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A New Fault Detector based on Modified Varri Method for Power System Relaying Applications

P.RPattanaik, S. Pati, Basanta. K Panigrahi, S.KSanyal, Anshuman Bhuyan

Abstract*: A Modified Varri based fault detector for power system relaying application is proposed in this paper. The qualifier to detect the fault consists of two sliding windows of frequency measure and amplitude measure. The proposed method provides proper discrimination between pre fault and post fault conditions even in the presences of noise, harmonics and uncertainties present in the signals. Further the methodprovides relatively higher index values than other fault detection techniques. Various test signals are applied to test the proposed method and response is compared with conventional techniques. The proposed method is effective and can be used for fault classification in distance protection.

Index Terms:Transmission line protection, Fault Detection, digital relaying, Modified Varri.

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I. INTRODUCTION

The digital relays have been replacing conventional relay in power system due to accuracy, simplicity, flexibility and reliability. The signal processing techniques have been applied to detect, classify and locate the faults in any transmission line. Researchers have proposed relay algorithms using DFT, Kalman Filter and recursive least square to get fundamental component of current and voltage [1], [2]. It has been possible to compute positive as well as negative sequence impedance from estimated current and voltage phasor. Adaptive methods have been suggested to get accurate trip decision under different system conditions [3]. Algorithm have been developed using neural networks, fuzzy logic and neuro-fuzzy techniques [4], [5].In Distance relay the detection algorithm is used to discriminate faulty state and then main relay algorithm is activated to classify and locate the fault. The detection of faults affects directly the speed and reliability of relay. Several methods have been proposed by researchers for power system fault detection. Some of the fault detection methods involve comparison of consecutive samples value, cycle's values and phasor values. However all these method are susceptible to frequency drift, interharmonics and other uncertainties.

A new approach to real time fault classification in power system was reported in [6] using combined wavelet based fuzzy logic techniques. Wavelet transform have been applied to detect high impedance fault in high voltage transmission line [7]. A Cusum based fault detector algorithm has been presented in [8]. A new algorithm was proposed for detecting fault during the power swing [9]. A fibre optics based sensing network has been developed for fault detection in power system [10]. A travelling wave detection method has been applied using parks transformation [11]. A decision tree based fault detection and classification during power swing has been proposed in [12].A moving sum based fault detection technique is suggested in [13].

Biomedical signal such as ECG and EEG have been analysed using modified Varri method [14]In modified Varri method two sliding windows are employed to obtain frequency measure and amplitude value of the signal in relevant windows. The frequency measure is computed by sum of difference of two consecutive signal samples. The amplitude values are computed by sum of one cycle data of signal. In this paper a novel technique is developed using Modified Varri method for fault detection in power system. The consecutive samples difference increases significantly at fault inception as compared to the difference during normal operating conditions. This behaviour makes the frequency measure to maintain high value during fault. Sum of one cycle data of a sinusoidal current signal is zero. This nature of a perfect sinusoid suggests that amplitude measure will have zero value in prefault condition and will maintain a higher value during faulted conditions. However, frequency deviation in prefault conditions can make the amplitude measure to have non zero values. In order to avoid such error an adaptive scheme has been proposed. To establish the effectiveness of proposed method comparative assessments have been carried out with other fault detection techniques.

II. FAULT DETECTION TECHNIQUES

Fault Detectors unit plays an important role in distance relaying operations. It is essential to activate main relaying algorithm within few milliseconds to isolate the faulty section from healthy section. The relay performance therefore directly depends upon functioning of fault detector unit. A fault occurrence in transmission

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P.R Pattanaik, Electrical Department, S'O'A University, ITER, Bhubaneswar, India, Email: ranjanpatanaik@gmail.com

S.Pati, Electrical Department, S'O'A University, ITER, Bhubaneswar, India. Email: subhendupati90@gmail.com

Basanta.KPanigrahi, Electrical Department, S'O'A University, ITER, Bhubaneswar, India, Email: basanta1983@gmail.com

S.K Sanyal, Electrical Department, S'O'A University, ITER, Bhubaneswar, India, Email: sksanyal1947@gmail.com

AnshumanBhuyan, Electrical Department, S'O'A University, ITER, Bhubaneswar, India, Email: bhuyananshuman@gmail.com

line results in distortion of line voltage and current signal. The distortion involves change in magnitude, frequency and phase of signals. Normally fault detection algorithm are based on these changes occurs in distorted signal during fault in comparison to prefault condition. The change in current signal during fault is more significant as compared to the corresponding voltage signal. It is appropriate to consider current signal to form the basis of a fault detector. In recent time's researcher have suggested several method for fault detection. Some of the popular detection techniques with proposed method are briefly discussed in subsections.

