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Feeding Electricity Ring Grids with Minimum Interruption Using Fuzzy Logic Based Relay Coordination Scenarios Under Interruption Conditions

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Abstract

In order to secure continuous and high quality supply of electricity, it is essential to protect end users' devices and network equipments against malfunction from production to consumption. Therefore, the protection of electrical equipment is essential and one of the devices performing the protection task is called the protection relay.

Industrial plants and large consumers that possess a high variation in loads and variable generation resulting from the widespread implementation of distributed generation requires the adaptive operation of relays in protection systems to prevent undesired malfunctions.

In this study, a novel fuzzy logic based adaptive relay coordination strategy with the advantages of reduced computational load and fast computing for distribution networks is proposed. In order to evaluate the performance of the developed relay coordination strategy, a real-world sample line for a ring-type distribution network has been simulated in PSCAD/EMTDC environment. The performance of the proposed system is validated with simulation results for different case studies.

Keywords: Relay coordination, Fuzzy logic, Ring networks

Kesinti Koşullarında Bulanık Mantık Tabanlı Röle Koordinasyon Senaryolarını Kullanarak Minimum Kesintili Elektrik Halka Şebekelerinin Beslenmesi

Öz

Üretimden tüketime kadar son kullanıcı cihazlarını ve şebeke ekipmanlarını arızalara karşı korumak, sürekli ve yüksek kalitede elektrik temini için esastır. Bu nedenle, elektrikli ekipmanların korunması önemli olup koruma görevini yerine getiren cihazlardan birisi de koruma rölesidir.

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Endüstriyel tesislerin ve büyük tüketicilerin yüklerindeki aşırı değişkenlik ve dağıtık üretimin yaygın olarak uygulanmasından kaynaklanan değişken üretim, istenmeyen arızaları önlemek için koruma sistemlerindeki rölelerinin uyarlanabilir çalışmasını gerektirmektedir.

Bu çalışmada, daha düşük hesaplama yükü ve dağıtım şebekesi için hızlı hesaplama avantajları ile bulanık mantık tabanlı yeni bir uyarlanabilir röle koordinasyon stratejisi önerilmiştir. Geliştirilen röle koordinasyon stratejisinin performansını değerlendirmek için, PSCAD/EMTDC ortamında gerçek bir ring tipi dağıtım şebekesi simüle edilmiştir. Önerilen sistemin performansı, farklı durum çalışmaları için simülasyon sonuçları ile doğrulanmıştır.

Keywords: Röle koordinasyon, Bulanık mantık, Halka şebeke

1. INTRODUCTION

The relay performing the protection of the equipment against malfunction during the period from production to consumption is essential to ensure the continuous, reliable and high-quality transportation of electricity to the consumers [1].

The main tasks of the protection relays in the electricity distribution system are to detect the fault, the type of fault and generate a necessary trip signal. By performing these tasks, it is also intended to remove the defective area from the distribution system and to prevent the re-activation of the defective area. The aforementioned requirements reveal the importance of the coordination of the protection relay appropriate to the system structure. Properly configured relay coordination increases system reliability and reduces problems caused by faults or modifications [2].

The adaptive protection systems (re-coordinated protection relays) provide adjusting the parameters of protection relays according to the state of the defective area, the type of fault and modifications. Thus, the protection system can adapt to different operating conditions and minimize the possibility of faulty operation of the protection system. Thanks to the dynamic operation capability, adaptive protection systems offers more selective and reliable protection compared to conventional protection systems. Therefore, electricity distribution companies prefer adaptive protection systems instead of conventional protection systems [3-5].

In the relay coordination implemented by the electricity distribution company in Turkey, the circuit breaker at the distribution center closest to the Transmission System Operator's (TSO) substation should be set to open in less than short-circuit current exposure time, which is determined as 1 second by the TSO. Because, any failure that can not be solved in the distribution network and floods on the gridline of TSO can cause damage to users who are fed from the related distribution line.

The faults and power flow modifications that occurred on distribution lines change the load distribution on both sides of the ring type network. Thus, the parameters of relay should be adjusted by considering the 1 second rule of TSO and, the overload protection relays must be provided with time curves automatically by measuring the load quantities in the lines.

