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COMPARISON OF PHASOR AND WAVELET ANALYSIS BASED FAULT CLASSIFICATION ALGORITHM

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ABSTRACT

Electricity has huge impact on country's economy, unwanted outages(faults) results loss of economy .To prevent loss an accurate techniques are need to restore system to normal condition. it is necessary to differentiate the algorithms on efficiency in classifying faults, so this study confer comparison of two techniques for classifying faults in transmission lines. One is build on current phasors and another is works on wavelet analysis. Wavelet analysis method uses swt(standard wavelet transform) that has an advantage over discrete wavelet transform to process current signals. while phasor based method which develops to overcome the complications faced by older methods using phasors to classify. current phasor method measures phase angle around sequence component currents. The two algorithms are studied with both matlab and simulink model at various fault location, inception and resistance for multiple faults. Studies shows that wavelet analysis method has a head over the phasor based method.

KEYWORDS*: Electrical Transmission System, Fault Classification, Phasor Analysis, Wavelet Analysis*

Article History

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INTRODUCTION

The main objective of protection is to detach fault section from the normal section of the system to prevent damage due to the fault, transmission line plays a key role in electrical system and its protection is prime for this purpose most often used relays are distance relays. One of them is impedance relay there are different new algorithms for calculating impedance in transmission line [1]. Accurate fault classification is necessary for tripping faulted phase in [2] shows the use of polarizing voltage and fault type selection by torque comparison. Most of fault classification techniques fails in high fault resistance cases, so in [3] a classification is done by using reactive power along with its symmetrical components, and it also overcome difficulty in setting threshold by using constant thresholds (1&0). All the fault classification algorithms so far developed based on steady state system behaviour, but in [4] they use digital fault recorders (DFR) to assess both normal and pq disturbance data, however because of immense data at DFR results failure of DWT & ANN technique for fault detection, clearing & classification at some cases. fault classification and detection is achieved by decision tree (DT) [5,6] where a differential feature of power & differential phase angle of superimposed currents are used to generate thresholds by DT results in accurate classification at different fault situations.

Fault classification algorithms mostly uses high frequency or low frequency components results in misclassification at low and high impedance faults[LIF,HIF], so in[7] author encompass high and low frequency components to differentiate LIF &HIF. To achieve fault classification, detection within a quarter cycle a wavelet alienation approach used in [8], and also fault is located precisely by ANN with its input. Another application of wavelet transform which uses maximum wavelet singular value for classifying faults through dwt [9]where mwsv is attained by sliding and sequential updating of data window. In order to achieve better performance and accuracy in fault classification needs synchronizing of sampling signals at two terminals which is achieved by global positioning satellite, along with wavelet transforms, ANN was used for classification and location of faults [10]. most of the intelligence techniques(SVM,ANN,FUZZY) integrate with wavelet transforms for extraction of transient signal features results in greater precision in classification of faults [11], [12]. In [13] proposed a deterministic wavelet method using discrete wavelet transmission for fault classification. Fault recorders and monitoring devices plays a key role in evaluating power system performances, so an accurate fault classification technique should required to increase the capability of system even in typical fault conditions, [14] proposed an algorithm of sequence components current phasors for fault classification. As high frequency transient information contains a key information, which helps for classifying different faults, in [15] it come up with a procedure of power spectral density in time &frequency domain for fault detection and classification.

This paper presents a review of techniques in [14], [15] with an interconnected power system and results of two techniques are compared to know the better technique for fault classification type which resists at diverse fault condition.

CURRENT PHASOR BASED METHOD

Mostly fault classification algorithms designed to perform categorization of faults when fault happens in transmission system .we have to develop an algorithm that it either work for a specific three phase transmission line or for fault recorder. Fault recorder and protective relay have distinct range of protection. Fault classification algorithms like under-impedance, torque, over-current techniques are affected by fault situations such a fault resistance & incidence angle. The phasor based algorithm explained in this thesis is for fault recorder whose range of protection is infinite, so the algorithm engage for this work should resist all abnormal conditions like power systems operating condition, fault conditions etc.,

The operating procedure of current phasor method designed to overcome the problems faced by other phasor (under-impedance, torque & over-current) techniques. The following are the requirements for fault classification by current phasor methods.

- Current samples of three phase transmission line.
- Post-fault phase angles of positive and negative sequence components of each phase.
- Zero & negative sequence relative magnitudes of current phasors before as well as after the occurrence of fault.
- Uses current zero sequence to find involvement of ground in fault.
- Zero & negative sequence components are normalized with positive sequence current component to sort out the trouble in occurrence of i_0 when there is no fault.

