Fault detection and classification during power swing using HHT and SVM

[1]Padmini Sharma, [2]R.N.Patel
[1]Associate Professor, [2]Professor [1] EEE
[1] C.S.I.T Durg, India

Abstract : To ensure reliability of the power system distance relay should be blocked during power swing. However, if any type of fault occurs during a power swing condition, it should be identify by the relay and generate the trip command to clear the fault as soon as possible. . Available fault detection technique may fail to response during power swing condition because already large variation is observed in voltage and current signal before the fault. Since the nature of power swing and three phase fault are symmetrical, it is more challenging to detect three phase fault during power swing. In this paper, a Hilbert Hanga Transform and support vector machine based fault detection and fault classification technique during power swing condition is proposed.HHT is used for feature extraction of current signal in various condition and SVM is used for classification purpose .The proposed method is tested for various fault and swing condition in WSCC nine-bus system simulated in PSCAD/EMTDC.

***IndexTerms* – HHT,EMD,SVM,SRM,ANN,PSCAD**

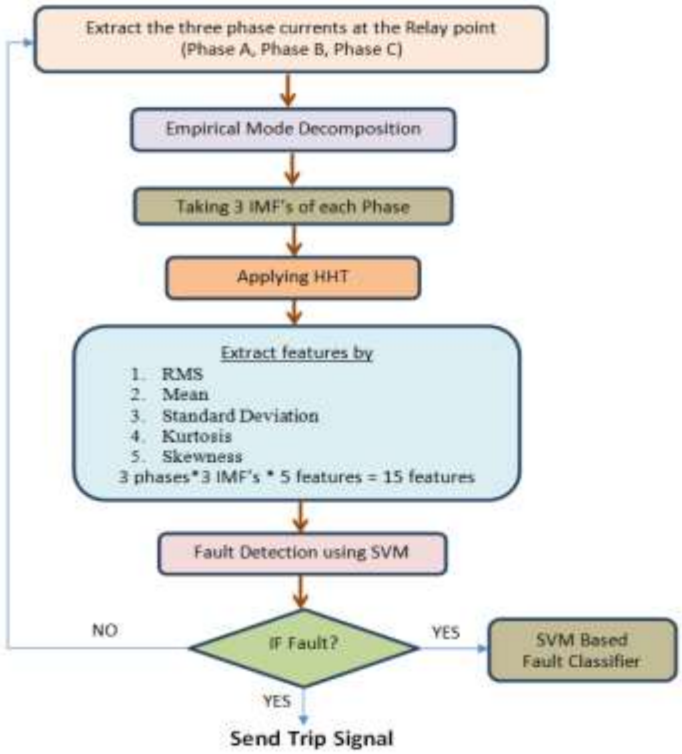
I. INTRODUCTION

Power transmission, is heart of whole power system network. The task performed by transmission line is very critical that why various protective devices are connected with line for its safe and reliable operations. The performance of relay play very important role to maintain the system stability in power system by sensing abnormal condition and removing faulty part from healthy portion of the system . Relay operation are more challenging when it is used for protection of transmission line because failure rate of it much higher as compared to other power system network. Third generation numerical relay now a day is very popular as compared to other conventional relay for transmission line protection. It is based on numerical devices such as microprocessors, microcontroller, and digital signal processors. Distance relays are more preferable for transmission line protection as compare to over current relay .Performance of distance relay affected in some crucial condition such as power swing, load encroachment, voltage instability .Power system faults, line switching, generator disconnection, and the loss or application of large blocks of load result in sudden changes in electrical power whereas mechanical power input to the generators remaining constant. Such system disturbances cause oscillations in machine rotor angles and can result in severe power flow swings. Such stress condition affect the performance of distance relay and it generate the trip command in non faulty condition also because during such type of disturbance impedance seen by the relay lies within its operation zone. So Mal-operation of distance relay under stress condition directly disturbs the performance of protective scheme. This may contribute to cascade tripping of transmission lines and consequent blackout. Such relay malfunction is avoided by incorporating power swing blocking (PSB) function in relay. But Blackout in the system arise question mark in the performance of PSB block. Different algorithms were provided by the researcher for improving the performance of numerical relay during power swing condition. But it is still challenging task to discriminate the swing from fault and set the block command and identification of fault during power swing condition and generate trip command. Power swing detection method is categories into three part based upon previous result. For propose research work research paper related to intelligent based technique is followed. Different feature of current signal, decompose by Wavelet Transform is used for power swing and fault discrimination purpose[1,2,3]. Fault detection during power swing is also challenging task. Discrete wavelet transform is used for detecting fault during power swing.[4]Wavelets and artificial neural networks (ANN) are introduced for detecting fault during power swing condition [5]. In these papers wavelets are used for extracting features from power system data with either ANN or fuzzy logic for classification. SVM classifier is introduced as classifier for power system faults in [6]. Hybrid combination is the latest trends for improving overall efficiency of the system .Wavelet in combination with SVM are used for detecting the fault during power swing condition [7- 8].Instead of wavelets, HHT is being used newly for feature extraction stage .For detecting power quality disturbance HHT with neural network is used in [9-11].Different parameters are consider by using HHT for various application presented in [12-14] .A combined application of HHT and SVM for feature extraction and classification between the different type of fault is listed in [15] three phase fault and power swing .In this paper classification is done between the different type of fault and power swing condition. Swing may be fast or slow and fault may be any type symmetrical as well as asymmetrical. Current waveform are obtained from the model simulated in PSCAD software ,under faulty and power swing condition .Faulty signal are obtain by changing the fault resistance ,location and load angel. Feature extortion using HHT and for training and testing SVM in MATLAB environment is used.