Several studies have been performed to investigate the adaptive relay coordination in distribution systems. The importance of the implementation of adaptive protection (adaptive relay coordination) for a distribution system with penetration of distributed-generation (DG) is emphasized in Vijetha and Sarma, [6]. In Ateş et al. [7], a complicated selectivity-based adaptive relay coordination algorithm is developed and compared with conventional protection scheme for a distribution system equipped with wind power based DG. In Patil and Saunshi [8], a central decision software (SCADA etc.) is proposed in order to manage the network and adaptive relay coordination. Besides, traditional methods such as selection criterion of pickup currents Ezzeddine et al. [9] and curve intersection approach Lu and Chung [10] have been proposed in the literature. The relay coordination is defined as a constrained non-linear optimization problem [11,12]. To solve the optimization problem, linear programming (LP) and nonlinear programming (NLP) methods are employed in [13-16]. Although the related methods can coordinate the parameters of relays, LP traps at local minimums while NLP has a high computational load. To eliminate the drawbacks of these methods, intelligent methods and evolutionary algorithms have been developed in the literature. A modified adaptive teaching learning based optimization algorithm is developed in [11]. Genetic algorithm [12,17], particle swarm optimization [18], seeker optimization algorithm [19], firefly algorithm [20] and differential evolution [21], methods have been proposed to coordinate relay paramerters. As it is well known, the metaheuristic methods are iteration-based and take long time to converge.

In this study, fuzzy logic based adaptive relay coordination strategy is developed to reconfigure the relay parameters by considering the fault/modification occurring on a real-world sample line. A strategy based on the fuzzy logic method is used instead of iterative methods frequently used in the literature to reconfigure the relay parameters. Hence, the significant computational load resulting from the iterative methods is reduced. The performance of the proposed system is validated with simulation results.

The paper is organized in the following manner: The network configuration of the modeled ring type distribution system is described in Section 2. The fuzzy logic based parameter coordination is presented in Section 3. Finally, Section 4 analyses the results and the contributions of this paper is presented in Section 5.

2. NETWORK CONFIGURATION

The main objective of the study is to reconfigure the relay parameters according to the fault/modification occurred on distribution network. The reconfiguration is performed using fuzzy logic method. In order to evaluate the fuzzy logic based adaptive relay coordination strategy, a simulation study that represents a real-world sample line in a ring-type distribution network has been conducted in EMTDC/PSCAD environment.

The single line diagram of the sample line which is illustrated in Figure 1 consists of two TSO connection, three distribution centers, eight circuit breakers, four line breakers (LBs) and loads. 50-62.5 kVA, 154/33.6 kV line transformers are employed to feed loads of ring type distribution network. LBs allow the network to provide uninterrupted power to consumers thanks to the functionality of ring type network during any event of failure. To evaluate the performance of the proposed strategy in point of reconfiguration of the relay parameters, a line-to-line (LL) fault which is one of the most frequently encountered fault types has been created in simulation studies.

The design parameters of the system are summarized in Table 1.

Table 1. Design parameters of the system

Parameter	Value
Transformer Power Ratings 1/2	50/62.5 kVA
Transformer Voltage Ratings 1/2	154/33.6 kV
System Frequency	50 Hz
Voltage Level of Network	154/31.5 kV
Line 1/2/3/4 Length	11/50/27/15 km
Distribution Centers	3 pcs
Number of Circuit Breakers	8 pcs
Line Breakers	3 pcs
Types of Conductors	Pigeon (3/0 AWG), Hawk (477 MCM)
Power Consumptions of Loads	26 MW + 2.4 MVAR