Formulas used in Current Phasor Based Algorithm

$$Rm_{0p}=\frac{i_{0p}}{i_{1p}} \quad (1)$$

$$Rm_{2p}=\frac{i_{2p}}{i_{1p}} \quad (2)$$

$$Rm_{0f}=\frac{i_{0f}}{i_{1f}} \quad (3)$$

$$Rm_{2f}=\frac{i_{2f}}{i_{1f}} \quad (4)$$

$$A=[angle(ia_{1f})-angle(ia_{2f})] \quad (5)$$

$$B=[angle(ib_{1f})-angle(ib_{2f})] \quad (6)$$

$$C=[angle(ic_{1f})-angle(ic_{2f})] \quad (7)$$

Where

Rm_{0p}, Rm_{2p}, Rm_{0f}, Rm_{2f} are the negative & zero relative magnitudes of currents before and after the faults.

i_{0p}, i_{1p}, i_{2p}, i_{0f}, i_{1f}, i_{2f} are the zero, positive & negative sequence components of currents at pre & post faults.

ia_{0f}, ia_{1f}, ia_{2f} are the phase a sequence components, sequence components for b & c are ib_{0f}, ib_{1f}, ib_{2f} & ic_{0f},ic_{1f},ic_{2f} appropriately.

A, B, C represents phase angle difference of sequence components for each phase.

Fault Classification by Current Phasor Method

The algorithm starts with sampling of three phase currents originating from source end with a sampling frequency of 0.5kHz.it uses phase angle & relative magnitude of current sequence components to develop logic for classifying faults. step by step procedure of fault classification algorithm is listed below.

- Import three phase current sampled signals (ia, ib & ic) from simulink to matlab.
- Compute pre-fault current sequence components & relative magnitude(i_{0p}, i_{1p}, i_{2p}, Rm_{0p}, Rm_{2p}).
- Compute post-fault current sequence components & relative magnitude(i_{0f}, i_{1f}, i_{2f}, Rm_{0f}, Rm_{2f}).
- If $Rm_{0f} > Rm_{0p}$ then it is single phase to ground fault,go to step 8.
- If $Rm_{2f} > Rm_{2p}$ & $Rm_{0f} \leq Rm_{0p}$ then it is double line fault, go to step 9.
- If $Rm_{0f} > Rm_{0p}$ & $Rm_{2f} > Rm_{2p}$ then it is double line to ground fault, go to step 10.
- If the conditions from step 4-6 was not satisfied then go to step 11
- Compute A, B, C
  - if $A=0^{\circ}$ & $B=C=120^{\circ}$,then it is a-g fault.
  - if $B=0^{\circ}$ & $A=C=120^{\circ}$,then it is b-g fault.

  - if C=0° & A=B=120°,then it is c-g fault.
- Compute A, B, C
  - if A=B=60° & C=180°,then it is a-b fault.
  - if B=C=60° & A=180°,then it is b-c fault.
  - if A=C=60° & B=180°,then it is c-a fault.
- Compute A, B, C
  - if A=B=60° & C=180°,then it is a-b-g fault.
  - if B=C=60° & A=180°,then it is b-c-g fault.
  - if A=C=60° & B=180°,then it is c-a-g fault.
- A=B=C=0°, then it is three phase or three phase to ground fault.

As the algorithm works for negligible fault resistance the angles in step 8-11 where affected. so those are modified as follows for detecting fault in case of non-zero faults.