A. Consecutive Sample Comparison

Comparisons of consecutive current samples are used to obtain fault detector indices. The detector continuously monitors the difference between present sample with previous sample and registers a fault if this difference exceeds a threshold value. It can be mathematically expressed as

$$p_k = |i_k - i_{k-1}| \quad (1)$$

A fault will be registered if

$$p_k > a, \quad D_1 = 1 \text{ else } D_1 = 0 \quad (2)$$

Where *'k'* is sampling instant, *'i'* is phase current, *'a'* is threshold value and *'D_1'* is detector output.

B. Sample of consecutive cycle comparison

Submit your manuscript electronically for review. This method utilizes the periodic nature of current signal for fault detection. A routine repeatedly check the difference between present sample and its corresponding sample in previous cycle. In normal condition this difference remains approximately equal to zero. However during occurrence of a fault the difference exceeds a threshold value and fault is registered by the detector. Mathematically it can be expressed as

$$q_k = |i_k - i_{k-N+1}| \quad (3)$$

A fault will be registered if

$$q_k > b \quad D_2 = 1 \text{ else } D_2 = 0 \quad (4)$$

Where *'N'* is window length, *'b'* is threshold value and *'D_2'* is detector output.

C. Phasor Comparison Method

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables. The comparisons of phasor have been conveniently applied to detect faults in power systems[3].The speed of detection has been increased with the application of efficient algorithm employing first and second derivative of current signal. The current phasor magnitude at k^{th} instant is compared with $(k-3)^{th}$ instant. The difference exceeding a pre specified threshold registered the occurrence of a fault. Mathematically it can be expressed as

$$(\hat{I}_p(k))^2 = \left(\frac{i''(k)}{w^2}\right)^2 - \left(\frac{i'(k)}{w}\right)^2 \quad (5)$$

Where 'i'' and 'i''' are the first and second derivative of current signal. A fault will be registered if

$$r_k > c, \quad D_3 = 1 \text{ else } D_3 = 0 \quad (6)$$

Where

$$r(k) = \hat{I}_p(k) - \hat{I}_p(k-3) \quad (7)$$

And *c* is a threshold value and *'D_3'* is detector output.

D. Proposed Fault Detector

Conventional fault detectors have certain limitations. An ideal fault detector has zero value before fault and high non oscillating value after fault. The detector has to respond for all types of fault and remain unaffected by any uncertainties present in the signal. Modified Varri method employs two shifting windows. The two shifting windows comprises of 'frequency measure' which is computed by taking one cycle sum of consecutive sample difference and 'amplitude value' which is sum of samples over one cycle data [14]. The signal is prior processed through a DFT based filter in order to enhance the performance of the fault detector. A sinusoidal current signal can be expressed as

$$i_k = I_m \cos(\psi\kappa + \varphi) \quad (8)$$

Where *'I_m'* is the amplitude of current signal, *'k'* is the sample number, *'φ'* is the phase angle in radians and *'ψ' = 2π/N'*.

DFT of the sinusoidal current signal corresponding to fundamental frequency is

$$I_1 = \frac{2}{N}\sum_{k=0}^{N-1} i_k e^{-j\frac{2\Pi}{N}k} \quad (9)$$

Where *'I_1'* is the phasor estimated in terms of peak and can also be represented as

$$I_1 = I_m e^{j\varphi} \quad (10)$$

The fundamental signal can be obtained by using phasor values at each instant as

$$\hat{i}_k = [I_m e^{j\varphi}] e^{j\omega_0 kTs} \quad (11)$$

The frequency measure is written as

$$F_{diff} = \sum_{j=k-N-1}^{k} \left|\hat{i}_k - \hat{i}_{k-1}\right| \quad (12)$$

The amplitude value index can be obtained as

$$A_{diff} = \sum_{j=k-N-1}^{k} \left|\hat{i}_k\right| \quad (13)$$

The measure difference function (g) can be expressed as

$$g_k = A_1\left|A_{diff(k)} - A_{diff(k-N)}\right| + F_1\left|F_{diff(k)} - F_{diff(k-N)}\right| \quad (14)$$

Where *'A_1'* and *'F_1'* are constant coefficients and their values depends upon applications. In this case the values of both the coefficients are set to be 1.