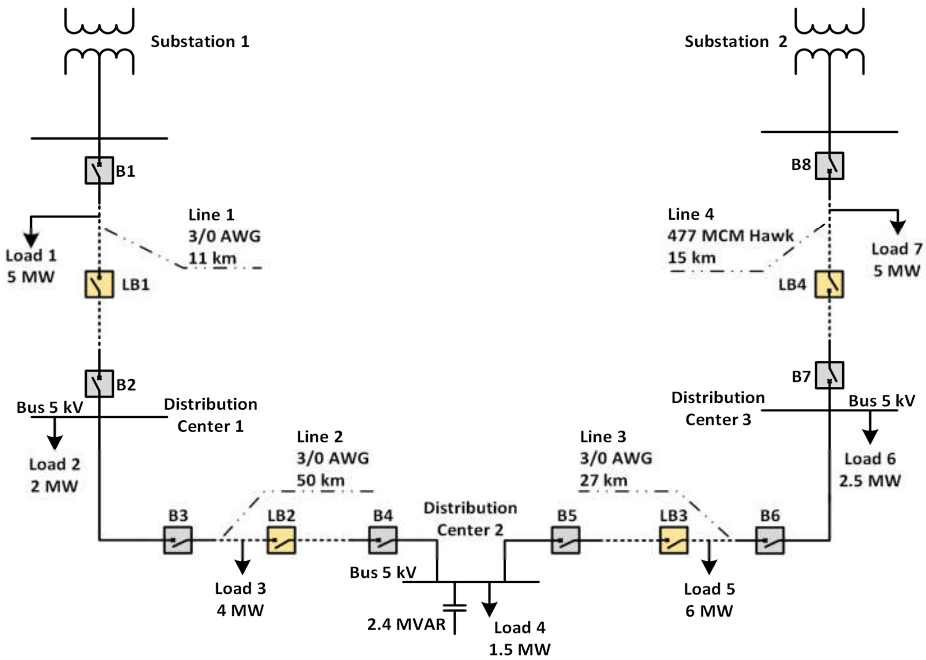

Figure 1. Single line diagram of the real-world sample line [22]

3. FUZZY LOGIC BASED ADAPTIVE RELAY COORDINATION

The relays are placed and parametrized by considering the location relative to the substation and 1 second rule of TSO. In the event of any fault or modification in the ring-type distribution line, the interrupted zones are bypassed by the LBs to provide uninterrupted power to consumers. Since the process of bypassing the consumers causes a change in the locations of the relays relative to the substation, coordination of the relay parameters is needed. The relay operating time is calculated by using the Equation 1 [23].

$$t=TMS\times\frac{0.14}{\left[\left(\frac{I_f}{I_s}\right)^{0.02}-1\right]} \qquad (1)$$

where t is the operating time of relay, Time Multiplier Setting (TMS) is the operating curve of the relay settings, I_s is the relay pickup current which is determined considering the primary rating of the related current transformer and I_f is the fault current.

The architecture of fuzzy logic based coordinator is shown in Figure 2. The method has three steps; Fuzzification: it is aimed to convert the values defined in real-world operation (non-fuzzy) into fuzzy set variables (linguistic term) $A_i^j\,(i=1,2,...n)$ and B_i^j (j denotes the number of rules), which are characterized by membership functions $\mu_{A_i^j}(x_i)$ and $\mu_{B_i^j}(y_i)$ (Figure 3), using the knowledge acquired from operator experiences; Decision Making: it is aimed to combine membership functions with the IF-THEN rules, which is summarized in Table 2, to derive the fuzzy output; Defuzzification: it is aimed to convert fuzzy values obtained by the result of the rules into exact values by using the method of Center of Gravity (Equation 2).

$$y_0=\frac{\sum_{i=1}^{n}\mu(w_i)w_i}{\sum_{i=1}^{n}\mu(w_i)} \qquad (2)$$

The two-stage fuzzy logic structure is modeled as 4 inputs 2 outputs. The inputs and output of the first fuzzy logic structure are denoted as time, I_f / I_p and operating curve (opc) respectively. The inputs and output of the second fuzzy logic structure are denoted as operating curve (which is the output of the other fuzzy logic structure), I_f / I_p and operation time parameter of relay. For ease of computation, the variables of the coordinator are described as; time *T*: , fault current: I_f, operating curve: *opc*, fault current/load current: I_f/I_p, operation time parameter of relay: T_{relay}.

