A novel reverse and forward directional relaying scheme in six phase overhead transmission lines using adaptive neuro-fuzzy inference system

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Article Info

Article history:

Received Aug 15, 2023
Revised Mar 12, 2024
Accepted Apr 26, 2024

Keywords:

Detection time
Directional relaying
Fuzzy logic
Membership function
Reach setting
Six phase transmission lines
Faults

ABSTRACT

Recent power system is structurally difficult and is vulnerable to undesirable conditions like transmission faults. In this event of transmission line faults, exact fault zone detection enhances the restoration process, thus improving reliability of the complete power system. In order to solve the above problem, this paper presents an adaptive neuro-fuzzy inference system (ANFIS) based fault zone detector, which combines artificial neural network (ANN) and fuzzy logic technique (FLT) in six phase overhead transmission lines (SPOTL). To overcome the limitation of ANN and fuzzy expert system (FES) architectures and, the selection work has been formulated as an optimization method and solved using ANFIS. The inputs are the zero sequence component currents at the middle bus of the transmission line. The training data are extracted using discrete Fourier transform and collected, and then ANFIS is trained to identify the fault zone. The ANFIS based scheme reach setting has been checked for various types of faults, with a wide range of faults and transmission line parameters. Simulation study ensure that this method has a high reach setting, does not require the design of communication channel. Further, the ANFIS study shows that ANFIS is suitable for all type of faults. The ANFIS significantly outperforms other techniques proposed in the literature in terms of various evaluation metrics.

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1. INTRODUCTION

Nowadays, the society has been developed based on advanced electricity and its applications. Increased capacity and reliability of the transmission line is most importance in the power system. There is imperative to adopt system that allow for enhancing power transfer capacity with minimal change in present transmission line due to restrictions of transmission line corridor and the necessity to decrease cost for construction and the environmental problems. This can be done by improving prevailing voltage withstand capability or upgrading current transmission line to high-order overhead transmission line (HOOTL). Among HOOTLs, six phase overhead transmission line (SPOTL) are known good effective, due to the ease in changing already existing three-phase overhead double circuit line (TPODCL) over the SPOTL. This can transfer 73% more electrical power relative to TPODCL with reduced radio interface levels, corona, audible noise, and surface gradient of conductor. The SPOTL have the capacity to address the frequently evolving power demand. Furthermore, some studies have presented on SPOTL and its benefits on power systems [1]-[3]. The SPOTL also have better voltage regulation, capacity of thermal loading and loading surge impedance. Nevertheless, the SPOTL has some issues as every system such as identifying the fault among sections/zones, locating the faults, and classifying the faults.

By prevailing literature survey, traditional fault detection methods for SPOTL are based on wavelets [4]-[6]. Few notable researches recommended extensive fault protection schemes on SPOTL in the literatures [7], [8]. Different techniques have been investigated upon lately for identifying the fault locations occurring on SPOTL [9], [10]. For past decades, a large number of classification methods are introduced by various researchers for SPOTL [11], [12]. Kapoor and Yadav [13] proposed hybrid method with the single-end measurements SPOTL. Another solution is focused in [14] based on the support vector machine method for SPOTL with zero sequence currents. The optimized version of discrete Fourier transform (DFT) has been addressed in the literature due to its prominent use in faults detecting. The most widely employed fast technique is DFT which was implemented specially for detection. The DFT method was penetrated in SPOTL for recognizing the shunt fault current signals [15]. Numerous researchers have provided zone directional relay systems in the SPOTL for shunt the faults [16], [17].

Before the faulty section reconfiguration, the replacement crew patrols the zone looking for the fault indications for protection. The whole restoration process can take large time. Therefore, the faulted transmission line must be identified and isolated from the transmission line. Hitherto, multiple authors have investigated the fault section with two bus data [18], [19]. Others have focused on the fault zone with single bus data [20]. In recent research, the zone direction relaying has been provided by using zero sequence currents [21]. A copious number of articles have been devoted to developing more intelligent and efficient fault zone detection method in TPODCL [22], [23]. At present, relevant scholars have made research on the fault zone detection for high voltage direct current (HVDC) [24]. Another notable zone detection system in the series compensated transmission line is artificial neural network (ANN), which is employed as primary protection [25]. Recently, due to the better performance of soft computing method, numerous fault location techniques have been presented.

