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A FUZZY LOGIC-BASED LONG DISTANCE HIGH TENSION POWER SYSTEM PROTECTION SCHEME

By

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ABSTRACT

Some times circuit breakers, which respond to relaying logic to protect transmission lines, trip falsely. Part of the problem may be due to incorrect relay operation often associated with conventional protection schemes. In this paper, a fuzzy logic based distance pro[illegible]n scheme has been developed. The approach needs only the line impedance, to formulate fuzzy rules, which are simula[illegible] using fuzzy logic toolbox in MAT LAB. The proposed fuzzy-set approach is well suited for the development of a strategy for tripping line breakers correctly, in an event of fault occurring. The result of simulation shows that the scheme can take care of the vagueness between time settings of one protective zone from the other during fault conditions. The sensitivity of the relay tripping can also be observed.

Key words:

Fuzzy – set, Fuzzy rules, Expert system, Artificial neural network, Genetic algorithm, Evolutional computing.

1. INTRODUCTION

The reliable operation of large power systems with small stability margins is highly dependent on control systems and protection devices. The application of microprocessor based (numeric) relaying protection has improved performance over the years. However, even these benefits have not led to a major impact on speed, sensitivity and selectivity of primary protective relays, and the gains are only marginal. These gains can be improved if the decision making is based on elements of artificial intelligence (AI).

These AI techniques in power systems include Expert systems (ES), Artificial neural networks (ANN), Fuzzy systems (FS), Genetic algorithm (GA) and recently, Evolutionary computing (EC) [1]. The application involves developing a programmable logic (PROLOG) for the manipulation of symbolic information in a manner that emulates human reasoning [2]. The goal of protection is to develop a strategy to operate (open) appropriate circuit breakers in an event of fault.

Because of uncertainty, imprecision and ambiguity exist in power systems, fuzzy logic is well suited for this purpose.

to distinguish between faults at P_2 and P_3 on either side of bus 2, as the impedance -to-fault for faults on either of this points is the same [4]. To overcome this problem, enormous mathematical operations are applied to ensure coordination in terms of relay operating times T_1, T_2, T_3 and percentage of the line impedances. The logic of Al-fuzzy logic is able to address these challenges.

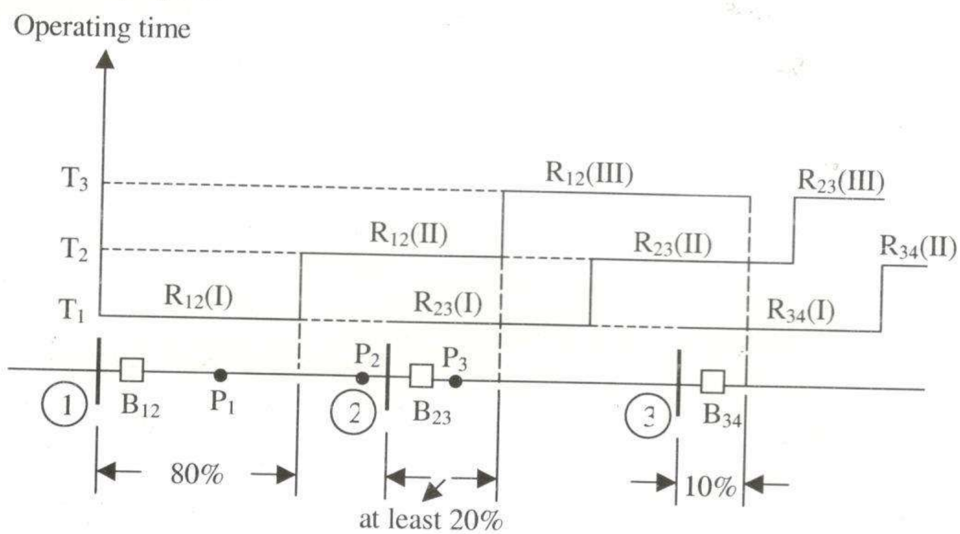

Fig.1. Setting of impedance

Consider the diagram of a typical conventional distance protection scheme, showing the setting of impedance relays, shown in Fig. 1.

For the setting of the first zone impedance of relay R_{12} in Fig.1, if in an attempt to cover the whole line, the impedance is set to the full impedance of the line 1-2, R_{12} will not be able

Significant amount of research work has been performed in the area of fault diagnosis, identification and classification. Among the various techniques reported for fault diagnosis is the ANN-based approach [5]. Although this approach is reported to be successful, the main disadvantage of ANN is that it requires a significant amount of training effort for good performance [6]. To avoid the problem of training in ANN, a fuzzy-set approach to fault-type identification was proposed [7]. This technique was able to identify the nature of fault (whether LG or LLG). However, the phases involved in the fault have not been explicitly determined, and no LL fault has been considered.