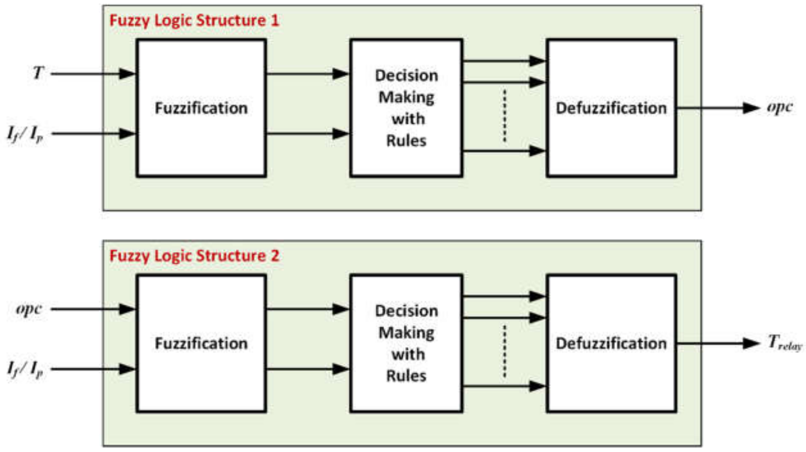

Figure 2. Fuzzy logic based coordinator architecture

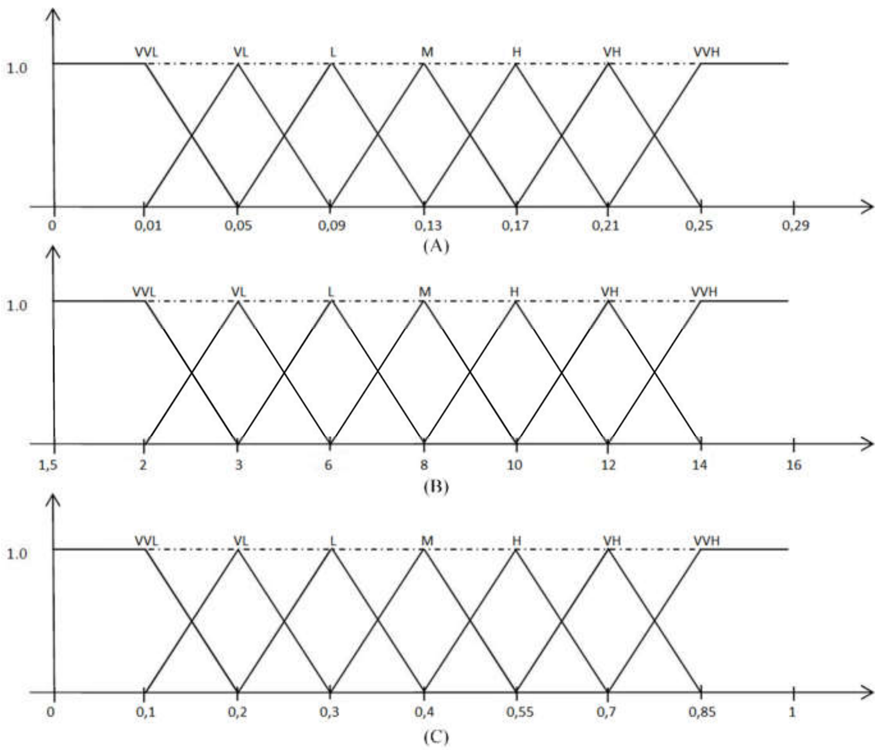

Figure 3. Membership functions of inputs of *opc* (A), I_f /I_p (B) and time (C)

Table 2. Fuzzy rules of the system

IF (*$Input_1$* is VVL) and (*$Input_2$* is VVL)	**THEN** *$Output_1$*
IF (*$Input_1$* is VVL) and (*$Input_2$* is VVL)	**THEN** *$Output_2$*
IF (*$Input_1$* is VVL) and (*$Input_2$* is VVL)	**THEN** *$Output_3$*
…	…
…	…
IF (*$Input_1$* is VVL) and (*$Input_2$* is VVL)	**THEN** *$Output_{49}$*

4. SIMULATION RESULTS AND DISCUSSION

In order to evaluate the performance of the proposed fuzzy logic based adaptive relay coordination for distribution networks, a real-world simulation model is developed for three phase 31.5 kV and 30 MVA ratings. The performance of the proposed strategy is verified with different case studies using simulation model. The details of the case studies are summarized in Table 3.

Line breakers used in the ring type systems ensure to provide alternative power transfer path for loads in an event of failure or modification of a distribution network. At least one of the three LBs on the line must be opened to prevent the phase conflict. Therefore, the LB2 and LB3 are used to separate the alternative supplies of ring type distribution network for case studies of 1 and 2 respectively.