2 Methodology-

Methodology for proposed work is divided into two main steps- feature extraction by using (HHT) and unique selection for particular purpose and in second step selected feature is used for classification using SVM A. Once the current waveforms for various conditions are obtained, they are decomposed into mono component signals by using Empirical mode decomposition (EMD).Then by using Hilbert Huang Transform (HHT) is used for instantaneous amplitude, phase and frequency measurements. The complete procedure for applying EMD and

HHT is explained in further sections. Excellent features are consider for each case which is used for training and testing SVM. Fundamentals of HHT and SVM are provided in sections below.



1

Figure-(1) Algorithm for fault detection technique during power swing

2.1 Empirical Mode Decomposition -

Empirical mode decomposition method is used for analysis non linear or non stationary signal. This method adaptively decomposed complicated and multi scale signal into a sum of finite number of zero mean oscillating components called as Intrinsic Mode Functions (IMF)[9] . It breaking down the signal in time domain region, with assumption that any signal or data consists of many intrinsic mode oscillations [11].Each IMF having the same length as the original and shows fixed characteristic oscillation on a different time scale it means they all having well defined instantaneous frequency. It filters out signal which form a almost orthogonal basis for the original signal. Completeness is based on the method of the EMD; the way it is decomposed implies completeness. Intrinsic Mode Functions (IMFs), are therefore enough to illustrate the signal, even though they are not necessarily orthogonal. Other conventional filter are based on the frequency domain but EMD filtering process is based on local characteristic time scale .So no need to set the different parameter humanly like center frequency and bandwidth and also no need to set decomposition layer .

Each IMF represents a simple oscillation of a given signal, it should be satisfy following two criterion. (1)The

IMF of a signal is consider as an oscillating wave has only equal number of maximum value and zero crossing or may be differ by one only. (2) At any point, envelopes mean values are zero defined by the local maxima and the local minima. Out of nth IMFs, fast oscillation modes of parent signal is captures by the first lower order IMFs while the last IMFs produced are the higher order IMFs which represent the slow oscillation modes of signal . EMD follow sifting process method for converting non stationary and nonlinear signal into symmetrical component and mono component. For a taken signal first of all EMD defines the local minima and local maxima and then for finding upper and lower envelope of the signal, cubic spline interpolation method is applied .After that with the help of upper and lower envelope local mean of the signal is calculated .Now calculation is performed for finding difference between signal and local mean, if the difference value satisfy the IMF criterion, which is mention above than it is accepted as an IMF. Now repetitively subtract the difference value from signal and repeat it again and again till the resultant residual satisfies the criterion of monotonic function.

2.2 Hilbert Hunga Transform-

If , f(t) is actual non stationary signal than Hilbert transform of the actual signal is given by H[f(t)] by following equation(1) .

....(1)

And the envelope of the analytical signal E(t) is given by:

....................................(2)

For analysis of mono-component IMFs of the EMD function ,if HT is applied then it is consider or called Hilbert Hunga Transform. The HHT represents the signal in the time-frequency domain by combining the empirical mode decomposition (EMD) with the Hilbert transform. Hilbert Hunga Transform is the combination of two stage process. In first stage empirical mode decomposition method is apply for decomposition the signal into intrinsic mode function (IMF) and in second stage Hilbert spectral analysis (HAS) method is apply to IMF for obtaining instantaneous frequency data. Length of each IMFs is same as the parents and it is decompose in the time domain region, HHT conserve the characteristics of the varying frequency. This is very big and important benefit of HHT, because in real-world signal usually has multiple causes happening in different time intervals. The HHT give a new approach for analysis non stationary and nonlinear signal in time domain. It is used for calculating instantaneous frequency ,instantaneous phase and instantaneous amplitude of each IMFs ,generated by EMD method by using Hilbert spectral method[13].Hilbert transform of real value time domain signal is the another real value time domain signal, such that Z(t) =F(t) +E(t) is a analytical signal. With the help of Z(t) we can define the magnitude and phase function of consider signal.