0° as 0°-20°,60° as 30°-90°,120° as 100°-140°,180° as ≥150°

WAVELET TRANSFORM BASED METHOD

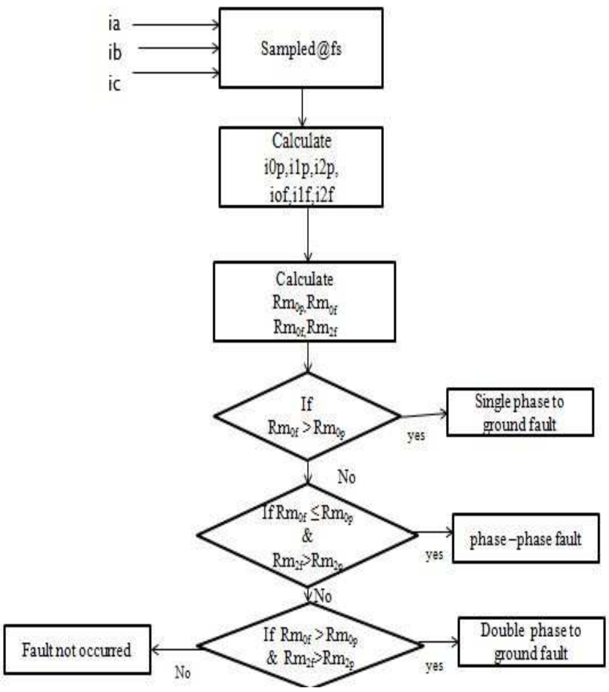

Figure 1: Block Diagram of Classification Algorithm.

Wavelet is the waveform whose average value is zero. Wavelet analysis is the splitting out of a signal into scaled & shifted form of original wavelet. Signals in fault condition experience sharp change in its waveform so these types of waveforms can be better analysed by using wavelets. Transient information is used to diagnosis fault. Wavelet transform is one of the tool for extracting features of transient state in time & frequency domains. This information is key for identification & classification of faults.

Stationary Wavelet Transform (SWT)

SWT has an edge over the dwt by having a feature of translation invariance. It is also called undecimated wavelet transform because of neglecting decimation process after convolution. It uses up sampling for producing coefficients length same as input length. It generally applicable to a signal whose length is a divisible of 2^j .mathematical formulation of stationary wavelet transform is as follows

$$swt_{j,k} = \int g(t)\psi_{j,k}(t)dt \tag{8}$$

Where j is the maximum decomposition level of a signal g(n),ψ is the mother wavelet ,k is the controlling parameter of wavelet location. In swt we get equal length coefficients at same level because k is independent of j.decomposition in SWT is as follows.

Stationary Wavelet Decomposition

Using swt the input current waveforms of source end is decomposed into approximate and detailed coefficients. Decomposition process draw out the transient features in time and frequency domain. Wavelet coefficients are obtained by up sampling the signal with a factor of two using low &high pass filters .high pass & low pass filters are obtain from the mother wavelet & related scaling function respectively. Approximation coefficient evolve from the first level filter is given as input to second level filter for continuing decomposition process up to maximum level and it is a depend on the length of input signal. Selecting the best mother wavelet gives accurate results during fault detection. Here in the algorithm 'db4' mother wavelet is used with a maximum decomposition level of 4.

Fault Detection & Classification by Wavelet Transform Method

The technique begins with sampling of three phase current signals with a sampling frequency (f_s) of 8kHz.transient information obtain from these signals are analysed using swt. A current signal of full cycle (160 samples)processed using swt with a sliding window of 1 sample and scaled to a maximum decomposition level (4).scaling of input current signals gives approximate and detailed coefficients (cA, cB).wavelet coefficients(cA & cB) of a each phase is stored in a matrix $Wm_{(L+1,N).}$ Thus this matrix contain transient information in time & frequency. Matrix is examine by wavelet covariance matrix cv^t & as follows

$$cv^t_{(N,N)} = Wm^TW\ m \tag{9}$$

$$cv^f_{(L+1,L+1)} = WmWm^T \tag{10}$$

Power spectral density in time& frequency domain obtained by the diagonal elements of (9) & (10) respectively as follows

$$PSD_t=diag(cv^t_{(N,N)}) \tag{11}$$

$$PSD_f=diag(cv^f_{(L+1,L+1)}) \tag{12}$$

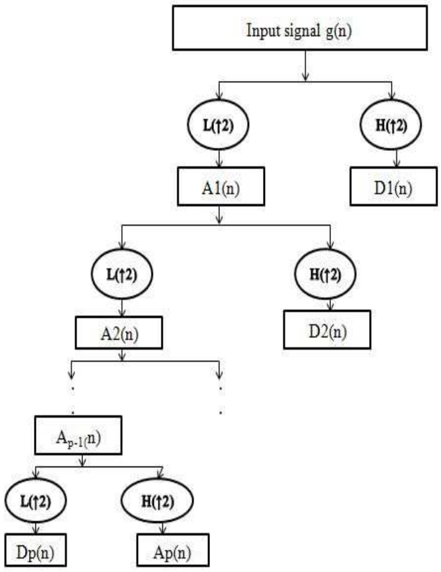

Figure 2: Decomposition Process.

