COMPARATIVE ANALYSIS OF FAULT DIAGNOSIS IN TRANSMISSION LINE USING SOFT COMPUTING TECHNIQUES

Gyanesh Singh[1], A.Q. Ansari[2], Md. Abul Kalam[3]

[1]Ph.D. Scholar, Jamia Millia Islamia University New Delhi India; 110025
[2]Department of Electrical Engineering Jamia Millia Islamia University New Delhi India;110025
[3]Department of Electrical Engineering BIT Sindri Jharkhand India; 828123
gyan9000@gmail.com

ABSTRACT

This paper proposes soft computing techniques for short circuit classification, location and nature for the different types of short circuit in long transmission multi-terminal line. Author proposes various soft computing methods e.g. Fuzzy Logic system (FLS), Python and Nonlinear auto regression with exogenous input (NARX) Artificial Neural Network (ANN). A comparative analysis proposes in this paper for accuracy, feature extraction for future fault identification and for suitable designing of protective devices such as relay and circuit breaker for separating the healthy section from faulty section. The above proposed soft computing techniques also provide a means for reliability of power supply to the consumers like industrial, agricultural, commercial and domestic. For better designing of protective devices, it is absolute necessity of accuracy as well as precision.

KEYWORDS: *ANN, NARX, Fuzzy Logic, Python, Matlab/Simulink, Power System.*

ABBREVIATIONS: *FLS- Fuzzy Logic system, ANN- Artificial Neural Network, NARX- Nonlinear auto regression with exogenous input, CSV- comma separated value, KNN- K nearest Neighbors, SVM- support vector Machine, BBMB- Bhakra beas management board, SVR- support vector regression.*

I. INTRODUCTION

In last few decades fault location and diagnosis using digital techniques in power system transmission line became a subject of interest. An accurate fault location techniques provide better performance in respect to post fault analysis and hence improving the reliability of the system. By knowing prefault current and hence applying in particular transmission can definitely improve transmission system performance and their operation. Different effects are applied to detect fault i.e. effect of fault resistance and fault inception angle between fault current and voltage were observed to determine fault location in various positions. Effect of the fault resistance for various ten types of fault like A-G,B-G,C-G,AB, BC,CA,ABG,BCG,CAG,ABC,ABCG. Among these most likely fault i.e. 90-95% is line to ground fault[26]. Power system is complex in nature and having various components like active and passive elements, interconnected through various grids. If load increases then various parameters are affected and they require protection for reliability of power supply. In this paper author has analysed real time data and that is authenticated by 220 KV substations BBMB New Delhi. The real time data of faults is obtained to analyse through advanced soft computing techniques such as python learning tools (PLT3.7) and artificial neural network (ANN) and their comparative study on the basis of training and testing of real time fault data, through K Neighbors based fault classifier and using Multinomial Logistic Regression. In ANN author uses curve fitting tools to train of almost 70 percent data and remaining 30 percent data have tested for validation of results in terms of accuracy and error analysis. Various steps are provided to validate the result and they are as under-(i) Collection of real time data and their authentication from BBMB. (ii) Making of excel file showing all the effect and causes of fault in transmission lines. (iii) making dot csv file for Python 3.7 tools as per their library which is already inbuilt form.(iv) Importing library data and implementation of various effects such as peak load time, kite flying, weather condition, season, days, months etc. (v) classification of nature and types of fault in transmission lines.(vi) classification and regression analysis using K Neighbors Classifier and Multinomial Logistic Regression. (vii) Training and testing of data using artificial neural network in curve fitting tool. (viii) Comparison of result in terms of their accuracy and error by showing graphical form. (ix) Representation of result in different plots like kernel, bar graph, histogram, rectangular plot, pie graph. With this analysis authors have given idea for future forecasting of faults and designing of protective devices for reliable power supply to the consumers[10-16]. Future forecasting and fault classifier could become easy for the general layout of power system by using advanced algorithm and by doing comparison with traditional methods such as standard normalisation and mathematical equation. Accuracy of result by some graphical representation like kernel graph, histogram and other linear graphical representation to show the comparison with artificial neural network tools[27]. Transmission line faults are common difficulties in today's world. Faults mainly depend on types of load and their nature. Transmission lines are divided in different zones and hence cannot predict easily the faults and their types. Several protective devices have incorporated in the past few years to classification of fault but none guaranteed the accuracy. In this paper author proposes an advanced machine learning algorithm to classification of faults and provided some future protection technique to minimize faults and reliability of supply to the consumer. In this python learning tools author compare the two algorithm namely using K Neighbors Classifier and Using Multinomial Logistic Regression. The data for experiments are obtained from BBMB Punjabi Bagh 220 KV substation New Delhi. The real experiments validates the improvements and future forecasting regarding faults in lines and analysis of results with their accuracy are elaborated in this paper. A discussion of real data and their implication in future conservation of energy [28]. In [1] creators recommended a thought for recognition of issue in a dc line dependent on the beat infusion by managing power hardware gadgets in the cross breed high voltage direct current breaker which is progressively precise and touchy as Compared with conventional detached assignment strategy, the proposed technique could be by expanding the abundancy of heartbeat on account of a high flaw impedance or an outer deficiency. The procedure of voltage infusion is adaptable, which could be either both side or one side infusion. In [2] creators recommended a plan to limit the sc current spike utilizing Variable recreations for a four terminal high voltage direct current framework, are utilized to survey essential and back-up insurance, when an essential transfer neglects to identify the sc current and voltage separately. Nearby, Primary and back-up insurance calculations for Multi-terminal high voltage direct current frameworks in view of the quick activity in clearing issues, contrasted with the air conditioner security and ongoing LDA based dc assurance methods of reasoning, as the Naïve Bayes order is utilized. The calculation understands a high operational speed by recognizing the deficiency in an essential insurance zone and stumbled the suitable dc electrical switch. The auxiliary insurance plot rapidly distinguishes and separates the broken segment during the disappointment of essential assurance with particular overshoot time. In [3] creators proposed a thought for multi-terminal and general shortcoming area strategy for N-terminal >3 transmission lines dependent on synchronized phasor estimation units. The advancement of the system depends on two-terminal shortcoming area method. In [4] creators proposed a thought for the improvement and usage of calculations for deficiency area in multi-terminal transmission lines, which is able to do accurately distinguishing the shortcoming point dependent on voltage and current phasor amounts, determined by utilizing estimations of voltage and current signs from smart electronic gadgets, situated on the transmission-line terminals. In [5] creators recommended a thought for issue recognition, characterization and area. The yields are the issue type and the flaw area gave by the issue classifier and the shortcoming locator, separately. The current and voltage signals are tested for the component extraction module. This module at that point separates highlights utilized by the shortcoming identifier, the issue classifier and the issue locator. In [6] creators proposed a thought for Electrical transmission lines deficiencies, when an issue happens, it is unimaginable the majority of the occasions to fix it physically and disappointments utilizing Support Vector Machine (SVM) for shortcoming determination. In [7] creators proposed a thought for measure flaw utilizing the first