2.3 SUPPORT VECTOR MACHINE-

The classification problem can be restricted to consideration of the two-class problem without loss of generality. In this problem the goal is to separate the two classes by a function which is induced from available examples. Support vector machines (SVM), are basically supervised learning models, associated with learning algorithms that analyze data used for classification purpose. SVM (Support Vector

Machines) are a useful technique for data classification and is being introduced in COLT-92 by Boser, Guyon & Vapnik. It is found to be more accurate than Artificial Neural Network (ANN) because it based on Structural risk minimization (SRM) whereas ANN is based on Empirical risk minimization (ERM). Support Vector Machine (SVM) is primarily a classier method that performs classification tasks by constructing hyper planes in a multidimensional space that separates cases of different class labels. SVM supports both regression and classification tasks and can handle multiple continuous and categorical variables. For categorical variables a dummy variable is created with case values as either 0 or 1. A classification task usually involves separating data into training and testing sets which is the composed of many instances. Each instance in the training set contains one "target value" (i.e. the class labels) and several "attributes" (i.e. the features or observed variables). The goal of SVM is to produce a model (based on the training data) which predicts the target values of the test data given only the test data attributes. Furthermore ,generally most of the SVM algorithms can only classify two class problem[16-18] i.e. separating the training data set i.e $(e_1,f_1),(e_2,f_2),(e_3,f_3)$…..(en fn), where e represent the feature vector and f represent the class vector which may be {1,-1}.This two classes are distinguish by each other through hyper plane. Dashed line in the figure represent the margin and different spot in the margin are called the support vectors. The distance of optimal separating hyper plane from origin is (b/||w||) .Amount of misclassification in case of non-separable classes is measures by a variable €.The distance of misclassification from the separating hyper plane is given by (€/||w||).

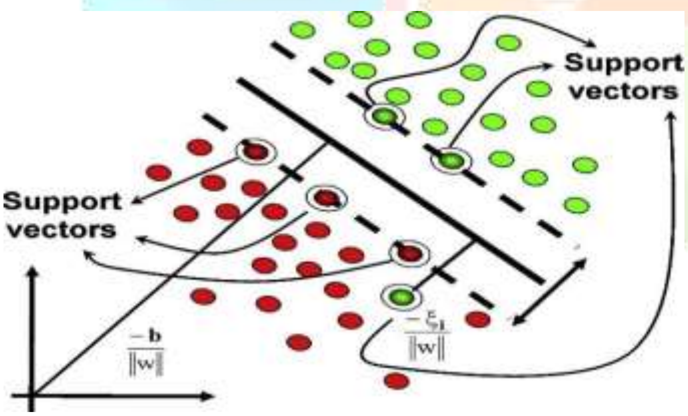


Fig (2) Example of support vector machine [20]

ane ,g(x) which correctly distinguish the data into their respectively classes is given by [17] $W^T x_i + b$ …………………………………………………………….(3)

Where b represent the constant value and W represent the vector. The value of this two data should calculate such that the unknown variable are categories correctly. By maximizing the separation margin between the two classes possibility of correct classification is possible as shown in equation (4) [17].

M= …………………………………………………….(4)

From the above relation it is clear that for maximizing M ,the value of W should be minimum. For a given set of linearly separable data ,this can be formulated according [17] as quadratic optimization problem as shown.

$$\min 1/2||W||\ldots\ldots(5) \text{ Subjected to } y_i\,(W^T x_i+b).> 1$$

2.4 Combined Support Vector Machine model for fault classification- In the propose research work multilayer support vector machine structure is used which constitutes five ,SVM A,SVM B,SVM C and SVM D,SVM E.SVM A is trained to discriminate the fault and power swing condition including if fault occur during power swing condition also. After detection of fault the role of remaining four SVM come into action. SVM B is trained for single line to ground fault in phase a, SVM C is trained for double line fault in phase in all phase (ab,bc,ca) ,SVM D for double line to ground fault in (abg,bcg.cag) and SVM E is trained for three phase to ground fault abcg . In testing phase each SVM classifies the fault as 1 if the particular fault is detected otherwise, it is classified as other. Fault is determined using the combination of results from all the five SVMs according to the logic sequences shown in Table [1&2] .