A fault will registered if

$$g_k > d \quad D_4 = 1 \text{ else } D_4 = 0 \quad (15)$$

Where'd'is threshold value and *'D_4'* is proposed detector output.

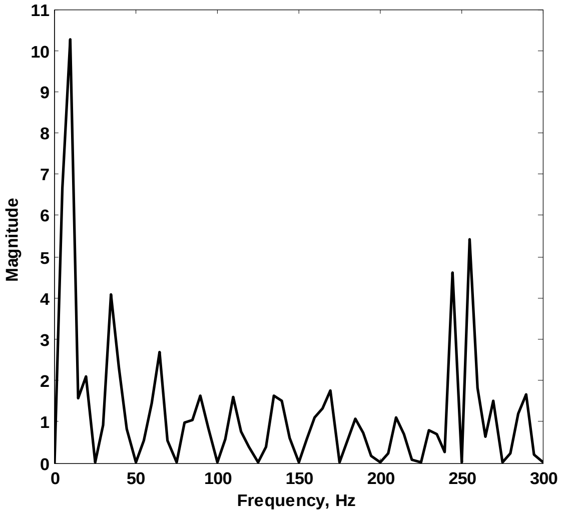

Fig.1. Frequency output of Modified Varri 50 Hz filters.

This shows that value of detector index at a particular instant requires the cyclic difference of *'A_{diff}'* and *'F_{diff}'*. The size of relevant window (*N*) depends upon system frequency. The system frequency may deviates from its fundamental value due to several factors. The window length needs to be updated with frequency value at that instant. Otherwise the proposed detector index may have non zero value in normal operating conditions. Frequency response of the Modified Varri filter has been shown in Fig.1. The fixed window length (20 samples) for a sampling frequency of 1kHz is considered. The technique is found to be more sensitive to frequency below fundamental frequency.

III. TEST RESULTS

The comparative assessments of different fault detector have been carried out with synthesized signal and signal obtained from simulations. Different cases of signal contamination and system condition have been considered to evaluate the performance of fault detectors discussed earlier. An ideal fault detector features include non-oscillatory high index value during occurrence of a fault. Some fault detectors have undesirable none zero index value before fault which make the detector unreliable as selection of a optimal threshold value becomes a cumbersome task. Such detector will raise alarm in normal condition if their index value accidently exceeds the threshold value. These situations can be avoided by raising the threshold value. But setting of high threshold value may make the relay insensitive to the faults with high resistance. Therefore it is necessary to select a optimum threshold for relaying applications. Many factors such as fault current magnitude, noise, DC offset, harmonics, frequency deviations, sampling rate and system condition must be considered before selecting the threshold.

Fault detectors have been tested for different cases and system conditions. The effect of noise, spike, harmonics, frequency deviation, high fault resistance, series compensation and fault types have been analysed and discussed below.

A. Faulted Current Data

A faulted signal is considered with fault at 0.043 s. The 50 Hz current signal processing is made using different fault detectors and corresponding indices are plotted in Fig.2. The results shows that earlier methods suffers from either low oscillating index values or maintaining non zero value before fault. The Modified varri index is found to be zero before fault and rises linearly after the fault.

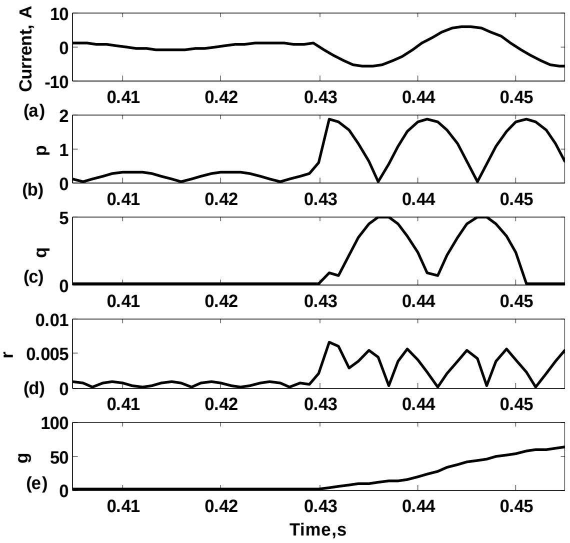

Fig.2. (a) Current Signal, (b) Sample comparison, (c) Cycle comparison, (d) Phasor Method (e) Proposed Method