Support Vector Machine (SVM) and Principal Component Analysis (PCA) is given to do the deficiency order, and contrast its outcome and what depends on SVM-RFE (Recursive Feature Elimination) strategy. PCA-SVM and SVM-RFE can adequately distinguish and analyze these regular shortcomings. RFE is utilized for highlight extraction, and PCA is used to extend the first information onto a lower dimensional space. PCAT 2, SPE statistics, and unique SVM are proposed to recognize the flaws. Some normal shortcomings of the Tennessee Eastman Process (TEP) are dissected as far as the pragmatic framework and impressions of the dataset. In RFE calculation, all factors are decreasingly requested by their commitments. The grouping precision rate is improved by picking a sensible number of highlights. In [8] creators recommended a thought for transfer assurance utilizing long momentary memory (LSTM) systems, Support vector machine (SVM) and information based line trip issue forecast in power frameworks. The transient highlights of multisource information are caught with LSTM systems, SVM and solid learning and mining capacity of LSTM systems is reasonable for an enormous amount of time arrangement in power transmission and conveyance. In [9] creators recommended a thought for deficiency area utilizing Vector space model with n-dimensional component vectors {(c 1, 1), (c 2,w 2), (c 3,w 3)}to speak to each element of the element vector speaks to a sort of client intrigue and the degree of its enthusiasm for the kind of intrigue model (counting the long haul intrigue model, the transient intrigue model.. Portrayal of the vector space model cannot just mirror the level of enthusiasm for the different intrigue classifications in the client model, yet additionally generally be anything but difficult to offer customized support for clients by vector figuring. In [10] creators recommended a thought for the classifiers to recognize and foresee issue types and areas over a 750KV, 600km long force transmission line by utilization of four incredible AI Bagging, Boosting, outspread premise capacities and credulous Bayesian classifiers were used for finding and distinguishing deficiencies in a force transmission line. AI method could be attainable for power framework security and proficiency. In [11] creators proposed a thought for, deficiency identification techniques by utilizing PCA T 2, SPE measurement, and unique SVM. At long last, PCA-SVM and SVM-RFE techniques are used for the characterization of a few sorts of issues. In [12] creators proposed a thought for computation of the real shortcoming separation precisely and distinguish in-zone and out-of-zone blames effectively. The geometrical connection between the turned separation point impedance and the pivoted estimated impedance in the unpredictable plane, the issue separation and separation point impedance are unraveled to the deficiency obstruction and uncaring toward power edge and flaw area varieties The separation point impedance, valuable impedance, and estimated impedance are turned at the same time in the mind boggling plane until the advantageous impedance corresponds with the positive heading of the genuine hub.. Besides, the proposed strategy can function admirably under different sorts of shortcomings e.g. a-g, b-g and so forth. In [13] creators proposed a thought for issue characterization, shortcoming area, issue stage choice flaw location and issue heading separation by utilizing fake neural systems approach. For power framework applications to prepared with disconnected information Artificial neural systems are important procedure. In [14] creators proposed a thought for Protection of Transmission line in Electric Power Systems (EPS). The propelled Application of Artificial Intelligent, Fuzzy Logic (FL) Adaptive Neuro-Fuzzy Inference System (ANFIS) for Distance Relay Protection for long Transmission line in Electrical Power frameworks (EPS), Artificial Neural Network (ANN) was acquainted with handle various issues in EPS. Insurance of Transmission line with various lengths is significant issues and deficiency recognition, grouping, and area in long Transmission lines. Applying the ANFIS procedure on assurance of long Transmission lines can be seen as a fluffy framework, a neural system or fluffy neural system. In [15] creators recommended a thought for deficiency separation estimation to a fixed arrangement repaid transmission line and precise plan for issue identification, order and assurance. Metal oxide varistor (MOV) vitality, utilizing Levenberg–Marquardt preparing algorithm based on counterfeit neural system (ANN). To prepare the ANN, MOV is utilized as information vitality signs to fixed arrangement capacitors (FSC). The single end estimation vitality signs of MOV is utilized in all the 3 stages more than one cycle length from the event of a flaw. For issue separation estimation, MOV vitality signals are taken care of as contribution to ANN. For every one of the ten kinds of issue in test power framework model at various flaw origin edges over various issue areas attainability and dependability have been assessed. At Power Grid Wardha Substation, Real transmission framework parameters of 3-stage 400 kV Wardha–Aurangabad transmission line (400 km) with 40 % FSC is recorded genuine information.