Table (1) SVM logic for fault detection during power swing-

SVM A	CONDITION
1	Fault during power swing
Other	Power swing

Table (2) Multiple SVM logic for fault classification during power swing

SVM 'A'	SVM B	SVM C	SVM D	SVM E	Fault Condition
1	1	other	other	other	LG
1	other	1	other	other	LL
1	other	other	1	other	LLG
1	other	other	other	1	LLLG

2.5 Selection of features- Different statically parameter is calculate from each IMFs . Very minor variation is seen in the magnitude of different calculate parameter, because power swing and three phase fault both are the symmetrical phenomena. Proper discriminating the power swing from fault ,five different feature are selected as most significant features. First three IMFs is consider for feature selection in the present case because maximum frequency content is available in these IMFs and declared to be enough for fault detection and classification .

(1) Standard deviation of amplitude

(2) Mean value of amplitude

(3) R.M.S value of amplitude

(4) Skewness of amplitude

(5) Kurtosis of amplitude

Thus five feature of each IMF among three IMFs consist a data set of fifteen features for each phase. Hence total forty five features are considered for fault and power swing discrimination.

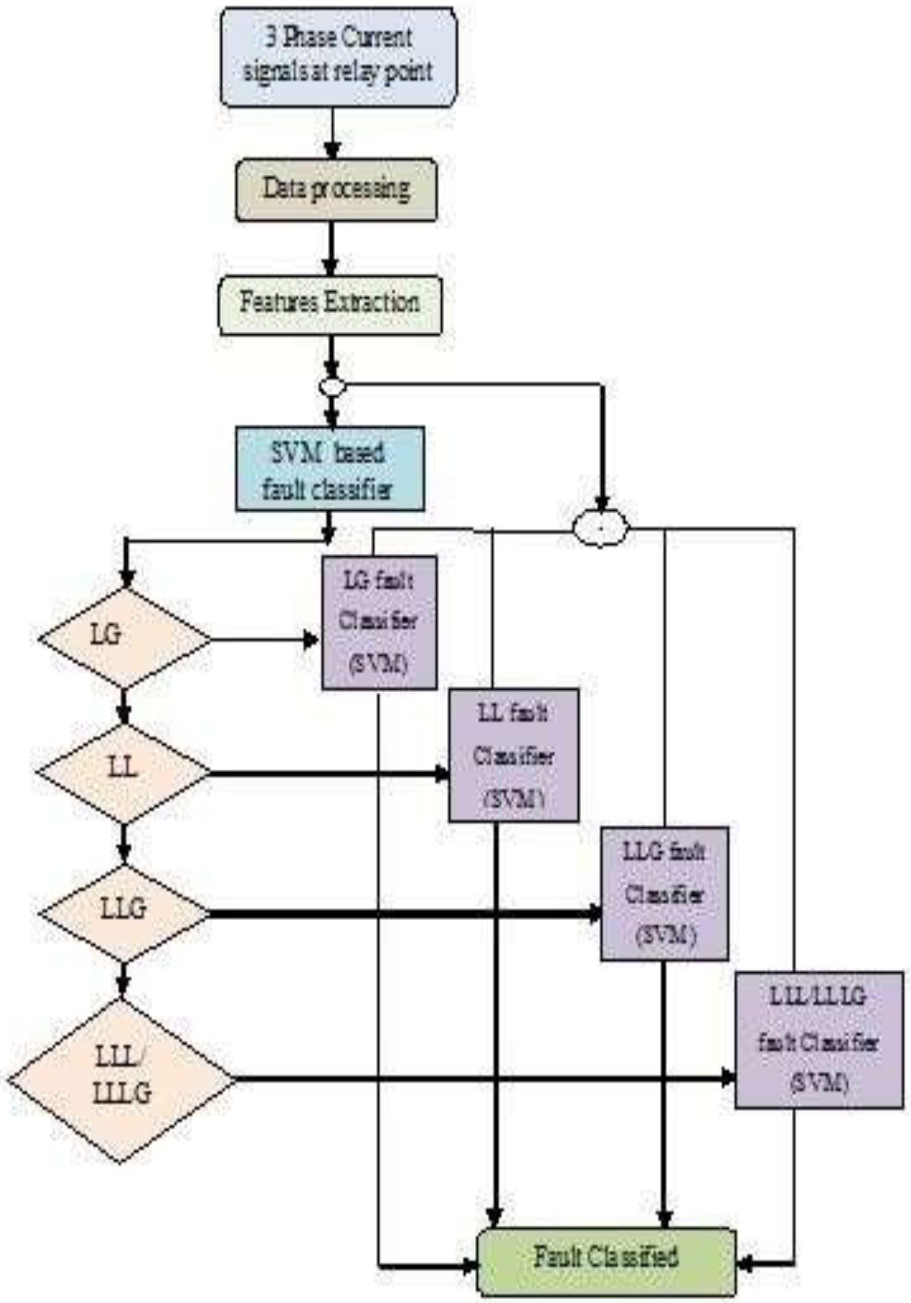


Fig (3) Algorithm for fault classification during power swing

3 SYSTEM UNDER STUDY -WSCC nine bus systems is simulated in PSCAD/EMDC software. A nine bus system is referred from power system control and stability by Anderson and found [19]. It represents a easy estimate of western system coordinating. Burgon modeling is used for transmission