With the development of soft computing methodology, incorporating soft computing in enhancing the precision has become a novel research approach. Recently, soft computing methods such as genetic algorithms, fuzzy logic technique (FLT), ANN, and various connectionist schemes viz. adaptive neuro-fuzzy inference system (ANFIS) are increasingly being identified as accurate learning system for designing complex phenomena in several aspects of natural sciences, physical, and engineering. Apart from numerous near-field applications, many researches work where ANFIS was used in recognizing faults have surfaced in the literature, especially in the last decade. Many ANFIS implementation reports briefly introduce fault detection in the recent literature reports [26], [27]. Most recently too, Kumar *et al.* [28] successfully employed ANFIS to design the faulty location. So far, our literature search has exposed that ANFIS has never been used in faults zone identification in SPOTL. Nevertheless, these reports motivation on its implementation methods ANFIS in the different platforms and did not provide a comprehensive understanding of the zone detection in SPOTL. It motivates us to introduce briefly ANFIS and summarize the arts of ANFIS zone detection implementation in the SPOTL. To address this problem, explainable soft computing proposes to make a shift towards more transparent ANFIS. This fault zone detector is the extension of article in [29] that extends the FLT application to identify faulted zone in a SPOTL considering several challenging cases. Important highlights of ANFIS are: i) ANFIS is very easy to implement and deployed employing if-then rules; ii) Effortless means to achievement single bus measurements of SPOTL in an environment familiar to power engineer; iii) ANFIS provides a rapid zone fault identification and it does not involve any communication channel; and iv) ANFIS gives high reach setting.

In the section 1 of this paper, the development of the ideas and techniques are elaborated. Next, section 2 explains a SPOTL simulation and faults, then followed by section 3 describes ANFIS design for detection of zone. Section 4 gives the clarification of simulation results and comparison study. Section 5 serves as the concluding remarks of the paper.

2. PROPOSED SYSTEM AND ITS PARAMETERS

As can be seen from Figure 1, the SPOTL has been simulated employing MATLAB software within it by employing SimPowerSystem toolbox in this study. The rating of SPOTL is 138 kV, 60 Hz, and distributed parameter blocks is placed at mid of the line. The SPOTL parameters are taken as the distributed block model. If faults occur in a SPOTL, not only it affects the protection system but also impacts the neighboring phase safety. These currents are used as inputs for ANFIS. Figure 2 shows the flow diagram of proposed work.

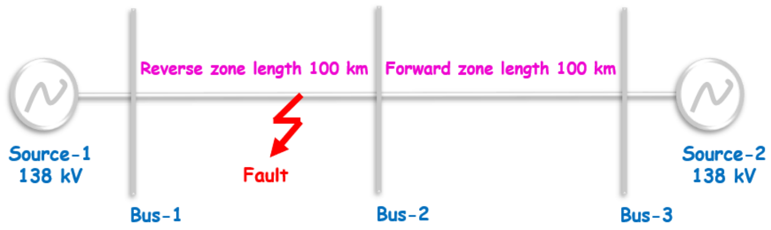

Figure 1. SPOTL single line diagram

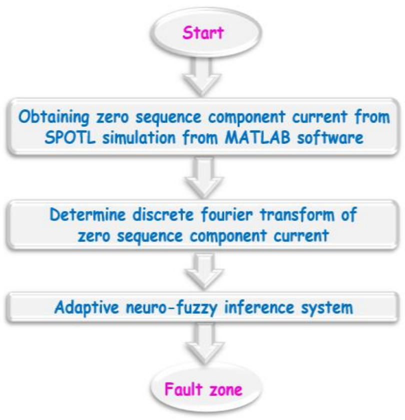

Figure 2. Flow diagram of proposed work

3. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

ANFIS is an adaptive network class, and integrates of the advantages of FLT and ANN. The complete mathematical process is as: i) First, it maps the data from the input by changing the shape and parameter of the membership function (MF); then ii) It remaps the input data to the output spaces by the MF of the output variables. In this, conclusion parameters of ANFIS are adjusted by least squares algorithm, and premise parameters of ANFIS are adjusted by gradient descent algorithm. Here, the channel for adjusting the conclusion parameters and premise parameters is called forward channel and backward channel respectively. In the present task, this work is performed employing an ANFIS method which is intelligent system combining FLT and ANN. The retro propagation algorithm is used for learning of ANFIS in order to find the premises parameters and the least squares method is employed for estimation of the consequent parameters. Both algorithms simultaneously make the optimization system selected for learning the ANFIS a hybrid system as depicted in Figure 3.