Case 1: Consumers fed from SB1 (Substation 1) and SB2 are separated by LB2. The circuit breakers closest to the SB1 and SB2 should be set to open in less than short-circuit current exposure time, which is determined as 1 second by the TSO. In the event of the failure, the current is monitored by the relays and issued trip commands to the circuit breaker when the determined withstand times of the relays are exceeded. Relay closest to the fault location is operated first. In case the closest relay fails to operate, the next relay in sequence operates. Therefore, the sequences of relays are determined as B1-B2-B3 for SB1 line and as B8-B7-B6-B5-B4 for SB2 line.

The tripping times of relays are calculated using fuzzy logic based strategy by considering the constraint of TSO and the related power flow condition. Figure 4 represents the comparison of the operating times of relays determined by manually and calculated by the proposed strategy. As can be seen from the figure, the proposed system determines the required tripping times accurately considering the sequences of relays. The performance of the proposed system is examined for a LL fault at the both sides of LB2 on Line 2 through a fault impedance of 3 ohm.

Table 3. The details of case studies

	Case 1	**Case 2**
Line Breaker	LB2	LB3
Fault Location	Line 2	Line 3
Fault Type	A-B fault (LL-F)	A-B fault (LL-F)
Short Circuit Impedance	3 ohm	3 ohm

Figure 5 presents the operating performance of the proposed strategy. The left axis of the Figure shows the breaker currents including the steady-state and fault conditions, while the right axis shows the calculated breaker tripping times. As illustrated in Figure 5, three-phase balanced LL faults occur at 0.85s in SB1 and 0.91s in SB2. The breakers are exposed to short circuit current throughout the tripping times of the breakers B3 and B4 (0.1983s and 0.1009s respectively) closest to the fault location. The relays send tripping commands to the related circuit breakers and reliable operation is achieved isolating the defective area from the distribution network.