To improve on the above techniques, a fuzzy logic-based fault classification scheme was proposed [6]. This scheme was able to determine accurately, all ten types of possible short-circuit faults (e.g. a-g, b-g, c-g, a-b, b-c, c-a, a-b-g, b-c-g, c-a-g, a-b-c/a-b-c-g); where a, b, c are the phases and g is ground.

There is no doubt that the above techniques are good in fault type identification. However, in those papers, no mention is made about the main goal of power system protection, which is to isolate the faulty section through appropriate circuit breaker operation. A proposal was made [8] in which current, voltage and their transients can be chosen as input signals to a fuzzy relay. The inferencing, with the rule base will then give output trip signals to the breaker. Because of the multiple inputs involved in this proposal, the number of rules was outrageously high, about 900 rules.

To address most of the above limitations, in this paper, a fuzzy logic-based distance protection scheme is developed. The proposed scheme uses input impedance-to-fault, of the transmission line to formulate fuzzy rules, which are then used to develop a strategy for tripping the line breaker in an event of fault.

This paper is organized as follows. Section II presents the methodology for the design. The basis for the design approach is described in section III. The fuzzy relay design implementation is presented in section IV; while the results are presented in section V. Lastly, section VI discusses the main conclusions of the work.

2. Methodology

The strategy for the relay operation and consequent tripping action follows the procedure shown in the simulation block diagram of Fig. 2.

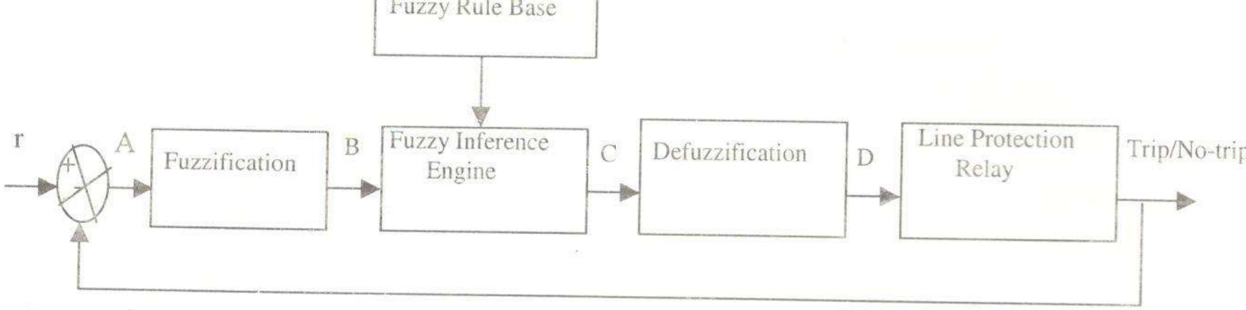

Fig.2: Fuzzy logic scheme for line protection.

In Fig. 2, the input quantity (impedance) is presented at point A, the justified input available at B is then given to the inference engine, which, following the given fuzzy rule base, gives a fuzzy trip action at its output C. The output at C is still fuzzy in nature. Defuzzification converts it into a crisp (actual) trip action, given at D. The simulation of the fuzzy logic scheme (FLS) in Fig.2 is performed using the fuzzy logic toolbox in MAT LAB environment.

3.0 Basis for the Fuzzy-Set Design Approach

In a transmission line, after a fault occurs, the impedance seen by the relay is **very small** compared to the load impedance seen during normal operation. The relay is made to respond to the impedance between relay location and the fault point, and operates when the impedance seen by the relay **within** a zone circle [9]. The terms used above, 'very small' and 'within' connotes descriptive human language, which suggest a degree of membership of the impedance seen by the relay to a larger set-**universe of discourse.** This is the motivation for the fuzzy logic approach.

From the typical line parameters given in appendix A, the positive sequence impedance of the line is given as:

$Z_1 = R_1 + jX_1 = 0.00377300275 + j0.026377 = 0.02665\Omega/\text{km}$.

The line length L = 96km. This implies that the line impedance, $Z_L = (R_1 + jX_1)L$.

Thus $Z_L = 0.02665 \times 96 = 2.6\Omega$.

Assume that the relay is to be set to detect faults on the line, a distance of x = 20km.

This means $Z_x = (R_1 + jX_1)x = 0.02556 \times 20 = 0.533\Omega$. This value represents the normal value of impedance setting used for the design. Any impedance below this value should cause the breaker to trip.

4.0 The Fuzzy Relay (Controller) Design Implementation

4.1 Identification of inputs:

The input variable is fault impedance (Z).