B. Fault Signal with Noise

Random white noise of SNR 20dB has been introduced to the faulted current signal data. The SNR increases during fault at 0.43s as the magnitude of current signal increases. The signal contaminated with noise is processed and corresponding detector indices are shown in Fig.3. The results show that earlier method get affected by noise maintaining non-zero value before fault and falls back to zero within one cycle after fault. The modified varri shows consistency as compared to other methods and yield a non-oscillatory response.

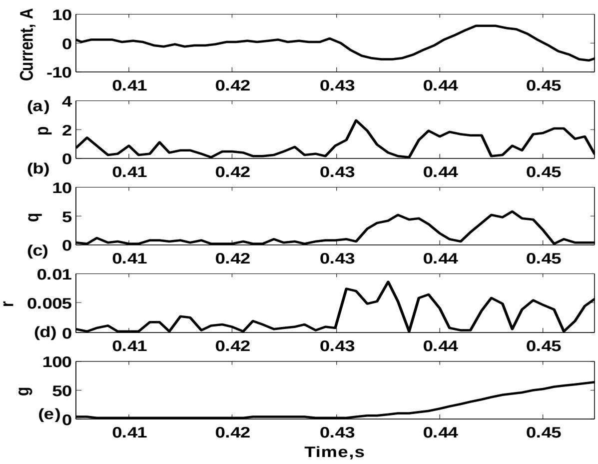

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Fig 3: (a) Signal added with 20 dB Noise, (b) Sample comparison, (c) Cycle comparison, (d) Phasor Method (e) Proposed Method

C. Signal with Harmonics

An ideal fault detector has to maintain zero index value in prefault condition. However uncertainties present in the signal may make fault detector to have undesirable non zero index value in prefault conditions. The fault detectors are tested with sinusoids added with some specific uncertainties in different cases. The behaviour of fault detectors against harmonics is analysed by processing a 50 Hz sinusoid signal contaminated with 25% third harmonic and 12.5 % fifth harmonics. The respective indices are plotted in Fig.4. The proposed method is not affected by the presence of harmonics unlike other methods.

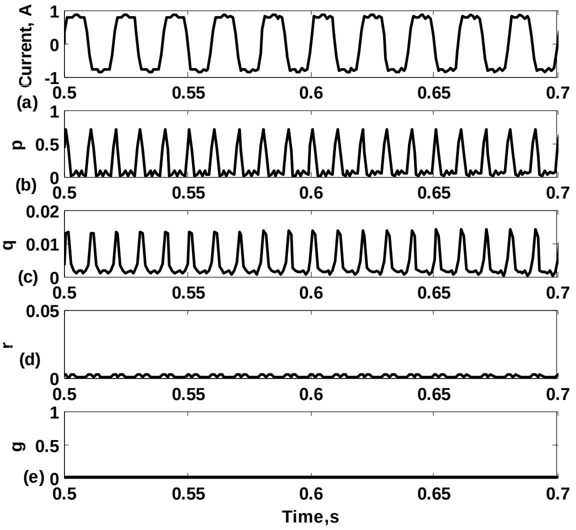

Fig. 4. (a) Current Signal with 3rd and 5thharmonics ,(b) Sample comparison, (c) Cycle comparison, (d) Phasor Method (e) Proposed Method

D. Signal with Spike

Spike in current signal can occur due to several factors. A spike at any instant can increase the value of sample at any instant. The detector which uses sampled data of current signal may behave erroneously in presence of spike. A spike at 0.55s is introduced in a current signal and response of fault detectors to the signal with spike is shown in Fig.5. It is found that proposed method is not affected in the presence of spike unlike other detection techniques.