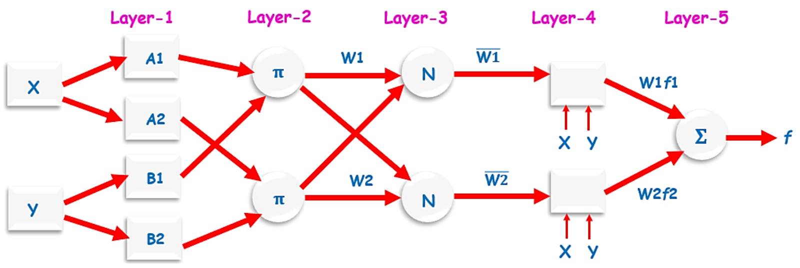

Figure 3. Adaptive neuro-fuzzy inference system

The ANFIS constructed with one input as well as one output. The input pattern, i.e., the zero sequence components are simulated by SPOTL. The output pattern is the fault zone. The intermediate hidden layers (second, third, and fourth) are processed all the information. The output with its calculation mechanism and its tools (triangular MF and IF THEN rules) makes the required calculation before it transmitting the data to the output layer. The ANFIS training is carried out by a two-steps process where the least squares technique estimated consequent parameters and then the gradient descent determined network weights. All the training epochs consists of phase before as well as back phase. The inputs are employed to find the layer-by-layer outputs neurons during the prior phase, allowing to find the consequent parameter values in the end. The backpropagation error algorithm is used for the weight of several layer adjustments during the reverse tracking. When back phase, the antecedents of the rule's weights updated retro algorithm error propagation. The parameters of consequent are updated while the parameters of antecedent are kept fixed; during the backtracking, the roles are interchanged during the forward tracking.

4. NUMERICAL EXPERIMENTS

The proposed ANFIS based relay for SPOTL has been tested with several fault cases. A large number of fault simulations are performed on SPOTL aiming to conform the reach setting of the ANFIS in finding the fault zones and conducted in MATLAB. The performance measures are calculated using forward zone = -1 and reverse zones = 1. The performance of the fault directional relaying has been checked in terms of reverse zone and forward zone for fault resistances R (Ω), fault types, fault locations L (km), and faults inception angles FIA (o), which are illustrated in detail in Table 1.