line simulation. For creating power swing in transmission line first fault is created in line T_{78} .Opening the breaker of line T_{78}, power swing is created in line T_{75}.Slow and fast power swing is generated by variation of first fault clearing time. Power swing of frequency (1.5-8) Hz is created by varying fault clearing time and fault resistance at different power angel. Second fault is created in T_{57} by varying the fault resistance and fault location with different power angel from (30-180) degree in 30 degree interval. Fault may be symmetrical or unsymmetrical. According to propose algorithm first it will check the fault or swing condition and if fault is classify then it again classify the type of fault. Fault data is generated by varying the Fault resistance from (.01-100) ohm and location of fault varies (50- 250) km from relay point at 50km interval. Thus a total of 720 cases of fault during power swing and 150 case of only power swing in a line are taken to training the SVM A .Apart from this different data set is generated for testing purpose in intermediate interval for each case.

.

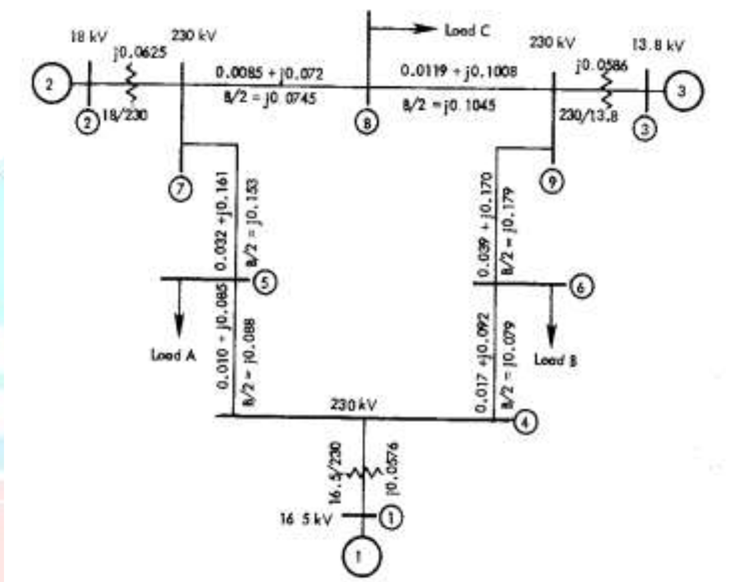
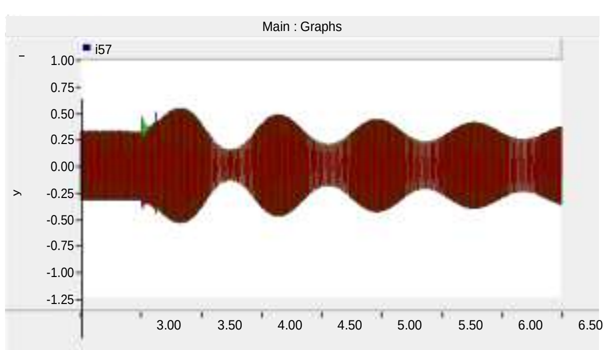


Fig (4) One line diagram of Nine Bus system

Current waveform of transmission line during power swing condition, fault condition and fault during power swing condition is shown by Fig (5),(6)and fig(7) respectively.

-



2.50

Fig (5) Current response in transmission line 57 during power swing condition

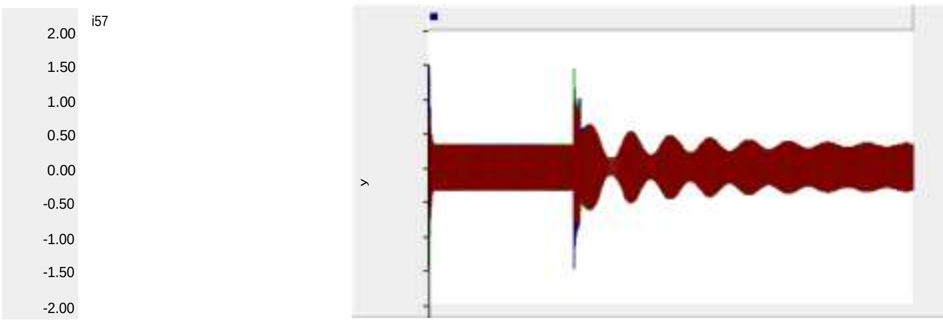


Fig (6) Current waveform in transmission line 57 during three phase fault condition