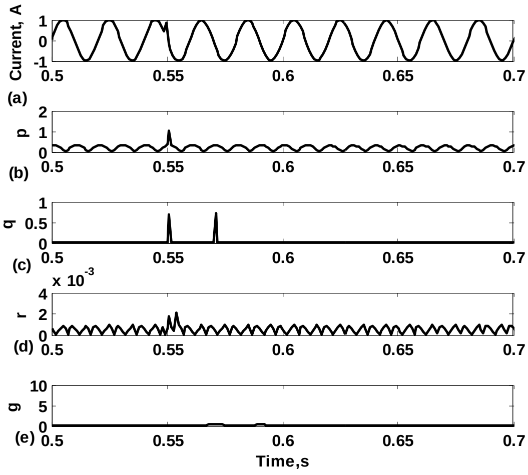

Fig.5. (a) Current Signal with spike at 0.55s, (b) Sample comparison, (c) Cycle comparison, (d) PhasorMethod (e) Proposed Method

E. FrequencyDeviation and Adaptive Windowing

The dynamic condition of modern power system results in change of system frequency from its nominal value. The fault detector has to be immune to such frequency deviations. The signal frequency is changed at 0.6s from 50Hz to 52Hz. The effect on different fault detector for change is studied. It can be clearly observed from Fig 6 that all the detectors have none zero index value in a pre-fault condition due to frequency drift.

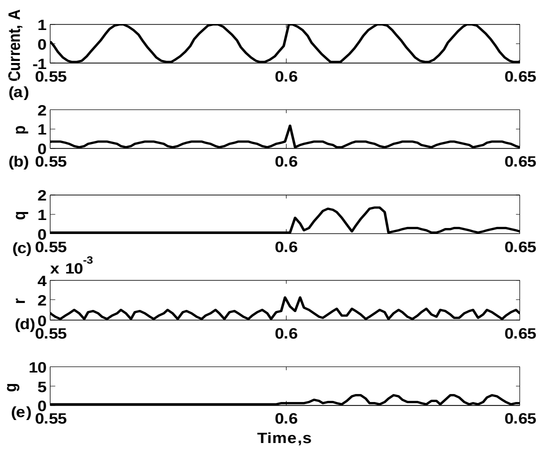

Fig.6. (a) Current Signal with frequency drift at 0.6s, (b) Sample comparison, (c) Cycle comparison, (d) PhasorMethod (e) Proposed Method

Such inaccurate response of proposed detector can be prevented with an adaptive windowing scheme. In adaptive widowing scheme the relay unit need prior information of signal frequency and according to signal frequency the window size will get updated to an accurate value. The proposed method may produce non zero index value under prefault conditions if there is a mismatch between system frequency and window size. Researchers have suggested numerous frequency measurement and estimation algorithms that can be implemented in adaptive relaying schemes [1].

Response of ModifiedVarri with fixed and adaptive windowing is obtained as shown in Fig.7 and Fig.8 for two extreme cases of frequency deviation in power system.

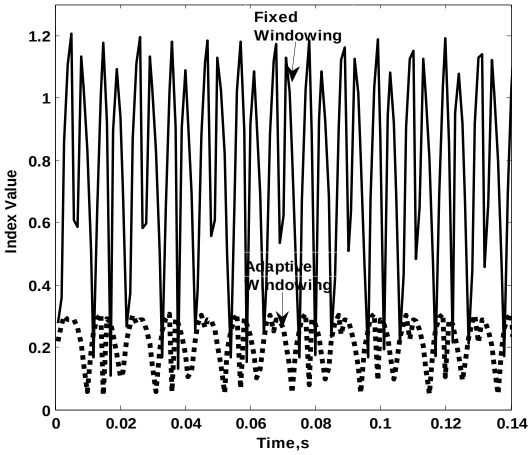

Fig.7. Response with adaptive and fixed windowing (52 Hz signal)

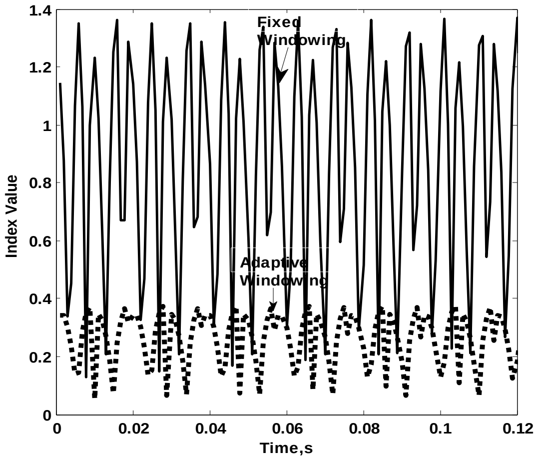

Fig.8. Response with adaptive and fixed windowing (48 Hz signal)