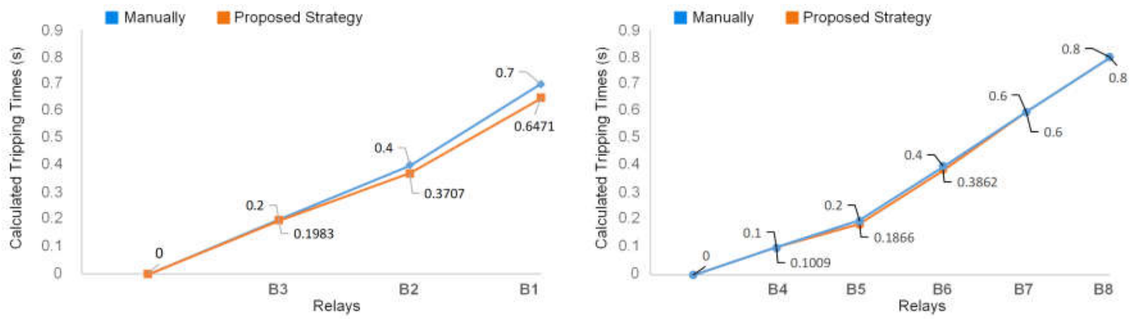

Figure 4. Comparison of the relay parameters for case 1

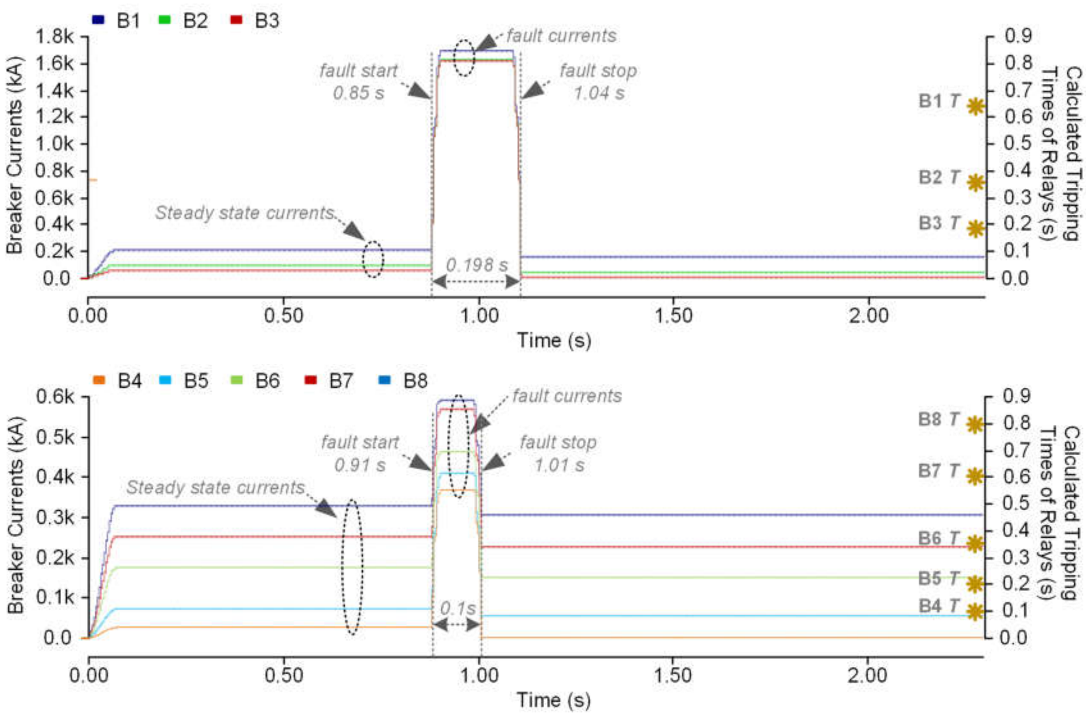

Figure 5. Test results for case 1

Case 2: In this case, the modification, that LB3 is opened to separate the alternative supplies of ring type distribution network while LB2 is closed, is investigated. When the system is operated without relay coordination, the tripping times and the sequences of relays will remain constant. Figure 6 represents the tripping times of relays of the modified system that is operated without relay coordination. As illustrated in Figure 6, in the event of a fault in line between B5 and LB3, B4 which is located in the SB1 line operates first due to the unconfigured relay parameters. Therefore, users of the distribution network between B4 and B5 are unnecessarily affected by the fault.