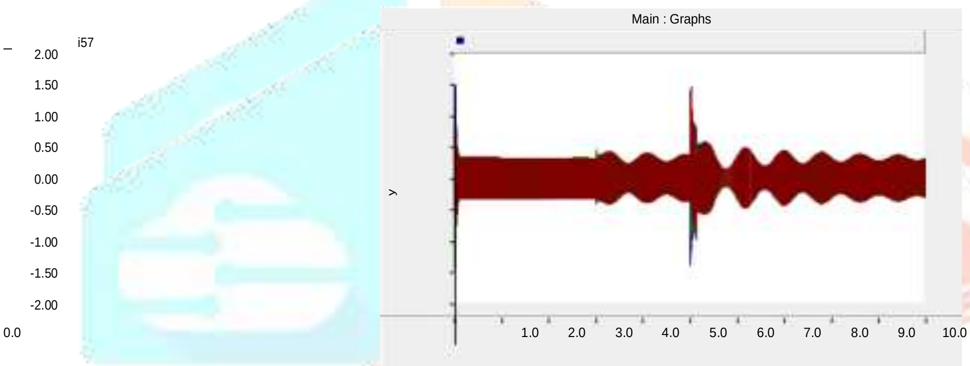


Fig (7) Current waveform when fault occur during power swing condition

4. RESULT AND DISCUSSION- The propose algorithm use one SVM for fault and power swing discrimination and remain four SVM is used for fault classification during power swing condition .Hybrid algorithm able to identify slow as well as fast power swing and block the relay to operate during such condition and avoid its mal -operation. Identification of three phase fault during power swing condition is very challenging task because both case are symmetrical phenomena. The present research work able to identify the power swing condition and block the relay to operate .Furthermore it is also distinguish the fault, if it occurs during power swing condition successfully. All the five SVM are trained carefully using the different feature of the signal obtain from EMD and Hilbert Huang Transform analysis in different case. One and half cycle is required for fault detection and fault classification during power swing and the methodology takes the computation time 1.95 second for classification the fault during power swing. Total fifteen features from every phase is selected, hence for one signal 45 feature is used for training the SVM for all three phases. Fifty cases are chosen in each case randomly for validating the proposed methodology. Classification accuracy for each case is obtained by using following formula.

Classification Accuracy = *100

Separately chosen fifty testing data set apart for each case, from training data set for validating the proposed hybrid algorithm. Results shows the classifier A identifies correctly fault during power swing condition with an efficiency of 100 % and overall fault classification classifier efficiency above 98 %