The results clearly indicate that adaptive windowing reduces the index value a low level as compared to fixed windowing. The lower index value suggests adaptive windowing for a flexible relaying performance. TableIshows required window sizes for different frequency and corresponding error with fixed and adaptive window length. The analysis is carried out for two sampling frequency of 1 kHz and 10KHz. It is revealed from TableI that higher sampling frequency results in higher index value of Modified Varri. The threshold value needs to be increased in case of high sampling frequency in order to avoid false alarm.

Table I. Error with fixed and adaptive windows

Frequency Information			**Maximum error (p.u.) (with respect to current signal strength of 1 unit)**			
Signal Frequency(Hz)	**Required optimal window size.**		**Fs = 1.0 kHz**		**Fs = 10.0 kHz**	
	Fs = 1.0 kHz	**Fs = 10.0 kHz**	**Fixed window (20 samples)**	**Adaptive window**	**Fixed window (200 samples)**	**Adaptive window**
48	21	208	0.2606	0.0575	2.0347	0.0131
48.5	21	206	0.1964	0.1320	1.1475	0.0084
49	20	204	0.1761	0.1761	0.5082	0.0035
49.5	20	202	0.10	0.10	0.1245	0
50	20	200	0	0	0	0
50.5	20	198	0.1175	0.1175	01270	0
51	20	196	0.1928	0.1928	0.4995	0.0036
51.5	19	194	0.2119	0.1398	1.0995	0.0085
52	19	192	0.2744	0.0689	1.9039	0.0133

F. HighResistance Fault

A 400 kV, 50 Hz two terminal power system model as shown in Fig.9 has been considered to analyze the performance of fault detectors with high resistance fault. The magnitude of fault current is depended on fault resistance and may vary over a wide range. An 'ag' fault is created at 0.68s with fault resistance of 100Ω. The fault data is collected from bus P. Earlier detectors shows oscillating low values and proposed detector produce non oscillating high index value.

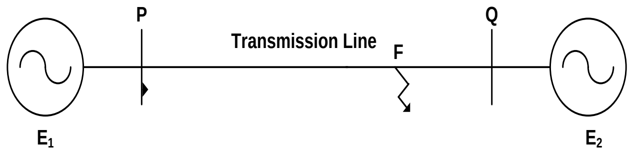

Fig.9.A 400 kV power system

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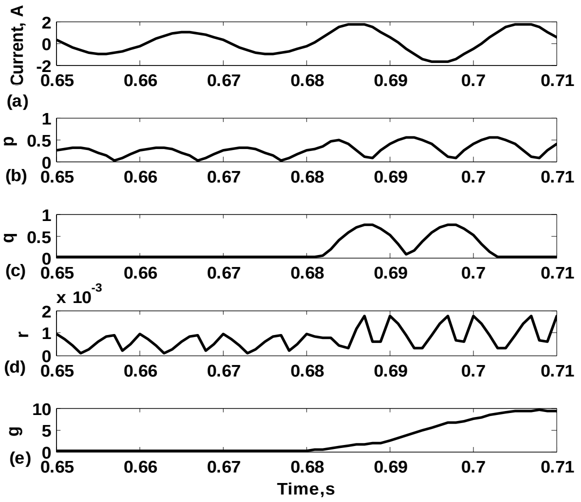

Fig.10 (a) Current Signal with fault at 0.68 and 100 Ω resistance, (b) Sample comparison, (c) Cycle comparison, (d) Phasor Method (e) Proposed Method

G. SeriesCompensated Line

Series compensating devices consist of capacitor with metal oxide varistor and air gap arrangement. These protective devices introduce non linearity in current signal during fault.

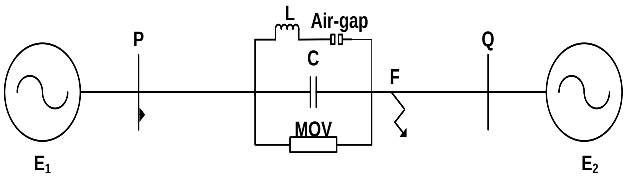

Fig.11: A series-compensated transmission Line.