Table 1. Test results for ANFIS directional relaying

Change in parameter	Type	FIA (o)	L (km)	R (Ω)	Zone	ANFIS output	Detection time (ms)
Fault type change	Cg	50	26	35	Forward	-1	5
	Dg	50	26	35	Forward	-1	2
	BCg	50	26	35	Forward	-1	4
	DEg	50	26	35	Forward	-1	7
	BCDg	50	26	35	Forward	-1	8
	CDEg	50	26	35	Forward	-1	2
	BCDEg	50	26	35	Forward	-1	1
	CDEFg	50	26	35	Forward	-1	4
	ABCDEg	50	26	35	Forward	-1	3
	BCDEFg	50	26	35	Forward	-1	6
	ABCDEFg	50	26	35	Forward	-1	5
Fault inception angle change	CDF	30	58	18	Reverse	-1	8
	CDF	60	58	18	Reverse	-1	4
	CDF	90	58	18	Reverse	1	5
	CDF	150	58	18	Reverse	1	5
	CDF	180	58	18	Reverse	1	3
	CDF	210	58	18	Reverse	1	5
	CDF	240	58	18	Reverse	1	4
	CDF	270	58	18	Reverse	1	4
	CDF	300	58	18	Reverse	1	7
	CDF	330	58	18	Reverse	1	1
Fault location change	ACg	115	4	61	Forward	-1	4
	ACg	115	16	61	Forward	-1	3
	ACg	115	27	61	Forward	-1	4
	ACg	115	33	61	Forward	-1	4
	ACg	115	39	61	Forward	-1	2
	ACg	115	45	61	Forward	-1	2
	ACg	115	55	61	Forward	-1	8
	ACg	115	67	61	Forward	-1	2
	ACg	115	72	61	Forward	-1	1
	ACg	115	85	61	Forward	-1	6
	ACg	115	96	61	Forward	-1	3
Fault resistance change	ABCDEg	190	71	5	Reverse	1	2
	ABCDEg	190	71	16	Reverse	1	2
	ABCDEg	190	71	28	Reverse	1	1
	ABCDEg	190	71	32	Reverse	1	3
	ABCDEg	190	71	41	Reverse	1	3
	ABCDEg	190	71	48	Reverse	1	4
	ABCDEg	190	71	55	Reverse	1	3
	ABCDEg	190	71	61	Reverse	1	2
	ABCDEg	190	71	70	Reverse	1	4
Fault zone change	ACDE	220	12	21	Forward	-1	1
	ACDE	220	12	21	Reverse	1	6
	ACDE	220	12	21	Forward	-1	5
	ACDE	220	12	21	Reverse	1	6
	ACDE	220	12	21	Forward	-1	3
	ACDE	220	12	21	Reverse	1	4
	ACDE	220	12	21	Reverse	1	3
	ACDE	220	12	21	Forward	-1	3
	ACDE	220	12	21	Reverse	1	2
	ACDE	220	12	21	Forward	-1	1
	ACDE	220	12	21	Forward	-1	3

In this section, Table 2 makes the ANFIS has been compared with the other reported methods. Several reports in SPOTL are non-directional relays [8], [10], [12], [15]. The ANFIS is directional relay and deciphered the difficulty of distinctive between reverse zone faults and forward zone faults and gives the exact fault zone in SPOTL. Furthermore, the ANFIS has been compared with efficient FLT direction relaying in terms of detection time [11]. Overall, the ANFIS achieves better than prior reported approaches. The algorithm and [8] require the voltage and current samples at both line ends, while the ANFIS requires the current samples at single bus measurements. The reach setting of SPOTL length in [29] is 99.7%. The ANFIS results in this study; the reach setting is 99.89%. It is clearly shown that:
- It is an absolute protection system which is capable of fault-directional relaying;
- It has less detection time i.e. < 1 ms;
- The reach setting is > 99%;
- It needs only single bus measurements; and
- It is more robust, simple, and easy as compared to the prior reported schemes.

Table 2. Comparison with other schemes

Reference	Input	Method	Reach setting	Detection time
8	Single bus voltage and current	ANN	Non-directional	One cycle time
10	Single bus power frequency currents	Wavelet transform	Non-directional	-
11	Single bus voltage and current	ANN	Non-directional	16.67 ms
12	Voltage and current samples	Haar wavelet and ANN	Non-directional	
13	Single bus voltage and current	ANN	Non-directional	
30	Single-bus current samples	FLT	99.7	-
Proposed method	Single-bus current samples	ANFIS	99.89	8 ms

5. CONCLUSION

In present research work, an ANFIS method to find fault zone in SPOTL is introduced. The fault currents are finally employed as inputs to an efficient zone identifier known as the ANFIS, to create an intelligent system. An ANFIS was trained and validated with the input features input features-output features. The ANFIS is located at middle bus, which is taken as the relay to be protected. It considers zone-1 as reverse zone and zone-2 as forward zone. It employs around 15000 fault samples to validate the directional relaying. Moreover, a preliminary study of testing the ANFIS has conformed to satisfactory performance and a better reach setting. The obtained simulation results corroborate the reach setting of the proposed ANFIS. Likewise, it can be detected in the fault sections with a response time less than 8 ms in critical scenarios, which is much less than implemented schemes. A comparison study clearly states the advantages of ANFIS. In future research work, we intend to estimate a similar system in SPOTL applications.

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