In [16] creators proposed a thought for a novel methodology utilizes a Resonant Fault Current Limiter (RFCL) and time arrangement expectation called Auditory Machine Intelligence (AMI). Relief of deficiency dependent on another kind of man-made consciousness system moderation of real flaw to tweak inductances in circuit so as to assess the leeway times for a shortcoming. From the above survey and detection of fault in multi-terminal line author proposed a final comparative analysis and given comparative tables on the basis of nature and its type and also various features like fault inception angle, pre-fault current and frequency variation etc.

In the next section authors discussed the proposed method, mathematical analysis, result and discussion followed by conclusion.

II. PROPOSED METHODOLOGY

In this paper author proposes comparative analysis of fault detection and location using soft computing techniques, in previous papers the problem of exact location and detection of fault types and then measure some protective device was big issue, we have study the two source machine and fault in transmission system have taken into consideration. Fault is calculated by traditional method and also validated with various soft computing techniques and the results then compared and have shown in table 10.

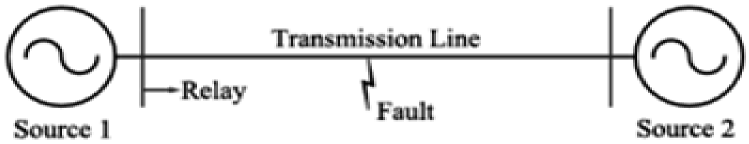


Fig.1. Analysed system for considering both side generator

2.1 Mathematical Calculation for fault analysis

As fault in transmission lines are classified in 11 types like a-g, b-g, c-g, ab, bc, ca, ab-g, bc-g, ca-g, abc and abc-g. When fault occures in any section then in that particular section mathematically voltage is zero or minimum and current rises or maximum, fault current depends on various parameters like fault impedance, fault inception angle, zone fault and other effect can change the voltage and current in the particular zone as well as section.

$$Z_{app}=\frac{Vr}{Ir}=(R_1+jX_1)D+\frac{RfIo}{Ir} \quad (1)$$

where Vr is the relay voltage signal, Ir is the relay current signal,Io is the zero sequence current at the relay, D is the distance to the fault, R_1 and X_1 are the line resistance and reactance per mile, R_f is the unknown fault resistance[26].

$$V_{abc1}= VF_{abc}+DZ_{abc}I_{abc1} \quad (2)$$

$$V_{abc2}= VF_{abc}+(L-D)Z_{abc}I_{abc2} \quad (3)$$

From equation 2 and 3

$$V_{abc1}-V_{abc2}+LZ_{abc}I_{abc2}=DZ_{abc}[I_{abc1}+I_{abc2}] \quad (4)$$

Where Zabc is the three phase series impedance of line per mile, VFabc is voltage vector at the fault.

$$VF_{abc}=V_{abc1}-DZ_{abc}I_{abc1} \quad (5)$$

$$IF_{abc}=I_{abc1}+I_{abc2} \quad (6)$$

$V_{abc1}=V_{Fabc}+DZ_{abc1}I_{abc1}$ (7)

$$V_{abc2}=VF_{abc}+L_2Z_{abc2}I_{abc2}+(L_1-D)Z_{abc1}(I_{abc2}+I_{abc3}) \quad (8)$$

$$V_{abc3}=VF_{abc}+L_3Z_{abc3}I_{abc3}+(L_1-D)Z_{abc1}(I_{abc2}+I_{abc3}) \quad (9)$$

From equation 7 and 8 we get

$$Vabc_1-V_{abc2}+(L_1Z_{abc1}+L_2Z_{abc2})I_{abc2}+L_1Z_{abc1}I_{abc3}=DZ_{abc1}(I_{abc1}+I_{abc2}+I_{abc3}) \quad (10)$$

Similarly using equation 7 and 9 leads to

$$V_{abc1}-V_{abc3}+(L_1Z_{abc1}+L_3Z_{abc3})I_{abc3}+L_1Z_{abc1}I_{abc2}=DZ_{abc1}(I_{abc1}+I_{abc2}+I_{abc3}) \quad (11)$$

In L-G fault assume prefault current is zero, so I_b=Ic=0, Vag= Z_f I_a

$V_0+V_1+V_2 = Z_f(I_0+I_1+I_2)$ (12)

$I_0=I_1=I_2= \frac{Vf}{Z0+Z1+Z2+3Zf}$ (13)

Similarly for others fault i.e. L-L fault $I_b+I_c=0$ and $I_a= 0$, $V_{bg}-V_{cg}= Z_f I_b$

$I_{f1}=I_{f2}=\frac{V1}{Z1+Z2}$ (14)

2.2 Sequence components

The sequence components for calculation of voltage and current in three phase power system transmission line, As per analysis the sequence components are positive, negative and zero sequence components and denoted as Va1 for positive sequence voltage in phase a, similarly Va2 negative sequence voltage in phase a and Va0 is zero sequence component of voltage in phase a respectively. An operator alpha is used for changing one phase to other by simply taking 120 degree of out phase and 240 degree or -120 degree in third phase. Sometime author considers effect of ground fault as earth fault to change the respective current as by changing fault impedance decrease or increase the current in different phases. From equation above in sub section 2.1 is used to calculate fault in different phase sequence and also to calculate voltage in respective zone as well.