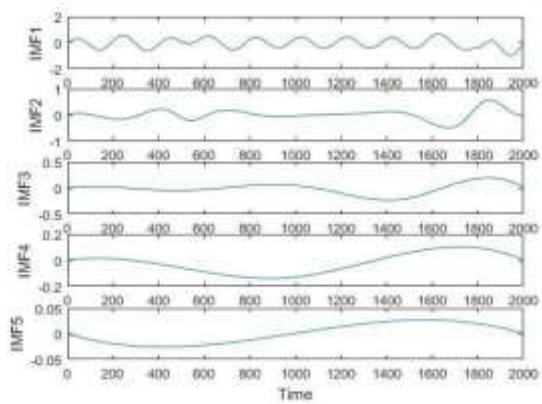


Fig (6) IMF_1 to IMF_5 of phase A during fast swing condition

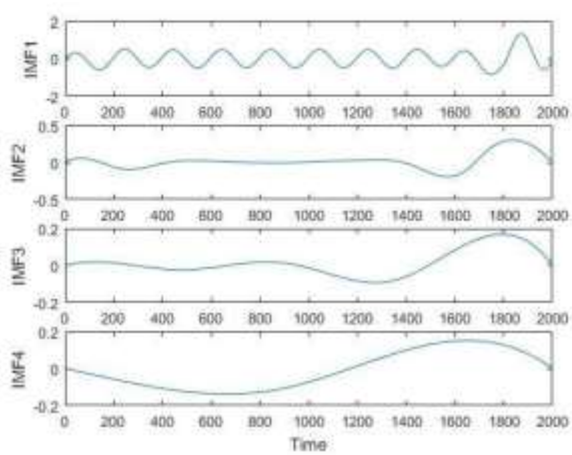


Fig (7 IMF_1 to IMF_4 of phase A during slow power swing condition

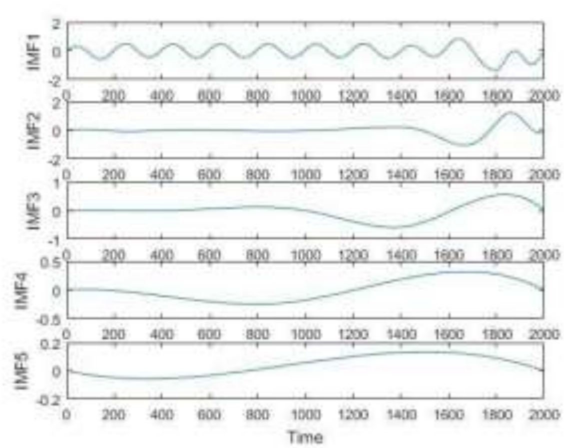


Fig.(8) IMF_1 to IMF_5 of phase A during three phase fault

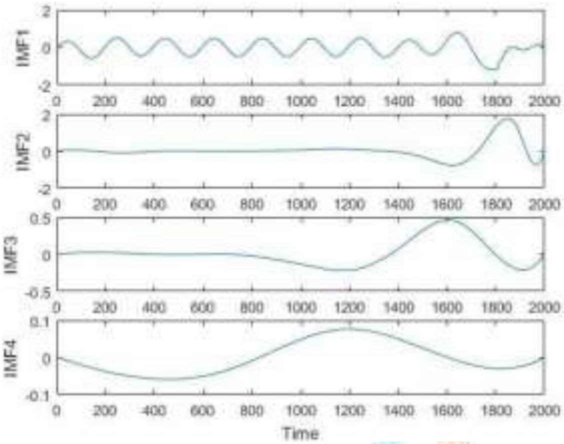


Fig.(9) IMF_1 to IMF_5 of phase A for double line to ground fault

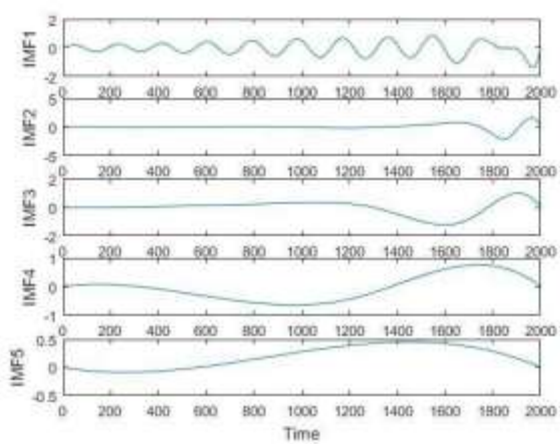


Fig.(10) IMF_1 to IMF_5 of phase A when three phase fault occurs during power swing condition

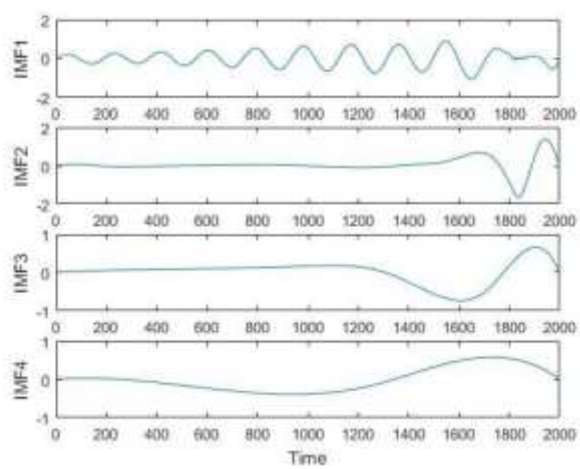


Fig. (11) IMF_1 to IMF_4 of phase A when double line to ground fault occurs during power swing condition

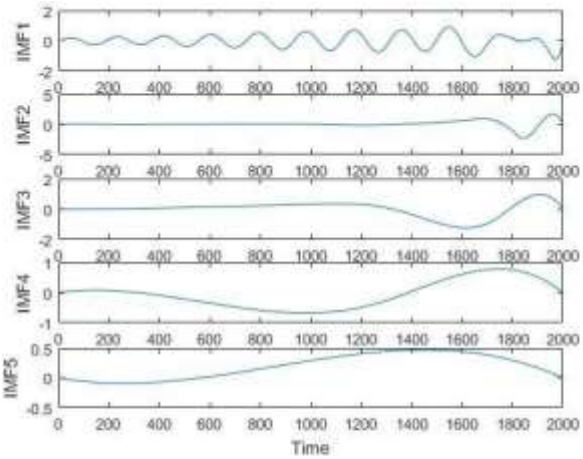


Fig.(12) IMF_1 to IMF_5 of phase A when single line to ground fault occurs during power swing condition

Table (3) SVM classifier performance for fault detection during power swing

Condition	No. Of Testing cases	No. of case classified correctly	Classifier efficiency	Overall Efficiency
SVM A	250	250	100%	100%

Table (4) SVM classifier performance for fault classification during power swing

Condition	No. Of Testing case	No. of case classified correctly	Classifier efficiency	Overall efficiency
SVM B	50	49	98%	98.5%
SVM C	50	50	100%	
SVM D	50	50	100%	
SVM E	50	48	96%	