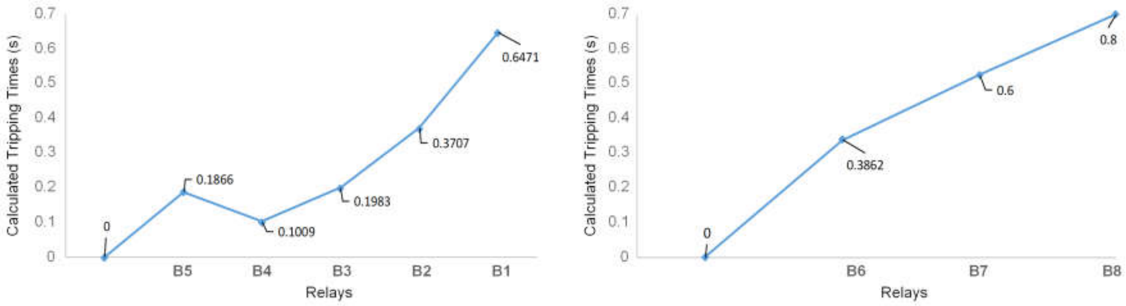

Figure 6. Relay parameters before reconfiguration

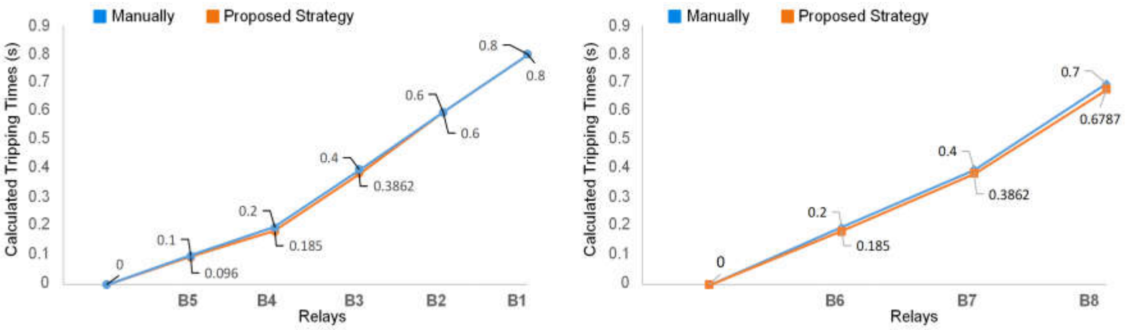

Figure 7. Comparison of the relay parameters for case 2

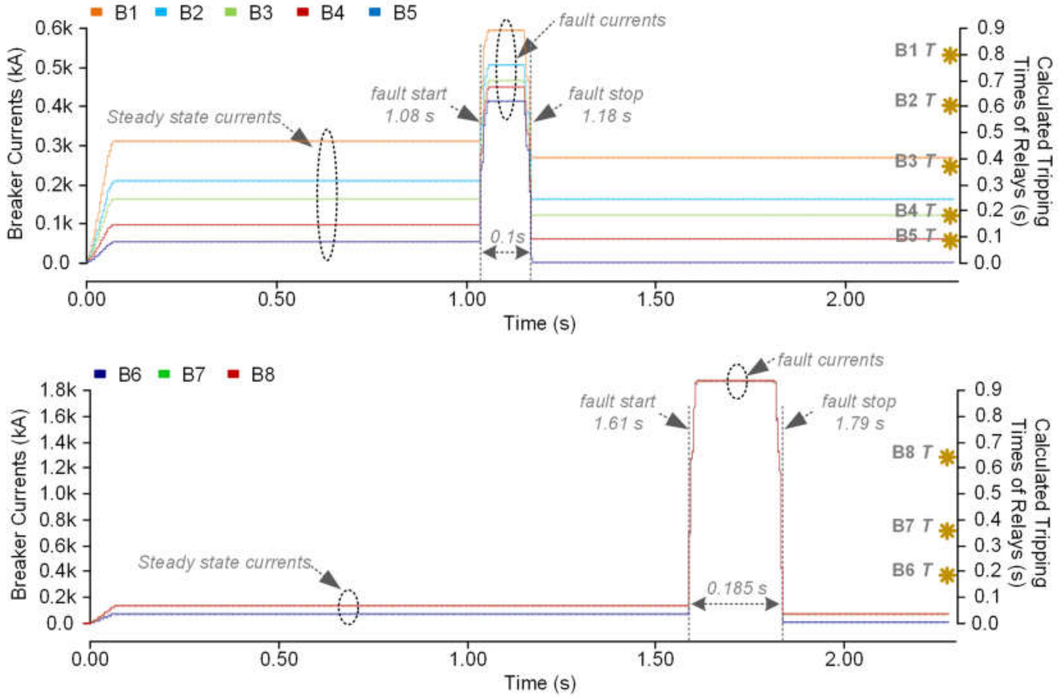

Figure 8. Test results for case 2

By considering the modification of power flow in the network, the sequences of relays are reorganized as B1-B2-B3 for SB1 line and as B8-B7-B6-B5-B4 for SB2 line by the proposed strategy. The relay parameters determined by manually and calculated by the proposed strategy is illustrated in Figure 7. The performance of the proposed system is examined for a LL fault at the both sides of LB3 on Line 3 through a fault impedance of 3 ohm.

Figure 8 shows the operating performance of the proposed strategy. As illustrated in Figure 8, three-phase balanced LL faults occurs at 1.08s in SB1 and 1.61s in SB2. The breakers are exposed to short circuit current throughout the tripping times of the breakers B5 and B6 (0.096s and 0.185s respectively) closest to the fault location. The relays send tripping command to the related circuit breakers and reliable operation is achieved isolating the defective area from the distribution network.

5. CONCLUSION

This study proposed a novel fuzzy logic based adaptive relay coordination strategy for distribution networks. The traditional strategies are constructed to solve the relay coordination problem with iterative methods. The advantages of the developed strategy are; reduced computation load, fast computing and adaptive operation.

The performance and reliability of the proposed strategy have been verified by the simulation of a real-world ring-type distribution network modeled in EMTDC/PSCAD environment. The results show that the proposed strategy can compute the relay parameters as close as possible to the manually determined values. Furthermore, the strategy able to be adapt the relay parameters to the power flow modification of the distribution system.

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