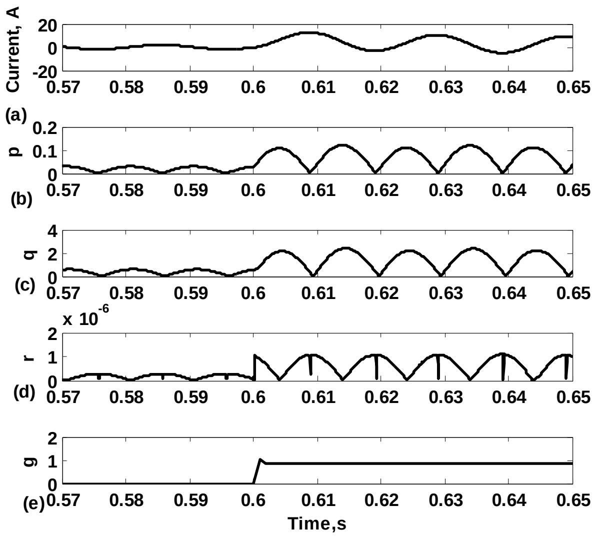

Fig.12. (a) Current Signal with fault at 0.6 and 0 Ω resistance in series compensated line, (b) Sample comparison, (c) Cycle comparison, (d) Phasor Method (e) Proposed Method

A transmission line with 30 % series compensation at midpoint is considered for analysis as shown in Fig.11. A solid 'ag' fault has been initiated at midpoint after the capacitor terminal and response of different fault detector is obtained as shown in Fig.12. All fault detectors except proposed yields oscillating index value. The proposed method response is found to be accurate and fast. The Modified Varri index rises sharply and maintains a constant value after the fault.

H. DifferentTypes of Fault

. The proposed fault detector requires three phase current data for real time relaying. However the detector can detect any type of fault with only one signal. This can be achieved with help of a complex transformation of three phase signal into a single complex signal. The required complex transformation can be expressed as

$$i_\alpha = \sqrt{\frac{2}{3}}\left(i_a - \frac{1}{2}i_b - \frac{1}{2}ic\right) \tag{16}$$

$$i_\beta = \sqrt{\frac{2}{3}}\left(0 + \frac{\sqrt{3}}{2}i_b - \frac{\sqrt{3}}{2}ic\right) \tag{17}$$

Transformed complex signal can be expressed as

$$i_{complex} = i_\alpha(k) + j i_\beta(k) \tag{18}$$

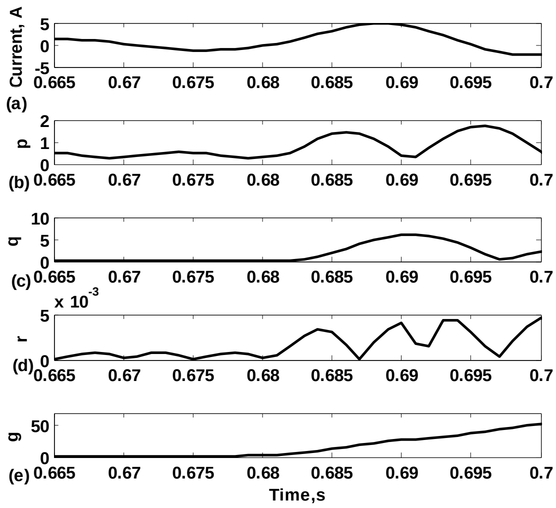

Fig.13. (a) Complex Current Signal, (b) Sample to Sample, (c) Cycle to Cycle, (d) PhasorMethod (e) Proposed Method

However this attractive feature comes with an extra burden of computation on relay unit. An 'ab' line fault is initiated at 0.0683s and three phase current signal is transformed into the single complex signal. The complex signal is processed through different fault detector and results are plotted in Fig.13. The proposed method index maintains high non oscillating value for line fault also. Fault

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detectors are subjected to different types of fault and responses are found to be similar.

