CHAPTER 9

Fuzzy Relaying of Small Station / Sub Station

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"All traditional logic habitually assumes that precise symbols are being employed. It is therefore not applicable to this terrestrial life but only to an imagined celestial existence."

Bertrand Russell, 1923
British Philosopher and Nobel Laureate

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Chapter 9.
Fuzzy Relaying of Small Station /Substation

9.1 Introduction
Relaying is an art of use of relay sensor in power station, line and substation. In the previous chapter a protective device like fuzzy sensor was considered for fuzzy based design but in this chapter a scheme for protection of power system using fuzzy relay has been discussed. LAN [3,18,21] method of communication is adapted for interaction between client and server fuzzy relay system. Thus a fuzzy based protection scheme is proposed which, replaces the existing conventional relaying techniques. Its simulation, performance and evaluation are discussed in this chapter.

9.2 Conventional Relaying Scheme
The use of single input relays like the over current relays become inadequate in complex interconnected power systems [53,93]. In an interconnected system, the fault current may pass through several breakers before reaching the fault point. Under this condition an ordinary overcurrent relay fails to isolate the breakers, which will clear the fault with minimum circuit interruption. In, other words the selectivity of operation is hampered. To ensure the selectivity of relay system, directional relaying is preferred. Fig. 9.1 shows a small power system with six circuit breakers. When a fault occurs at $F_1$, current flows to the fault in two parallel paths as shown by the arrows. If the load connected after breaker 6 is a static one, the fault current passing through breakers 4 and 5 will be equal in magnitude. If ordinary overcurrent relays are used in these places, both the breakers will trip. This causes an unnecessary interruption of power flow in the sound line. If on the other hand, breaker 4 and 5 are operated by a fuzzy directional overcurrent relays or fuzzy directional sensors, which operate only when the current flows from bus-bar to the line and not when it flows from the line towards the bus, then the breaker 4 will not trip for a fault at $F_1$. Similarly breaker 5 will not trip for any fault in the line 3-4. A fuzzy rule base is developed for this scheme to cause to operate the fuzzy directional sensor in desired direction.
Distance relays are mostly used for overhead long distance transmission lines protection. Here a single relay is used for protecting a fixed length of line. The same fuzzy directional relay's output may be made proportional to the distance of the fault point from the relaying point.

[Fig. 9.1 Directional relaying]

Non directional relays directional relays

[Fig. 9.2 Basic arrangement of distance relay]

Fig. 9.2 shows the basic arrangement of distance relay. For a fault at the far end of the line the relay voltage will be \( IZ_L \), where \( V \) is voltage in line, \( I \) is current in line and \( Z_L \) is the impedance of the line from the relay to the fault point. If \( V/I < Z_L \), the fault is internal and on the other hand if \( V/I > Z_L \) the fault is external. Modern distance relaying are built with three distance measuring units (Physically separate units or one unit, for first and second zones with a timing unit to increase the each of the first zone, and a second unit with another timer for the third zone).Fig. 9.3 shows the multisteped time lag distance and directional protection arrangement [38,73,93].

The first zone unit is adjusted to protect between 80- 90% length of the line section from the power feeding end, its operation is instantaneous (About 1-2 cycles). The second zone is set to cover
about 30% of the next line section and operates with an intentional time lag (0.2-0.5 sec) set by the second zone timer [73,93].

This allows the first zone relay of the next section to operate first for any fault occurring within its first zone. On the other hand it provides primary protection for the line section left over by its own first zone and also to give remote back-up to the next section up to about 30% of its length. Any three phase distance protection scheme must be able to cater for LG (Line to ground) faults, L-L (Line to Line) Faults, L-L-G (Line to Line to Ground) faults and L-L-L (Line to Line to Line) faults.

![Fig. 9.3 Multistepped time lag distance and directional protection](image)

### 9.3 Concept of Fuzzy Relaying

Fig. 9.4 shows proposed fuzzy relaying scheme for power system protection. Where $C_1, C_2, \ldots, C_n$ represents sensor coils. $CB_1, CB_2, \ldots, CB_n$ represents circuit breakers. $CFS_1, CFS_2, \ldots, CFS_n$ represents client fuzzy sensor working as switch. $F_1$ and $F_2$ represents fault location.