III. CLASSIFICATION OF FAULT ON VARIOUS EFFECTS

Author tried to classify fault types and nature using table as shown below- Table 1 describes the classification on the basis of class or value with different effect like distance, resistance, inception angle, power angle and fault types.

TABLE 1: Different effects used for simulation in Matlab Simulink

Different effects	**Classification on the basis of their types or values**
Short circuit distance(Km)	30,60,90,120,150,180,210,240
Short circuit Resistance(ohm)	0.05,6,18,21,32,42,48
Short circuit inception Angle(degree)	0,20,40,60,80,100,120,140,160,180,200
Pre – Short circuit Power Angle (degree)	15,30,45
Short circuit Type	a-g, b-g, c-g, ab, bc, ca, ab-g, bc-g, ca-g, abc-g, non-Short circuit

Table 2 below describe the average time of fault and their types. As per table author tried to calculate average time in mili second with their types. As per table 2 the range of average time is between 5-6 ms.

TABLE 2: General time of Short circuit diagnosis for different Short circuit Types

Short circuit Type	**General Time of Short circuit Detection (ms)**
a-g	5.23
b-g	5.46
c-g	5.60
Ab	5.12
Ac	5.22
Bc	5.23
ab-g	5.98
ac-g	5.62
bc-g	5.81
abc-gn	5.90

3.2 Accuracy in fault calculation

In this sub section author described the variation in accuracy for different types of fault like a-g, b-g etc., as for non-faulty section it is 100% accuracy also for other than this fault variation is more than 99%. Also this variation describes that fault accuracy as well as precision will suggest for protection devices.

TABLE 3: Variation of accuracy for different types of short circuit in transmission line

Type of short circuits	Variation in accuracy %
a-g	99.96
b-g	99.27
c-g	99.27
Ab	99.94
Ac	99.68
Bc	99.50
ab-g	99.63
ac-g	99.56
bc-g	99.25
abc-g	99.84
Non –faulty	100

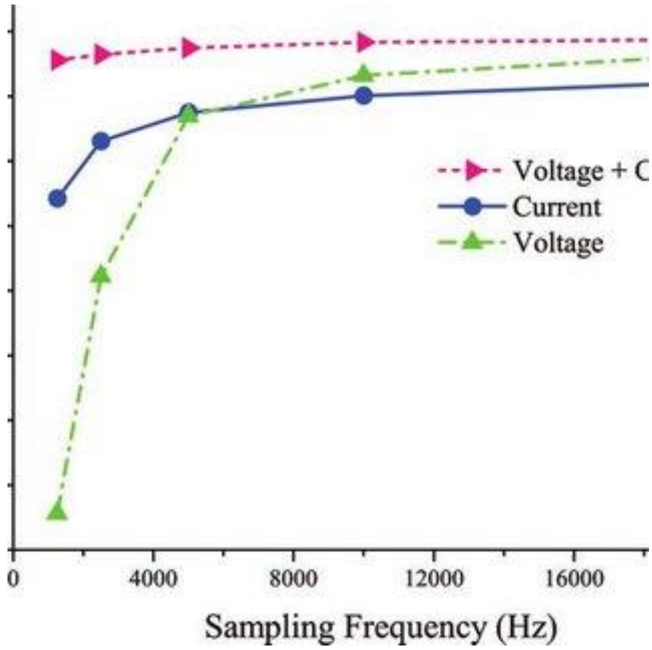


Fig. 3. Variation of accuracy with respect to frequency showing voltage current, only current and only voltage waveform

TABLE 4

Different effects	Class value
Short circuit distance(Km)	30,60,90,120,150,180,210,240
Short circuit Resistance(ohm)	0.05,6,18,21,32,42,48
Short circuit inception Angle(degree)	0,20,40,60,80,100,120,140,160,180,200
Pre – Short circuit Power Angle (degree)	15,30,45

TABLE 5

	Per unit voltage and current						
Case No.	Va	Vb	Vc	Ia	Ib	Ic	Types of fault
1	12	12	12	0.001	0.001	0.001	No fault
2	0	16	17	0.16	0.01	0.01	AG
3	17	0	16	0.01	0.16	0.01	BG
4	16	17	0	0.01	0.01	0.16	CG
5	0	0	16	0.3	0.2	0.01	ABG

Accuracy on Train Test

```
print(classification_report(y_train, classifier.predict(X_train)))
```

```
             precision    recall  f1-score   support

         -1       1.00      0.88      0.93         8
          0       0.94      1.00      0.97        16
          1       1.00      1.00      1.00        12

avg / total       0.97      0.97      0.97        36
```

So we got approximately 94% accuracy on the train set.