4.2 Fuzzification:

The input is converted to fuzzy variables. For the impedance (Z), these are (i) very large value (VL) (ii) large value (LV) (iii) normal value (NV) (iv) small value (SV) and (v) very small value (VS). For the expected output, the fuzzy variables are, (i) Absolute trip (AT) (ii) possible trip (PT) (iii) possible no trip (PN) (iv) no trip (NT) and (v) absolute no trip (AN).

4.3 Normalization and Definition of Membership Functions (MF).

We now normalize the impedance according to the calculated value of 0.533Ω, to percentage impedance, giving Z = 53.3%, for normal value. The antecedent MFs, VS, SV, NV, LV, VL and the consequent MFs, AT, PT, PN, NT, AN; are defined according to the normalized value, by fuzzy sets over the given universe of discourse, using fuzzy logic toolbox in MATLAB. The results are the membership functions presented in Figures 3 and 4 respectively.

4.4 Formulation of the Rule Base.

For the single input single output (SISO) system, we use five rules, which are formulated with expert knowledge about distance protection. The rules are of the Mamdani type [10].

1. **IF** /Z/ is VS **THEN** breaker is AT. ELSE
2. **IF** /Z/ is SV **THEN** breaker is PT. ELSE
3. **IF** /Z/ is NV **THEN** breaker is PN. ELSE
4. **IF** /Z/ is LV **THEN** breaker is NT. ELSE
5. **IF** /Z/ is VL **THEN** breaker is AN.

4.5 The Rule Inferencing.

The output of the first step is the degree of fulfillment (DOF) of each rule. We use the **max-min** composition rule of inferencing. The connective of the rules ELSE is interpreted as OR(V). For this system, we simulate with a percentage impedance of **Z = 20%.** We apply a MATLAB program to obtain the **DOF** = 0.3333, 0.3333, 0.0000, 0.0000, 0.0000.

Using the Larsen Product ϕ_p implication operator, we also get the rule consequents, the result of which is presented in Fig.5.

4.6 Aggregation of Consequent Fuzzy Sets.

We use the '**max**' operator for aggregation, to obtain the output fuzzy set, the result of which is presented in Fig.6.

4.7 Defuzzification Process.

The aggregate output obtained in E above is a fuzzy trip output. Defuzzification transforms it into a crisp value to operate the breaker. We use the **centroid** defuzzification method to obtain the crisp output, presented in Fig.7, indicating an output of **18.4787%**.

To see the output for different input percentage impedances, we write a MATLAB loop program that converts the input universe of discourse and computes the output for each input impedance. The result is presented in Fig.8.

5.0 Simulation Results

The results obtained from the system simulation are shown in response curves of Figures 3, 4, 5, 6, 7, 8. Figure 3 shows the antecedent membership functions for impedance, where VS, SV, NV, LV, and VL are as defined in section 4.2. Figure 4 shows the consequent membership for the breaker, where AT, PT, PN, NT and AN are also defined in section 4.2. Figure 5 shows the consequent fuzzy set on application of the Larsen Product implication operator. Figure 6 shows the aggregate of the consequent (output) fuzzy set, while Fig.7 shows the result of a defuzzified output to produce crisp trip signal that operates the breaker. Figure 8 shows the input/output relationship of the fuzzy system, for different input impedances.