Rule base as a fuzzy server (RB-FS) represents rule base for distance and directional relay characteristics in pre and post fault condition [3,94].

MIMO-NN represents Multiinput and Multioutput Neural Network for driving fuzzy sensor.

In the concept of fuzzy relaying, sensor coils $C_1, C_2, \ldots, C_n$ access the fault as per its amplitude, distance and direction and fed to MIMO-NN for approximating the signal, the outputs of MIMO are fed to fuzzy sensing server which contains a number of IF-THEN rules. The decision signals thus obtained from the fuzzy sensing server are sent to the client fuzzy sensors (Fuzzy relays), which manipulate the input and provide action signal after proper defuzzification, which actuates the
mechanism of circuit breakers [3]. The server fuzzy sensor works as a human brain which generates human reasoning, the client fuzzy sensor only follows the server command and manipulates its output to produce an action command for actuating mechanism of circuit breakers [94].

The functioning of entire system is assured by local area protection network (LAPN). LAPN as LAN is used in small substation for protection purposes, similarly Wide Area Protection Network (WAPN) as wide area network (WAN) is used in long transmission line for protection of its expensive equipments.

Fault signal

Inputs from sensor coils to MIMO-NN

Outputs from MIMO-NN

Fig. 9.4 Fuzzy relaying scheme for power system protection [3, 94].

Local Area Networks (LAN) are used within a few kilometers area. They are widely used to connect personal computers and workstations in company offices and factories to share resources (CFS's, H/W, S/W) and exchange information. In this scheme of protection, the entire system may work as a LAPN considering all PC's as CFS with fuzzy EPROM and server sensor as a master controller in centralized control [3, 94]. The command signals should activate the actuating mechanism
of CB’s as per signal received by the fuzzy IF-THEN rule base for distance and directional situation of fault as it actuates the printer or any other devices in an organization to do the specific job. LANs are distinguished from other kinds of networks by three characteristics as given below [3,18] -

(i) Its size  
(ii) Its transmission technology  
(iii) Its topology

LAN’s often use a transmission technology consisting of a signal cable to which all the machines are attached. Various topologies are possible for broadcast LAPN. Fig 9.5 and Fig 9.6 shows the two types of LAPN i.e. bus type and ring type respectively at any instant one machine (RB-FS) is the master (server) and is allowed to transmit [18,21] action signals. All other machines (CFS) are required to retain signals from sending. An arbitration mechanism is needed to resolve conflicts when two or more machines want to transmit action signal to CB’s simultaneously. The arbitration mechanism may be centralized or distributed. Ethernet™ is a bus based LAPN with decentralized control.

The second type of LAPN is the ring, in which typically each bit circumnavigates the entire ring in the time it takes to transmit a few bits, often before the complete packet has been transmitted. Some fuzzy IF-THEN rules are needed for arbitrating simultaneous access to the ring [21,94] Referring to the Fig. 9.3 of conventional protection system, a multilayer protocol hierarchies shown in Fig.9.6 is suggested [21] for distance and directional relaying of first, second and third section of line. Layers on one CFS carries on an interaction with layer n on another CFS or RB-FS. The rules and conventions used in this conversation are collectively known as the layer n protocol [3,94].

The entities comprising the corresponding layers on different CFS are called “peers”. In other words it is the peers that communicate using the protocol. In reality, no data are directly transferred from layer n on one CFS to layer n on another CFS or RB-FS. Instead, each layer passes data and control actuating signals to the layer immediately below it, until the lowest layer is reached [21,78,94].

Fig. 9.5 Bus type LAPN

Fig. 9.6 Ring type LAPN
Below layer 1 is the physical medium through which actual signal flow takes place. In Fig. 9.6 virtual interaction of CFS is shown by dotted lines and physical signal flow (command signal) by solid lines. It is useful to make explicit some of the assumptions underlying the model of communication [95]. It is assumed that physical layer, data link layer, and network layer are independent processes that communicate by passing acting signals back and forth.