Accuracy on Test Set

```
from sklearn.metrics import classification_report
cr = classification_report(y_test, y_test_pred)
print(cr)
```

```
             precision    recall  f1-score   support

         -1       1.00      0.67      0.80         6
          0       0.71      1.00      0.83         5
          1       1.00      1.00      1.00         2

avg / total       0.89      0.85      0.84        13
```

So we got approximately 93% accuracy on the train set.

Voltage vs load_of_line

```
sns.jointplot(x = data['load_of_line'], y = data['voltage'], kind = 'reg', color= 'g')
plt.show()
```

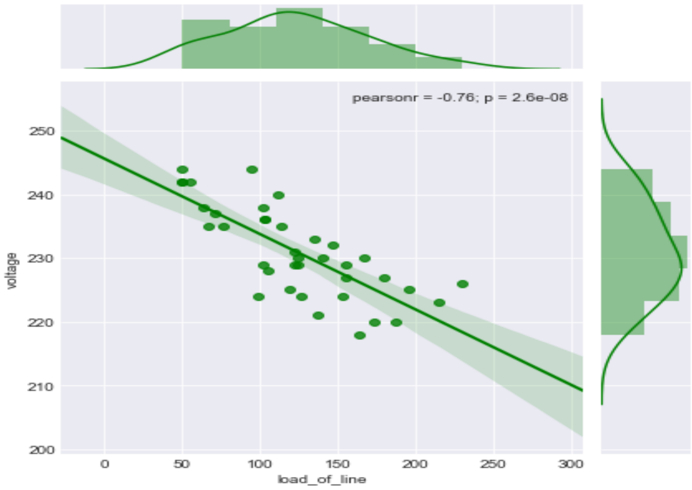


Table 6 Accuracy train test

Using Multinomial Logistic Regression

Accuracy on Train Test

```
print(classification_report(y_train, classifier.predict(X_train)))
```

```
             precision    recall  f1-score   support

         -1       0.88      1.00      0.93         7
          0       1.00      0.80      0.89        10
          1       0.92      1.00      0.96        11

avg / total       0.94      0.93      0.93        28
```

So we got approximately 94% accuracy on the train set.

Table 7 Accuracy test set

Accuracy on Test Set

```
from sklearn.metrics import classification_report
cr = classification_report(y_test, y_test_pred)
print(cr)
```

```
             precision    recall  f1-score   support

         -1       0.75      1.00      0.86         3
          0       1.00      0.86      0.92         7

avg / total       0.93      0.90      0.90        10
```

So we got approximately 93% accuracy on the train set.

Table 8 Fault variation with several effects

EFFECT	AG	BG	CG
Without fault	VA=12K IA=2.41	VB=12K IB=2.41	VC=12K IC=2.41
WITH FAULT	VA=0 IA=84.51	VB=15K IB=2.74	VC=16K IC=2.85
CAPACITOR	VA=0 IA=252.69	VB=48K IB=918.96	VC=51K IC=963.29
REACTOR	VA=0 IA=168.78	VB=3K IB=136.98	VC=3K IC=137.86
SVC	VA=0 IA=84.51	VB=15K IB=2.74	VC=16K IC=2.85
RESISTOR	VA=0 IA=141.88	VB=10K IB=63.73	VC=15K IC=91.69

Table- 9 Fault Classification Network Truth Table

Fault Situation	A	B	C	G
A-G	1	0	0	1
B-G	0	1	0	1
C-G	0	0	1	1
ABG	1	1	0	1

TABLE 10: Comparison of % accuracy

S.No.	Effect	Fuzzy Logic	ANN	KNN	Multinomial Logistic	Deep learning	NARX
1.	WITH FAULT	90.4	92.5	93.4	94	98	97.8
2.	CAPACITOR	89	91	92	95	98.5	98
3.	REACTOR	89	90	91	95.6	97.5	97
4.	SVC	86.5	88	89	97	98.9	98
5.	RESISTOR	87.5	89.5	94	94.5	98	97.5
6.	Fault inception angle	89.5	90.5	91	93.5	97.5	96
7.	Fault distance	89	90	92	92.8	97.8	96.5

IV. TEST NETWORK

Author simulate the results with the help of standard test network as shown in figure 1, it has two source and transmission line and fault at some distance. In the following subsections author described analysed network with their result in table 1-10.

4.1 Test Network and outcome studies

In this subsection author tried to describe the network studied and various tables as 1-10. Table-1 described Different effects used for simulation in Matlab Simulink and various class or types. Table-2 described General time of Short circuit diagnosis for different Short Circuit Types. Table-3 described Variation of accuracy for different types of short circuit in transmission line.

4.2 Python coding and its related outcomes

Table 6 described Accuracy train test Using Multinomial Logistic Regression, that shows various recall values and f- score. Table 7 described Accuracy test set and table 4 described the training set and test set classification of accuracy. As per table one can easily see the accuracy almost 94% on training and validation test.

V. SIMULATION RESULTS AND WAVEFORMS

Simulation of result is validated using Matlab/Simulink also validated by NARX, Python, Mathematical analysis, with the help of wave form and table one can easily see the results and waveform for final validation.

5.1 Fuzzy logic system

Author proposed a fuzzy logic to compare the results taking input as fault and then see current and voltage variation for different types. From figure 2 one can easily see the variation in phase current and nature by varying different parameters effect as fault impedance and distance etc.