5. CONCLUSION-The propose algorithm use one SVM for fault and power swing discrimination and remain four SVM is used for fault classification during power swing condition .Hybrid algorithm able to identify slow as well as fast power swing and block the relay to operate during such condition and avoid its mal -operation. Identification of three phase fault during power swing condition is very challenging task because both case are symmetrical phenomena. The present research work able to identify the fault condition in normal case and also distinguish the fault ,if it occur during power swing condition successfully. All the five SVM are trained carefully using the different feature of the signal , obtain from EMD and Hilbert Huang Transform analysis in different case. Different fault and power swing signal is obtain by varying the length from 50 km to 250 km and varying the fault resistance (.01-50) ohm of consider transmission line. The performance of propose hybrid algorithm does not affect with the complexity of power system network also the fault and power swing classification efficiency does not depend upon the swing frequency ,fault resistance and also to location of fault .Different swing frequency(1.5- 6 Hz) signal is generate by varying the fault clearing time .Reliability and viability of propose research work are demonstrate by the final result obtain from SVM. The main advantage of present work is the one algorithm is able to discriminating the power swing and fault condition also identify the three phase fault if it occur during power swing condition .So no need to develop the another algorithm for numerical relay for fault identification during power swing condition. Propose hybrid method require one and half cycle for fault identification.

REFERANCESS-

.

[1] Brahma, S. M. (2006,). *Use of wavelets for out of step blocking function of distance relays.* Paper presented at the IEEE Power Engineering Society General Meeting.

[2] Youssef OAS. ‘Online applications of wavelet transforms to power system relaying – Part II’. IEEE Power Eng Soc Gen Meet 2007:1–7.

[3] Chengzong, P., & Kezunovic, M. (2010). Fast Distance Relay Scheme for Detecting Symmetrical Fault During Power Swing. *IEEE Transactions on Power Delivery, 25*(4), 2205-2212. doi: 10.1109/tpwrd.2010.2050341

[4] Youssef OAS. Combined fuzzy-logic wavelet-based fault classifi-cation technique for power system relaying. IEEE Trans Power Delivery 2004;19(2):582–9.

[5] Youssef OAS. An optimized fault classification technique based on support-vector-machines. IEEE/PES Power Syst Conf Expos 2009:1–8.

[6] Sevakula RK, Verma NK. Wavelet transforms for fault detection using svm in power systems. IEEE Int Conf Power Electron Drives Energy Syst, Bengaluru, India; December 2012. p. 1–6.

[7] Livani H, Evrenosoglu CY. A fault classification method in power systems using DWT and SVM classifier. IEEE/PES Trans Distrib Conf Expo 2012:1–5.

[8] Shukla S, Mishra S, Singh B. Empirical-mode decomposition with hilbert transform for power-quality assessment. IEEE Trans Power Delivery 2009;24:2159–65.

[10] Manjula M, Sarma AVRS, Mishra S. Empirical mode decompo-sition based probabilistic neural network for faults classification. Int Conf Power Energy Syst 2011:1–5.

[11] Manjula M, Sarma AVRS, Mishra S. Detection and classification of voltage sag causes based on empirical mode decomposition. Annual IEEE India Conf (INDICON) 2011:1–5.

[12] Huang NE, Wu MLC, Long SR, Shen SSP, Qu W, Gloersen P, Fan KL. A confidence limit for the empirical mode decomposition and Hilbert spectral 18 analysis. Proc R Soc A: Math Phys Eng Sci 2003;459:2317–45.

[13] Huang E, Shen Z, Long SR. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proc R Soc Lond 1998;454:903–95.

[14] Barnhart B. The Hilbert–Huang transform: theory, applications, development. Ph.D. dissertation, University of Iowa; 2011.

[15] Guo Y, Li C, Li Y, Gao S. Research on the power system fault classification based on HHT and SVM using wide-area informa-tion. Sci Res Energy Power Eng 2013;5:138–42.

[16] Gunn SR. Support vector machines for classification and regression. Ph.D. dissertation, University of

Southampton, UK; 1997.

[17] Cristianini N, Shawe-Taylor J. An introduction to support vector machines and other kernel-based learning methods. Cambridge University Press; 2000.

[18] Zhang Q, Yang YQ. Research of the kernel function of support vector machine. Electr Power Sci Eng 2012;28(5):42–5.

[19] P.M.Anderson and A.A Fouad, power System Control and Stability the IOWA state university press AMES IOWA USA ,volume I, first edition 1977 ,chapter 2 ,page 37-38.

[20] N. Ramesh Babu, B. Jagan Mohan, Fault classification in power systems using EMD and SVM, 2090-4479(2015) Ain Shams University. Production and hosting by Elsevier B.V