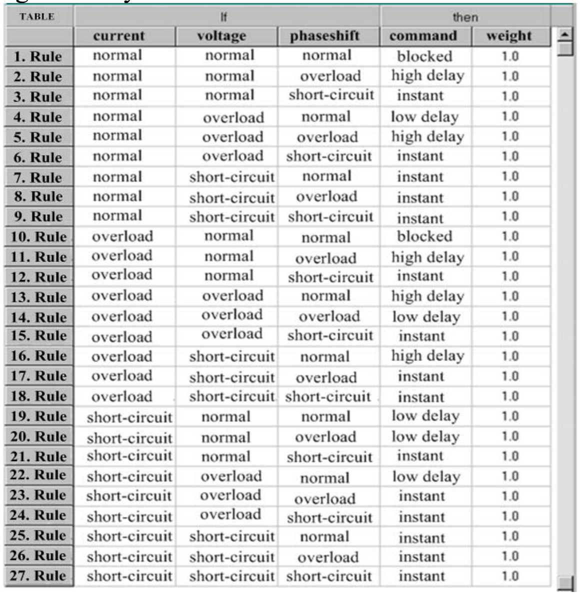


TABLE	If			then	
	current	voltage	phaseshift	command	weight
1. Rule	normal	normal	normal	blocked	1.0
2. Rule	normal	normal	overload	high delay	1.0
3. Rule	normal	normal	short-circuit	instant	1.0
4. Rule	normal	overload	normal	low delay	1.0
5. Rule	normal	overload	overload	high delay	1.0
6. Rule	normal	overload	short-circuit	instant	1.0
7. Rule	normal	short-circuit	normal	instant	1.0
8. Rule	normal	short-circuit	overload	instant	1.0
9. Rule	normal	short-circuit	short-circuit	instant	1.0
10. Rule	overload	normal	normal	blocked	1.0
11. Rule	overload	normal	overload	high delay	1.0
12. Rule	overload	normal	short-circuit	instant	1.0
13. Rule	overload	overload	normal	high delay	1.0
14. Rule	overload	overload	overload	low delay	1.0
15. Rule	overload	overload	short-circuit	instant	1.0
16. Rule	overload	short-circuit	normal	high delay	1.0
17. Rule	overload	short-circuit	overload	instant	1.0
18. Rule	overload	short-circuit	short-circuit	instant	1.0
19. Rule	short-circuit	normal	normal	low delay	1.0
20. Rule	short-circuit	normal	overload	low delay	1.0
21. Rule	short-circuit	normal	short-circuit	instant	1.0
22. Rule	short-circuit	overload	normal	low delay	1.0
23. Rule	short-circuit	overload	overload	instant	1.0
24. Rule	short-circuit	overload	short-circuit	instant	1.0
25. Rule	short-circuit	short-circuit	normal	instant	1.0
26. Rule	short-circuit	short-circuit	overload	instant	1.0
27. Rule	short-circuit	short-circuit	short-circuit	instant	1.0

Figure 7. Rules base

Figure 8 shows the command surface for three constant values voltage corresponding to the cases described above (normal, overload and short-circuit).

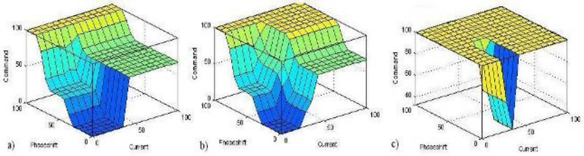


Figure 8. Command surfaces for three voltage values

In order to simulate the behavior of the proposed fuzzy logic relay we have developed a rathe simplified model of a railway substation with 50km contact lime modeled (figure 9 and 10). Using this model we randomly generated several situations representing combinations of input variables (normal operation long distance short circuit overload)

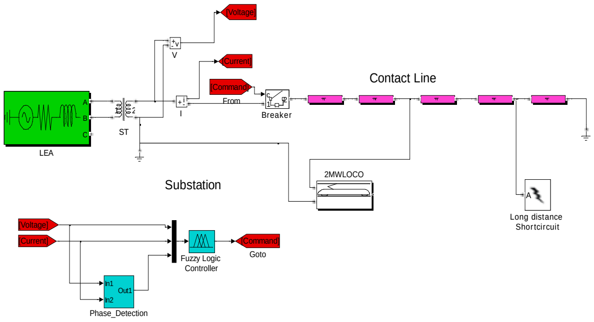


Figure 9. Simulation diagram Substation ST and locomotive and long distance fault

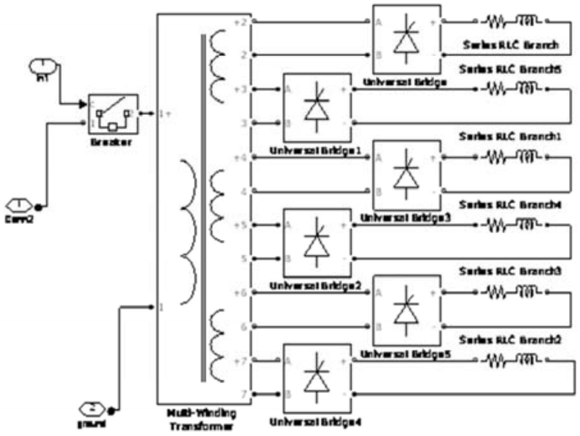


Figure 10. The locomotive model (2MWLOCO)

In figure 11 are presented some work regimes (recorded) in a real substation.