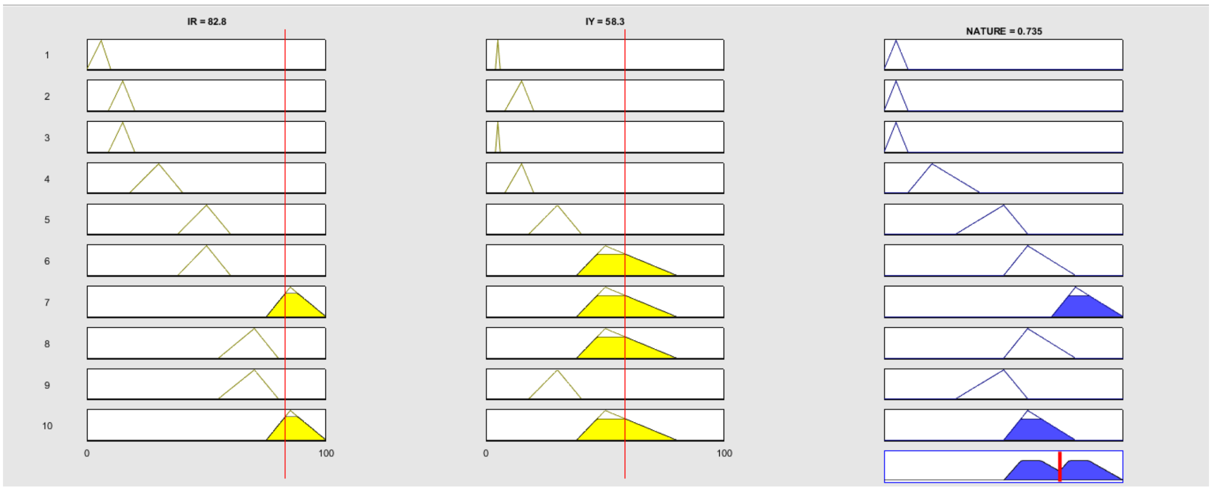


Fig.2 (a) Fuzzy membership function for one phase

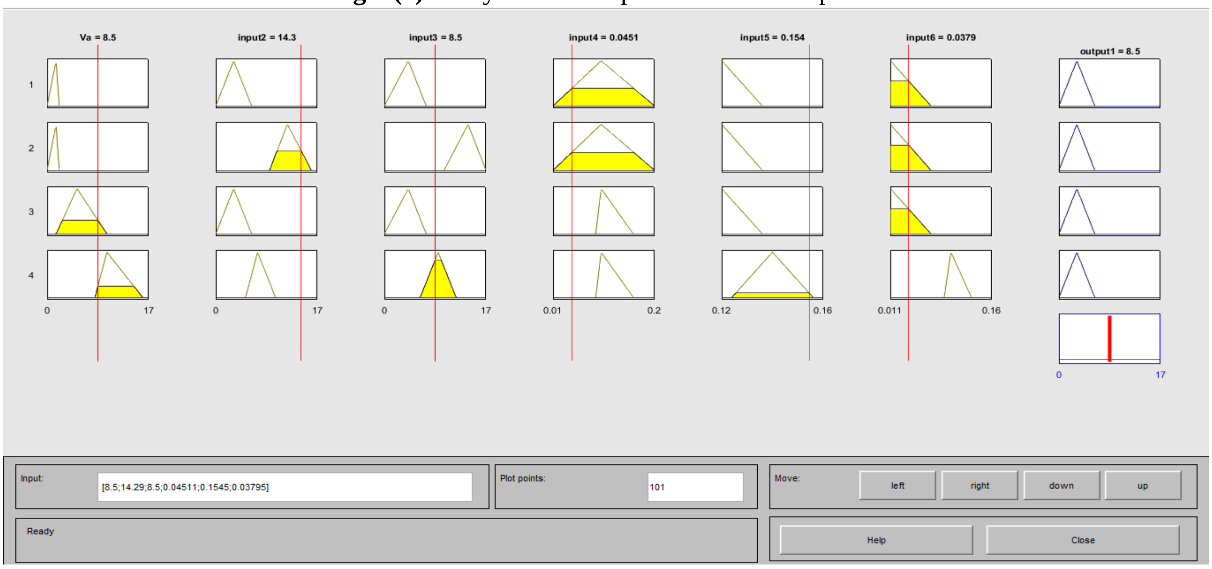


Fig.2(b) Fuzzy Membership input output for three phase

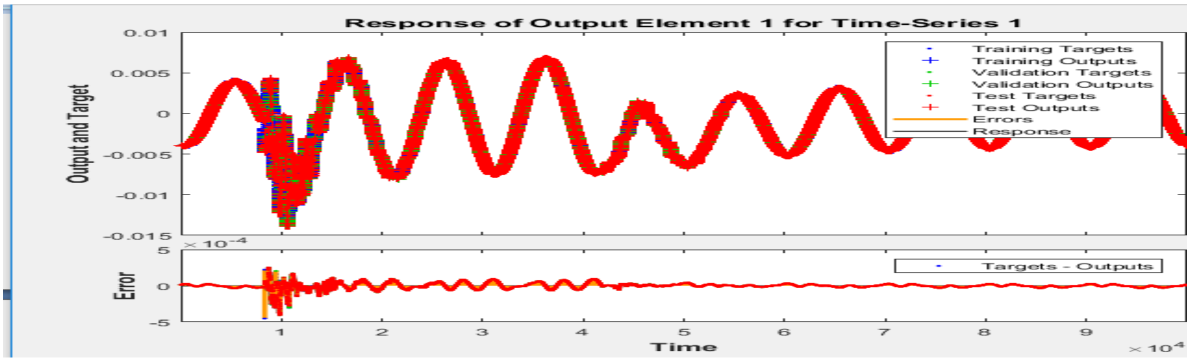


Fig.c.