Condition for checking fault occurrence in the system is obtained by normalising psd equations in (11) & (12) as below

N_t=(|| PSD_t ||)/(sqrt(x)) (13)

N_f=(|| PSD_f ||)/(sqrt(x)) (14)

Where x=|| PSD_t $||^2$+|| PSD_f $||^2$

The threshold Nt takes value lesser than 0.1 when system is in normal condition ,if Nt value greater than 0.1 at the time of fault in system. For ground fault threshold value greater than 0.2-0.3.The threshold value is fixed with extensive simulation studies. Classifying faults is done by equations in figure.4

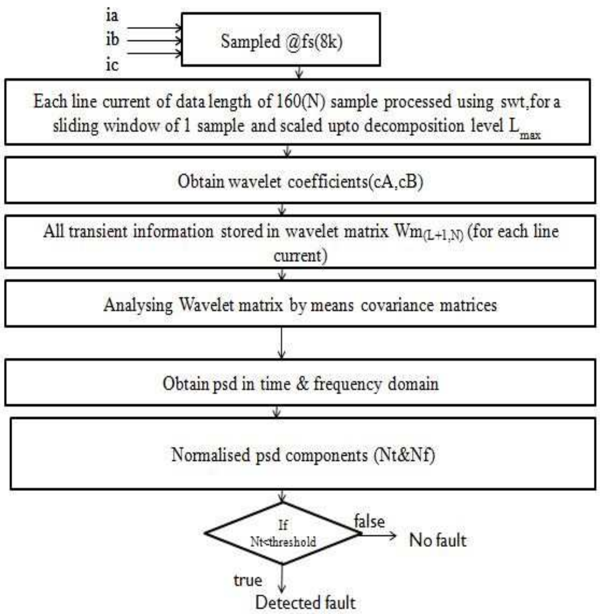

Figure 3: Flow Chart for Fault Detection.

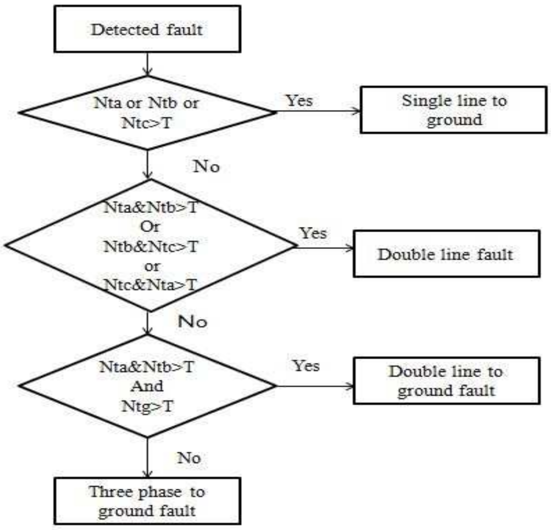

Figure 4: Flow Chart for Fault Classification.

TRANSMISSION LINE MODELLING IN SIMULINK

To implement fault classification algorithm matlab software is used, and the data required for performing is yield from simulink where the power system is simulated. A distributed transmission line model with of length 200 km powered by two three phase source at sending & receiving end of a line. Line is partitioned into two equal section and fault is created in between using three phase fault block. The parameters of simulated system listed in Table.1 below. Where $Z_{1L,}Z_{0L,}C_{1L},C_{0L}$ are the transmission line positive & zero sequence impedance and capacitance respectively. The current phasor method & wavelet method requires three phase current phasors & current sampled signals which were imported from corresponding subsystem block in simulink model in figure.5

Table 1: Parameters of Simulated System

Parameters	Value
Frequency (Hz)	50
Voltage Vs (KV)	400
Voltage Vr (KV)	400
Phase angle of sending end (degrees)	0
Phase angle of receiving end(degrees)	10
Transmission line length(km)	200
Z_{1L}(ohm/km)	0.02+j0.295
Z_{0L}(ohm/km)	0.188+j1.0995
C_{1L}(nF/km)	12
C_{0L}(nF/km)	8.3

SIMULATION RESULTS AND COMPARISON OF TWO TECHNIQUES

To test the performance of the current phasor algorithm the data generated in simulink is imported into matlab. The outcome of the algorithm is shown in Table.2, where the interconnected system is tested with changing fault type, fault resistance to see its consequence on the algorithm. Following results are taken at fault inception of 20ms ,at a distance of 100km & with fault resistance ranging from (10-100) ohms. Analysis reveals that the current phasor method classify the faults exactly only at some fault resistance ,it fails to classify if the line distance between two sections was unequal. Double phase fault (a-b) at R_f of 40 ohms with line length of 100km classify exactly but fails if length changes to 50km.