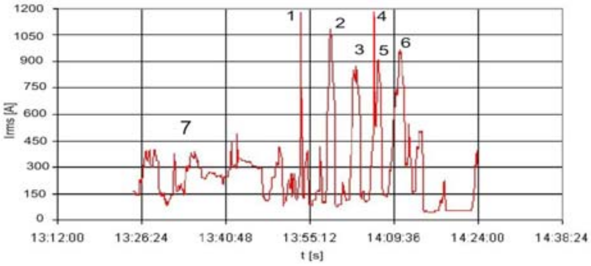


Figure 11. ST load current in different work conditions: 1,2,4 – long distance short-circuit; 3,5,6 – overload; 7 – normal load

Fuzzy controller simulation is realized in Matlab – Simulink (figures 12, 13 and 14), the analysis of the response (figure 15) proved the correct functioning of the fuzzy system, according to the rules base established.

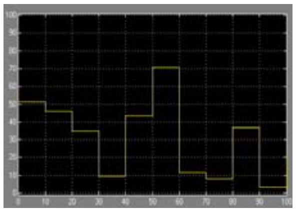


Figure 12. Input magnitude CURRENT

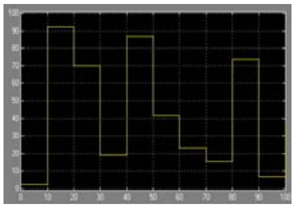


Figure 13. Input magnitude VOLTAGE

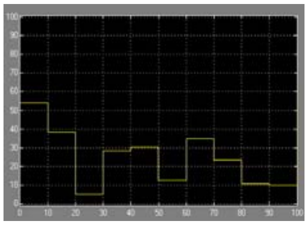


Figure 14. Input magnitude PHASE SHIFT

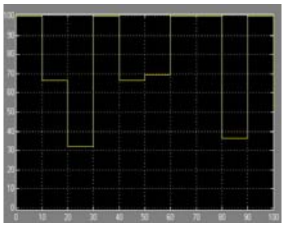


Figure 15. Output magnitude COMMAND

The fuzzy system has been implemented on an eZdsp TMS320F2812 development board produced by Spectrum Digital.

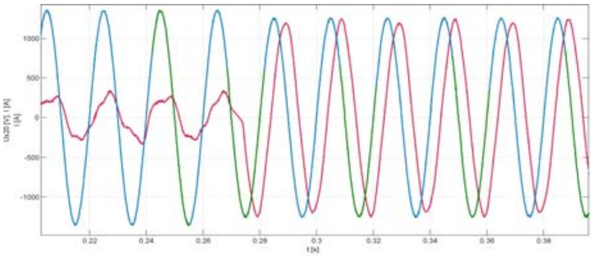
4. Hardware Implementation and Testing for the Fuzzy Logic Relay for Railway Protection

The development cycle is based on three stages: first the fuzzy logic relay is designed and tuned on Matlab – Simulink using a Simpower System model of the railway ST because the testing in the real system would have been extremely expensive and dangerous. This allows the simulation, parameters tuning and optimization of rules data base.

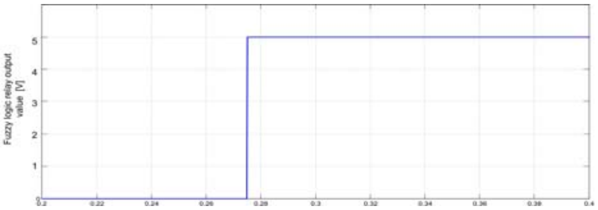
In the second stage, the final structure of the fuzzy logic operations are prepared for hardware implementation. In order to achieve a high speed operation some hardware specific features of the DSP are employed to reduce the computation resources for the application. One operation which requires intensive computation is the deffuzification which need complex instruction. Each input (voltage, current and phase shift) is sampled using an 8 bit ADC. The input variables are quantified in order to obtain the degree of membership of each point of the input for each fuzzy set. For each point is associated an index value corresponding to the membership function. The rule base in coded using the same index system in order to have the correspondence between the index of active membership functions with the corresponding part of the rule base.

Finally, the structure of the system operation is coded using Code Composer Studio development environment in C. The resulting assembly code is optimized for speed in order to have the shortest cycle time. For the hardware implementation we have considered a Spectrum Digital DSP development board with TMS320F2812 processor.[8]

From the point of computation resources this can offer sufficient processing speed in order to meet the application requirement at a reasonable development time (since no assembly coding was necessary). This hardware solution used to implement the fuzzy logic relay structure is simple and provide good performance/price output. After manual verification of the correct functioning of the DSP fuzzy processor the entire system was put under test in a real ST (in parallel with the existing protective system). In figure 16 a one long distance short circuit it has been identified and the actual response of the relay is presented in fig 16 b. One may notice the extremely fast response of the proposed fuzzy relay system (the short circuit was not identified by the usual impedance relay due to the misclassification of the fault).



a) long distance short circuit



b) relay response

Figure 16. Fault processing by the fuzzy logic relay

The existing protection system obviously has considered the event as an overload and it disconnected the main switch about one minute after.

5 Conclusion

The paper introduces a complex for the protection of the contact line and of the railway electric transport installations, based on the fuzzy logic. The system we presented has been built in practice and its experimental implementation has shown a series of advantages with respect to the actual systems, such as: low cost; adaptability to any real situation by the appropriate modification of the rules base; very short response time (5μs) of the fuzzy controller; it functionally replaces several protection systems, taking over all their functions. The system has the great advantage over other fuzzy logic relay systems that is designed considering the specific railway power system behavior.

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