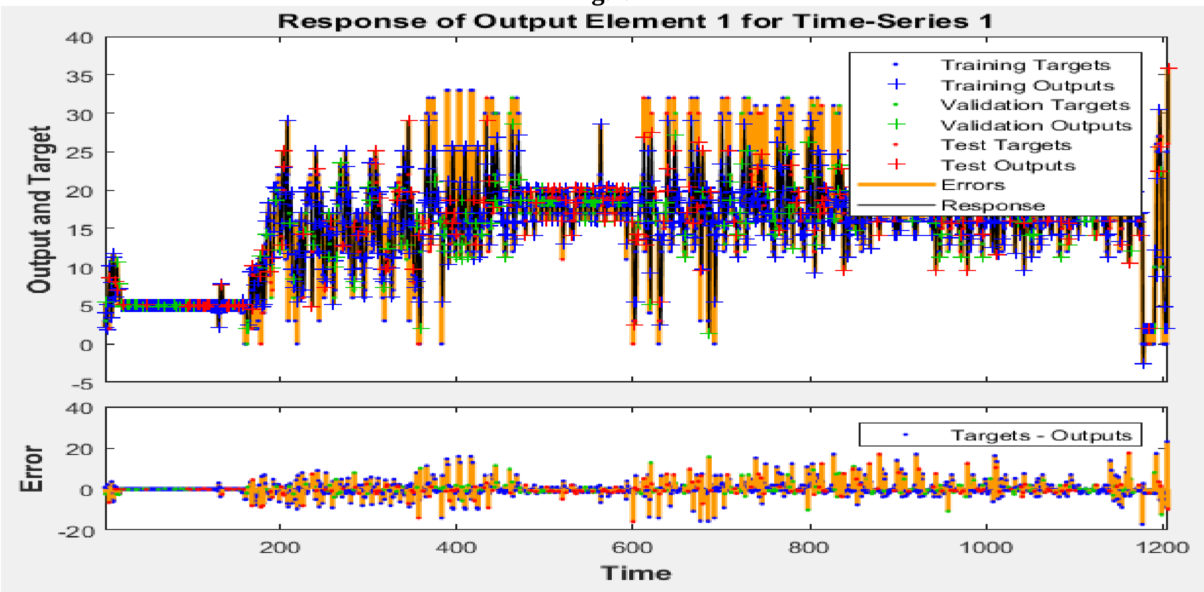
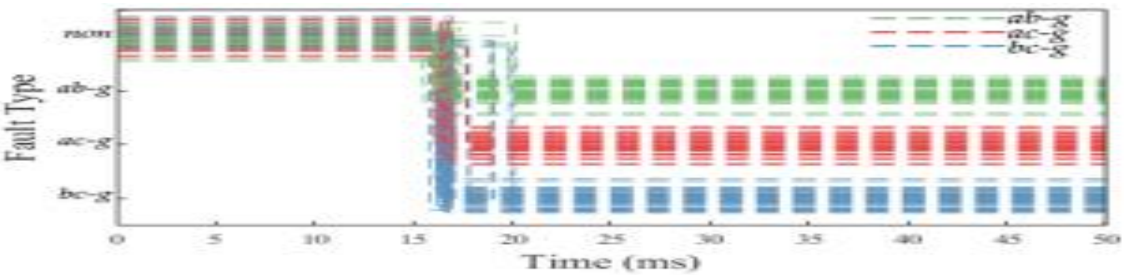


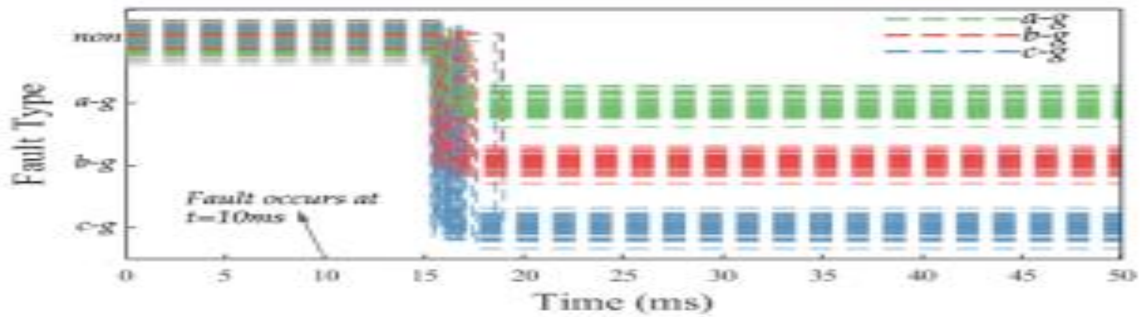
Fig.2 c, d. Training testing and validation and error with respect to out put

5.2 Fuzzy training and validation of testing as well as error analysis

This sub section validates the training and testing of results as well error calculation so that one can design suitable protective devices. Fig 2 c-d described the waveform of training and testing as well as error waveform in faulty region.