Table 2: Results of Current Phasor Algorithm

Sr. No.	Actual Fault Type	Fault Resistance (R_f) in ohms	Current Phasor Method
1	a-g	10	a-g
2	b-g	20	b-g
3	c-g	30	c-g
4	a-b	40	a-b
5	b-c	60	b-c
6	c-a	100	c-a-g(misclassified)
7	a-b-g	50	a-b-g
8	b-c-g	70	b-c-g
9	c-a-g	80	c-a-g
10	a-b-c	90	a-b-c
11	a-b	40(at unequal line length)	a-b-g

Table 3: Results of Wavelet Transform Method

Fault Type	Fault Resistance(R_f)in ohms	Fault Inception Angle ϕ_i in Degrees (°)	Wavelet Transform Method
a-g	10	0	a-g
b-g	20	15	b-g
c-g	30	30	c-g
a-b	40	45	a-b
b-c	60	60	b-c
c-a	100	75	c-a
a-b-g	50	90	a-b-g
b-c-g	70	105	b-c-g
c-a-g	80	120	c-a-g
a-b-c	90	135	a-b-c
a-b	40	45	a-b

Table.3.shows the results of wavelet transform method, by testing the interconnected system at ten fault types, fault resistance (10-100)ohms &fault inception angles(0°-180°) with varying different.

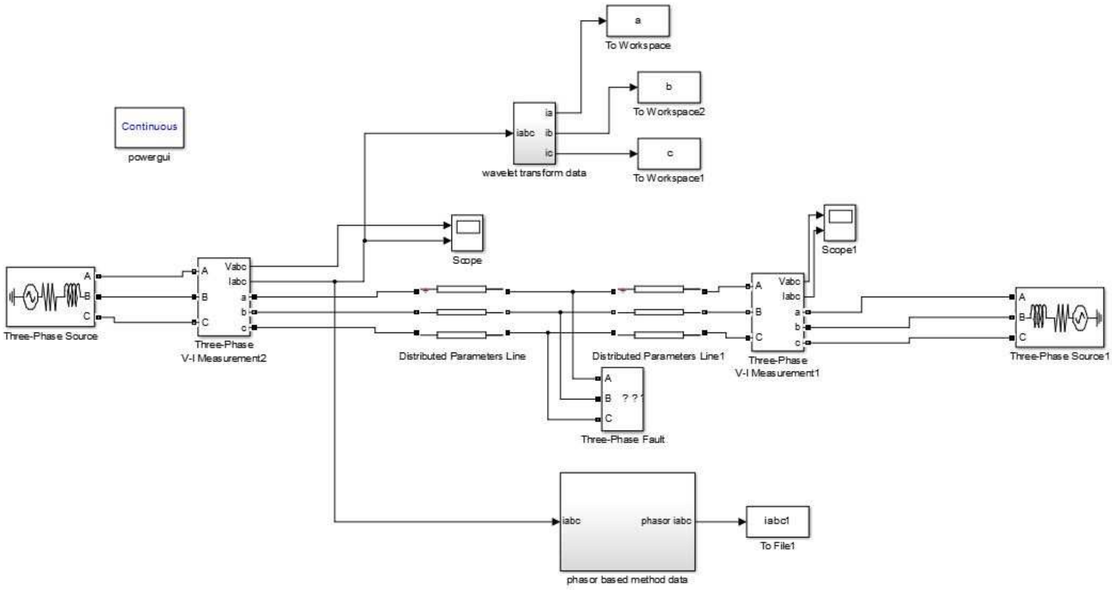

Figure 5: Simulink Model of a Power System.

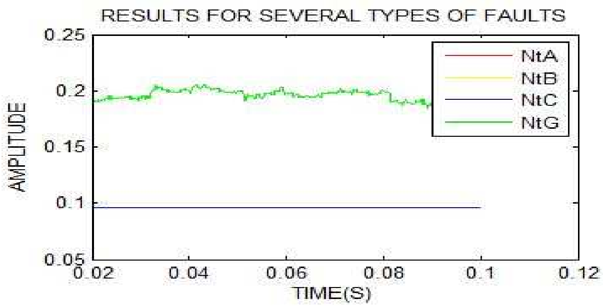

Figure 6(a): System with no Fault.