IV. CONCLUSION

A new efficient fault detector has been proposed for relaying application. The method is based on Modified Varri technique. It comprises two sliding window of frequency and amplitude measure. The technique is straightforward and easy to implement. A comparative assessment of Modified VaariTechniques is carried out with various fault detectors. The proposed method maintains high non oscillating index value as compared to other detection techniques. Adaptive schemes improve the performance of the proposed method. The method shows good consistency when tested under different system condition. The detection time is comparable to other fast detectors.

REFERENCES

1. Bo, Z. Q., et al. "Transient based protection for power transmission systems." 2000 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No. 00CH37077). Vol. 3. IEEE, 2000.
2. Sidhu, Tarlochan S., Daljit S. Ghotra, and Mohindar S. Sachdev. "An adaptive distance relay and its performance comparison with a fixed data window distance relay." IEEE Transactions on Power Delivery 17.3 (2002): 691-697.
3. Lin, Whei-Min, et al. "A fault classification method by RBF neural network with OLS learning procedure." IEEE Transactions on Power Delivery 16.4 (2001): 473-477.
4. Chen, Kunjin, Caowei Huang, and Jinliang He. "Fault detection, classification and location for transmission lines and distribution systems: a review on the methods." High voltage1.1 (2016): 25-33.
5. Youssef, Omar AS. "Combined fuzzy-logic wavelet-based fault classification technique for power system relaying." IEEE transactions on power delivery 19.2 (2004): 582-589.
6. Kim, Chul-Hwan, et al. "A novel fault-detection technique of high-impedance arcing faults in transmission lines using the wavelet transform." IEEE Transactions on Power Delivery 17.4 (2002): 921-929.
7. Mohanty, S. R., A. K. Pradhan, and A. Routray. "A cumulative sum-based fault detector for power system relaying application." IEEE transactions on power delivery 23.1 (2008): 79-86.
8. Lotfifard, Saeed, JawadFaiz, and MladenKezunovic. "Detection of symmetrical faults by distance relays during power swings." IEEE transactions on power delivery 25.1 (2010): 81-87.
9. Law, Chiu T., KaluBhattarai, and C. Yu David. "Fiber-optics-based fault detection in power systems." IEEE Transactions on power delivery 23.3 (2008): 1271-1279.
10. Lopes, F. V., D. Fernandes, and W. L. A. Neves. "A traveling-wave detection method based on park's transformation for fault locators." IEEE Transactions on Power Delivery 28.3 (2013): 1626-1634.
11. Swetapadma, Aleena, and AnamikaYadav. "Data-mining-based fault during power swing identification in power transmission system." IET Science, Measurement & Technology 10.2 (2016): 130-139.
12. Pradhan, A. K., A. Routray, and S. R. Mohanty. "A moving sum approach for fault detection of power systems." Electric Power Components and Systems 34.4 (2006): 385-399.
13. Azami, Hamed, KarimMohammadi, and BehzadBozorgtabar. "An improved signal segmentation using moving average and Savitzky-Golay filter." Journal of Signal and Information Processing 3.01 (2012): 39

AUTHORS PROFILE

P.R Pattanaik received the B.Tech in Electrical Engineeringfrom BPUT and M.Tech degrees from SOAUniversity in 2011 and 2014 respectively. He iscurrently working towards the Ph.D degree at SOAUniversity. His research interest are Power SystemProtection and Power System Transients.

S.Pati received the B.Sc(Engg) ,M.E in Electricalengineering from Sambalpur University and Ph.D from KIIT University in 1990,1997 and 2017 respectively. He is currently an associateprofessor in the department of electricalengineering at SOA University. His research areaincludes Power System Protection and PowemSystem Transients.

Basanta.KPanigrahi received the PhD degree from SOA University Bhubaneswar in 2018 and he is currently an Assistant Professorat the Department of ElectricalEngineering, ITER, Bhubaneswar, India. His research area includes digital signal processing and soft computing applications in power system and powerquality.

S.K Sanyal received the B.Sc(Engg), M.Sc(Engg) and Ph.Ddegrees in Electrical Engineering from SambalpurUniversity in 1970, 1973 and 1980 respectively.He is currently a professor in the department ofelectrical engineering at SOA University. Hisresearch area includes Power System Protectionand Power System Operation and Control.

Anshuman Bhuyan is working as a Research Scholar in the department of Electrical Engieneering, ITER, SOA University Bhubaneswar. His research area includes protection of distributed generator and power system fault analysis.