(a)



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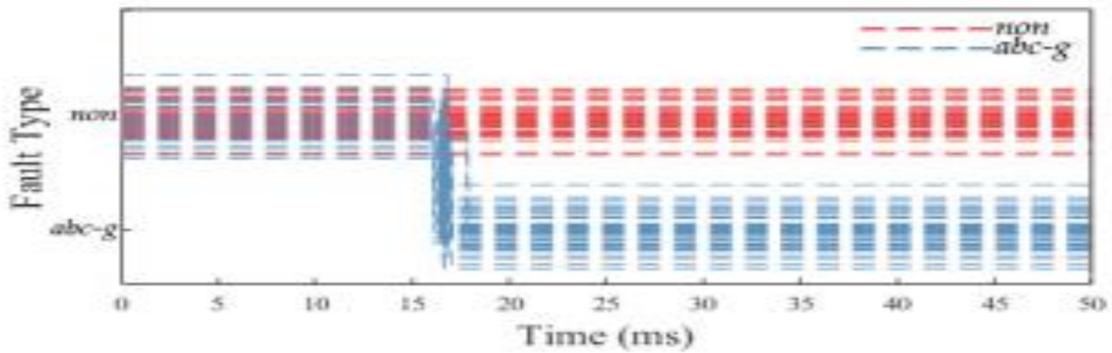
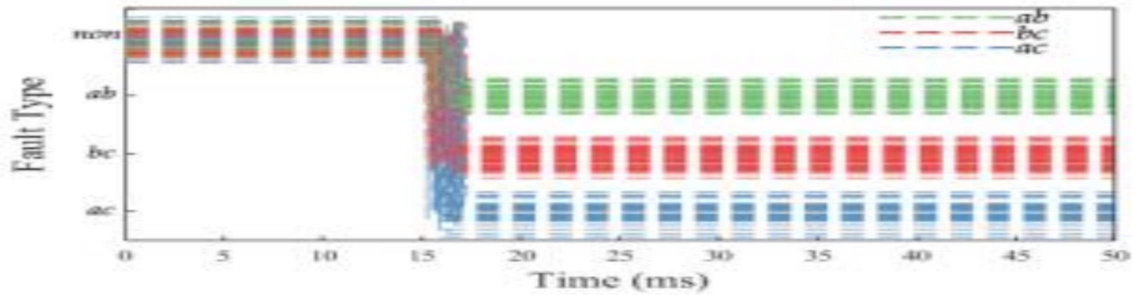


(c)



(d)

Fig. 3. a-d Shows Variation of short circuit with respect to various time and their nature

VI. RESULTS AND DISCUSSION

From the fig 2 and table 1-10 author described the results and also in table -10 a comparative analysis of results has shown, accuracy and other effects have shown to validate the final conclusion. From table 10, NARX shows best accuracy in different effects like fault inception angle, fault resistance etc.

6.1 Mathematical result validation

First of all author proposed a calculation methods and algorithms for analysis of fault current and voltage and by that diagnose the types and nature of fault. With the equation and algorithms 1-20 authors described traditional technique and after that suggested some soft computing techniques like ANN, NARX, Python etc in coming subsections.

6.2 Soft computing techniques for results validation

In this subsection author tried to explain the results obtained using soft computing technique like ann,fuzzy logic python etc, Table 10 shows a comparative table to show the results obtained by soft computing techniques like K nearest Neighor, multinomial, deep learning, decision tree ann, and many more for accuracy in linear and non linear regression analysis. From the table it can be easily check that NARX, Deep Learning and Multinomial and KNN show best accuracy in terms of regression analysis approximately 97%.

VII. CONCLUSION

From above comparisons and for various effects deep learning and Narx are the best for fault diagnosis in terms of accuracy and so with this design of suitable protective devices for better operation for system as well as consumers. With the fast development in AI and others soft computing techniques one can design best protective device for reliable operation.

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AUTHORS BIOGRAPHY

Gyanesh Singh Assistant professor Dewan V S Institute of Engineering &Techonlogy, completed BE degree in Electrical Engineering in 2002 from AKGEC GZB, Master in Electrical Engineering from NITTTR, Chandigarh in 2011, Persuing Phd in Electrical Engineering from Jamia Millia Islamia Central University new delhi. Research area in power system fault, protection of transmission lines multiterminal. More than 7 papers in National and International Journal, International conferences and national conferences. 17 years of teaching experience in the field of electrical engineering, Teaching undergraduate students in subject like Electrical engineering, Measurement and Instrumentation, Network analysis and synthesis, Electrical Machinery, Control System, Power electronics, Power system ,Electric Drives etc.

Prof. A. Q. Ansari is an astute performer with proven expertise in devising and effectuating programmes and policies aimed at ensuring smooth operations and execution of academic, research and administration tasks within the institute premises, possesses potential for distinctive achievement through strategy, innovation, implementation and control. He is a stickler for quality, team builder to the core and a natural motivator with perseverance and integrity. He commands excellent communication skills that have been honed through interacting with people at national and international levels. He is popular among his students for excellent content delivery, clarity of presentation, and extraordinary punctuality and discipline.

Dr. Md. Abul Kalam is Associate Prof. with the Electrical Engg. Deptt. JSSATE Noida(U.P). He has received his BE Degree in Electrical Engg. from Jamia Millia Islamia, New Delhi in 1999 and M.Tech. From UPTU, Lucknow in 2007. He received Ph.D degree in 2014 in Power system. from Jamia Millia Islamia, New Delhi. His area of Interest are Power System, Intelligent Techniques based Protection of Transmission System and Energy.