In some cases, the physical and data link layer processes will be running on a processor inside a special network I/O chip and the network layer on the main CPU, but other implementation i.e. three processes inside a single I/O chip, the physical and data link layers as procedures, are also possible [18].

![Diagram of multisteped relaying protocols and interfaces](image)

**Fig. 9.6 Multisteped relaying protocols and interfaces**

### 9.4 Fuzzification and Rule Base Development for Fuzzy Server Sensor

A fuzzy relaying scheme must response for the severity, distance and direction of the fault current. Thus amplitude of the fault, its distance from the sensor coil and its direction with reference to the costly equipments which are being protected may be taken as fuzzy variable for developing the rule base [94]. The relaying scheme must response for its nearest, severest and directed towards the equipment to be protected [18]. The selectivity and sensitivity of any CFS and RB-FS must be ensured. The small power system or substation may be consist of a number of relays (CFS), but the
relay which senses the nearest, severest and directional fault should only operate to interrupt the power section, remaining all other relay (CFS) remain in operated in order to ensure the unnecessary interruption of entire power network which decreases the reliability of the power supply utility in their turn [18,78,94].

A generalized form of rule base is developed as given below [78] -

**Fig. 9.7 Fault analysis for rule base development**

IF the amplitude of fault current is $A_i$
AND its distance from coil $C_i$ is $d_i$
AND its direction is towards the coil $C_j$
THEN trip the coil for interruption

AND its direction is away from the coil $C_i$
THEN may trip for interruption ...(9.1)

The amplitude $A_i$, distance $d_i$ and direction $DR$ may have many fuzzy term in the form of predicates as given below -

$A_i$ represent Amplitude if fault at $i^{th}$ sensor coil $C_i$, $i=1,2,3,---n$

Predicates: Small amplitude (severe) $A_i^S$
Medium Amplitude (severer) $A_i^M$
High Amplitude (Severest) $A_i^H$

$d_i$ represent Distance of fault from $i^{th}$ sensor coil $C_i$, $i=1,2,3,---n$

Predicates: Near $d_i^N$, Nearer $d_i^{Nr}$
Nearest $d_i^{Nat}$, Slightly away $d_i^{Sa}$
Away $d_i^a$, Far away $d_i^{Fa}$

$DR$ represent distance of fault with respect to sensor coil $C_i$

Predicates: Towards the sensor coil $C_i$ - $DRT$, $DRT^1$, $DRT^2$, $DRT^3$, $DRT^4$,

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Away from the sensor coil $C_i - DRA$

Fig. 9.8, 9.9 and 9.10 shows the fuzzified form in triangular shape of amplitude, distance and direction of fault current for different predicate of corresponding parameters in generalized form [94]. Table 9.1 is Fuzzy associative memory (FAM) for rule base development of fuzzy server sensor.

**Fig. 9.8** Conceptual view of fuzzification of 'Amplitude'.

**Fig. 9.9** Conceptual view of fuzzification of 'Distance'.

**Fig. 9.10** Conceptual view of fuzzification of 'Direction'.

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Table 9.1 FAM Rule Base

<table>
<thead>
<tr>
<th>Direction</th>
<th>(A_i^S)</th>
<th>(A_i^M)</th>
<th>(A_i^H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_i^N)</td>
<td>May trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td></td>
<td>Don’t trip</td>
<td>May trip</td>
<td>Trip</td>
</tr>
<tr>
<td>(d_i^{Nr})</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td></td>
<td>May trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td>(d_i^{Ns})</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td></td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td>(d_i^{Sa})</td>
<td>May trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td></td>
<td>Don’t trip</td>
<td>Don’t trip</td>
<td>Don’t trip</td>
</tr>
<tr>
<td>(d_i^a)</td>
<td>Don’t trip</td>
<td>Don’t trip</td>
<td>May trip</td>
</tr>
<tr>
<td></td>
<td>Don’t trip</td>
<td>Don’t trip</td>
<td>May trip</td>
</tr>
<tr>
<td>(d_i^{Fa})</td>
<td>Don’t trip</td>
<td>Don’t trip</td>
<td>Don’t trip</td>
</tr>
<tr>
<td></td>
<td>Don’t trip</td>
<td>Don’t trip</td>
<td>Don’t trip</td>
</tr>
</tbody>
</table>