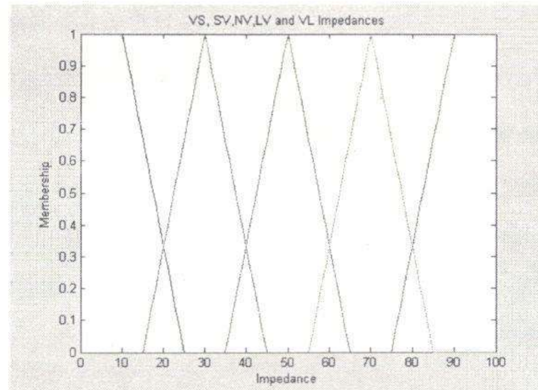

Fig. 3: Antecedent membership functions forinput Impedance

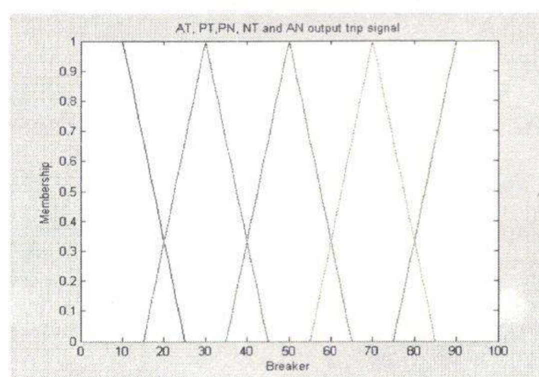

Fig.4: Consequent membership functions for breaker

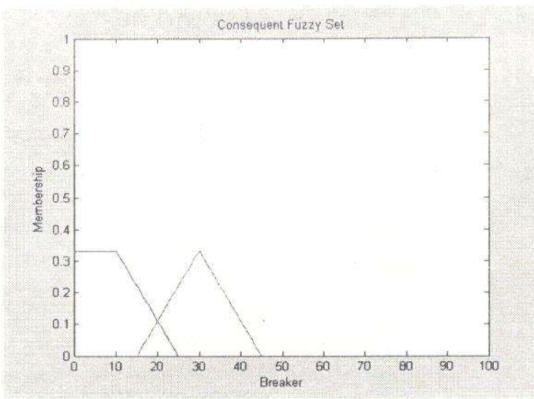

Fig.5: The consequent fuzzy set

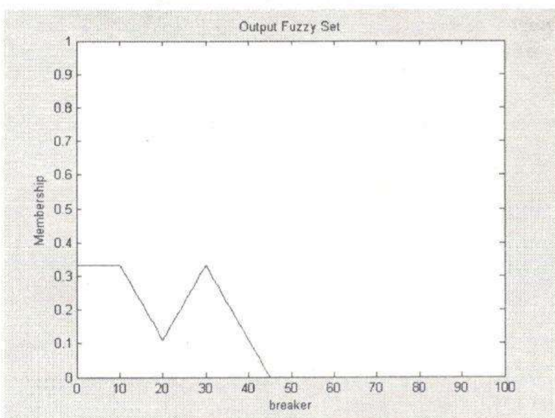

Fig.6: Aggregate (output) fuzzy set

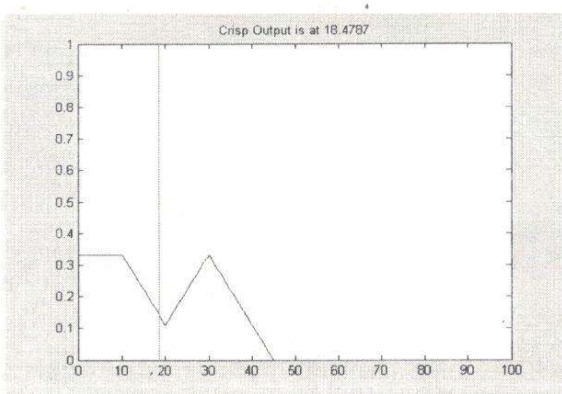

Fig.7: Result of a defuzzified output to breaker

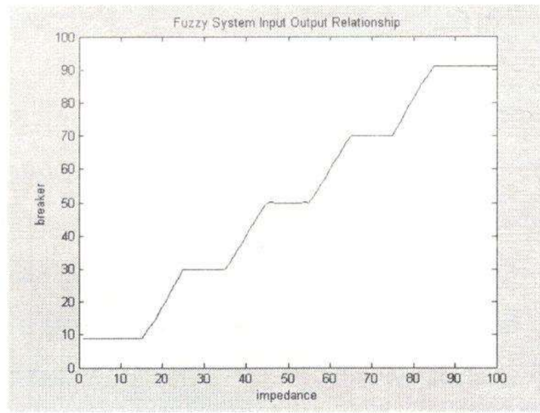

Fig. 8: Input/output relationship of the fuzzy system.

The result obtained from the rule inferencing gives DOF = 0.3333, 0.3333, 0.0000, 0.0000, 0.0000. This means only two rules 'fired' (those with DOF≠0), for 20% impedance. Also in Fig. 7 we obtained result which indicates that the crisp output trip signal to the breaker when the rules are fired is given as **18.4787%**. Denormalization translates this value to approximately **0.185Ω,** for 20% impedance used for the simulation. Since this value is very small, compared to the calculated line impedance setting of **0.533Ω** used for simulation, the breaker would absolutely trip.

6.0 Conclusion

A fuzzy logic-based long distance, power system protection scheme has been proposed. The application involved developing a strategy for tripping the line breaker in an event a fault occurs. The approach was effective in implementing a fuzzy procedure (5 rules) to solve a problem that requires complex mathematical modeling, when the conventional approach is used. With only the impedance -to-fault, the system simulation shows that the technique is able to make tripping decisions (logic) for the breaker, which acts on the logic to protect the transmission line.

APPENDIX A

THE LINE PARAMETERS

- Voltage rating 330kV
- Current rating 1360A
- Line length 96km
- Surge impedance 300Ω
- Positive sequence impedance
  $Z_1 = 0.02665\ \Omega/km$
- Zero sequence impedance
  $Z_0 = 0.09027\ \Omega/km$
- Frequency 50Hz
- Conductor size $2 \times 350\ mm^2$

The data for Enugu-Onitsha high tension line is courtesy of the Power Holding Company of Nigeria (PHCN).

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