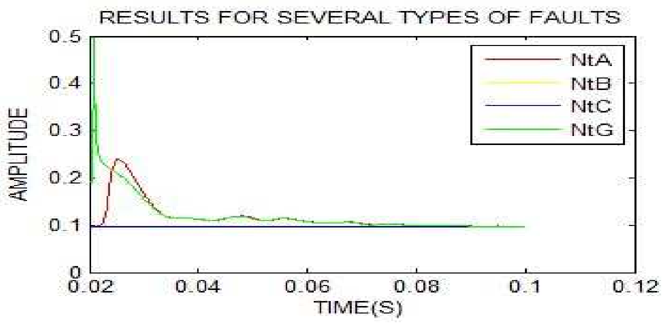

Figure 6(b): 1F-g with Negligible R_f.

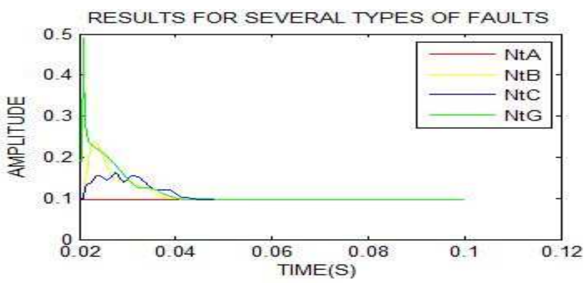

Figure 6(c): 2F-g Fault with R_f =20.

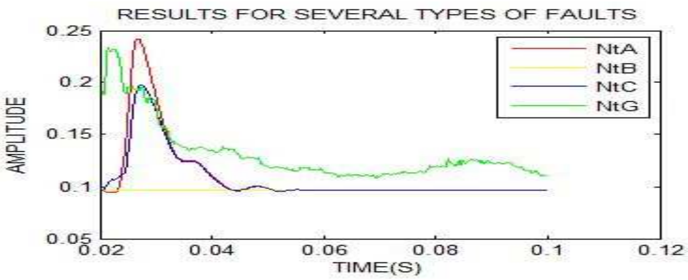

Figure 6(c): 2F Fault with R_f =10.

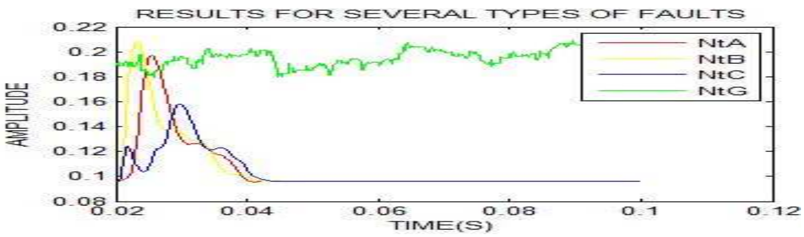

Figure: 6(d): 3F Fault with R_f =50.

Different section length of transmission lines. Results concluded that the wavelet based algorithm classify the fault precisely at various fault conditions. The plots shown in figure 5.a is the threshold limits of the three phases & ground when system is under normal state. Below plots shows the different faults at various fault resistances.

Results from two algorithm shown that the wavelet transform method classify the faults precise than current phasor method at varying fault conditions. The technique used in protection system in practical should have pass through all the possible cases effectively, in this note wavelet method is efficient than former algorithm. Table.4 presents the outline of comparison techniques.

Table 4: Comparison of Two Techniques

Current Phasor Method	Wavelet Transform Method
Requires three phase current samples	Requires three phase current samples
Analysing Steady state data	Analysing Transient state data
Fourier transform is used to calculate current phasor	Swt is used to for feature extraction
Classification based on phase angle between phases	Classification based on threshold limit
Can be used for fault recorder	Used for specific transmission line protection
Accurate only for some fault condition	Precisely classified at diverse fault conditions($R_{f,}$, ϕ_i)
Generalised approach	Performance depends on type of mother wavelet used
Simple algorithm	Little complex algorithm

CONCLUSIONS

Techniques which classify faults based on transient &steady state data is presented. Two methods are studied in simulation and matlab software by using Fourier & wavelet transform for extracting the features required for fault diagnosis. Studies from the simulation conclude that the wavelet transform method accurately classify at all fault conditions. comparison of these techniques also listed by examine the techniques .even the phasor method is used in fault recorder but there is a chance of misclassification for different fault resistance and inception angles. Wide range of future extension is possible by using wavelet transform with artificial intelligence techniques.

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