Table 9.1 develops 36 rules for corresponding reasoning of three predicates for amplitudes, six for distance and two predicates for directions. The rules can be written in linguistic form as given below [78,94]-

FAM Rule 1: IF \(A_i^S\) AND \(d_i^N\) AND DRT THEN Relay may TRIP
FAM Rule 2: IF \(A_i^S\) AND \(d_i^{N}\) AND DRA THEN Relay don’t TRIP
FAM Rule 3: IF \(A_i^M\) AND \(d_i^{Nr}\) AND DRT THEN Relay TRIP
FAM Rule 4: IF \(A_i^M\) AND \(d_i^{Ns}\) AND DRA THEN Relay TRIP
FAM Rule 35: IF \(A_i^H\) AND \(d_i^{Fa}\) AND DRT THEN don’t TRIP
FAM Rule 36: IF \(A_i^H\) AND \(d_i^{Fa}\) AND DRA THEN don’t TRIP

The inference engine for fuzzy server sensor (RB-FS), thus developed may be used for fuzzy reasoning of faults to be cleared.
9.5 Multi-Input Multi-Output Neural Network Driver

The feed forward network (FF net) structure is one of the most popular and arguably most important ANN structures. Presently the most popular training algorithm, the back propagation-based generalized delta rule (GDR) is used [95]. It is a form of gradient descent applicable to units whose activation function is semi linear. The overall computational approach used here for exploring the FF net and training algorithm is shown in Fig.9.11. The situation may be viewed as comprising two parts: feed forward (implementation) of the learned mapping and training of the multi input – multi output (MIMO) multilayer neural network [95].

The training algorithm would use the feed forward implementation as part of training. In this sense they are coupled. FF network is composed of a hierarchy of processing units, organized in a series of two or more mutually exclusive set of neurons or layers. The training set for this type of network consist of

\[(A^S, A^M, A^H, d_i^N, d_i^N_r, d_i^{N_t}, d_i^{R_a}, d_i^N, d_i^{R_a}, d_i^{R_a}, d_i^{R_n}, d_i^{R_t}, D_R, D_R^A)\]  \(\ldots(9.3)\)

The network weights for the \(p\)th training pair may be corrected using error functions [95]. The simulation results were generated using neural network tool of MATLAB.

9.6 Discussion

The conventional methods of protection for any fault with respect to its distance, direction and amplitude have been introduced in the plane of pilot wire and microwave relaying. The conventional relaying system is not much reliable due to variability in various parameters i.e. voltage, current and temperature dependent impedances. An expert system has been proposed to develop using LAN, fuzzy sensor server and client servers. Computer networking is the base of this relaying scheme [3,18,21]. A rule-base has been developed for building an inference engine. Fuzzy reasoning and approximating techniques have been implemented [78,94]. All the CB actuating mechanism are connected with the output of rule base fuzzy sensor (RB-FS) or server sensors via client fuzzy sensors (CFS) specified for the particular CBs. Fault sensed by rule base of CFs would search for an appropriate rule base from fuzzy server sensor (RB-FS) and send the command to the actuating mechanism of CB’s as per the decision taken by the fuzzy reasoning (IF-THEN) rules [78,94].

A Multi-Input-Multi-Output neural network (MIMO-NN) is introduced in between sensor coils and RB-FS for conditioning or signal processing of input and work like a driver NN [95]. LAN covers a small substation for command signal communication. Fig 9.11 actually shows the detail of block diagram of MIMO-NN shown in Fig. 9.4.
Fig. 9.11 MIMO-NN Driver (FF net)