Six Phase Transmission Line Boundary Fault Detection using Mathematical Morphology

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***Abstract*— This paper presents a mathematical morphology based boundary protection scheme for the detection of close-in and remote-end faults that occur on six phase transmission line. A 400 kV, 50 Hz six phase transmission line of 200 km length has been simulated using MATLAB software. The proposed scheme makes use of six phase current measured at the relay location (bus-1) of a six phase transmission line. To assess the performance of the proposed method, various fault parameters are varied. Simulation results reveal the appropriateness of the proposed scheme.**

Keywords*— Six Phase Transmission Line Protection; Mathematical Morphology; Boundary Protection; Fault Detection; Close-In And Remote-End Fault Detection.

I. INTRODUCTION

For the protection of six phase transmission line against the shunt and series faults, a protection scheme based on logic has been proposed by G. C. Sekhar and P. S. Subramanyam in [1]. A comparative study of electric field calculations beneath six phase and double circuit transmission lines has been described by R. M. Radwn and M. M. Samy in [2]. By the usage of charge simulation technique, calculation of electric field has been done for both double circuit and six phase transmission line at one meter above the earth level. Ebha Koley, Khushaboo Verma and Subhojit Ghosh [3] proposed hybrid WT and modular ANN based scheme for the protection of six phase transmission line which utilized the measured data of single end only. An algorithm for the over current protection of six phase transmission line with the help of numerical relay has been described by Shanker Warathe and R. N. Patel in [4] and based on test results, it was found that the numerical relay protects well six phase transmission line from over current problem. Classification of phase to phase faults on six phase transmission line by using Haar WT and ANN has been reported in [5]. F. Namdari and M. Salehi [6] proposed mathematical morphology and initial current travelling wave based high speed protection scheme for three phase transmission lines. Rapid discrimination of the fault direction and internal faults from the external faults has been done by comparing the arrival time and polarity of the initial current travelling wave captured from both the ends of a transmission line under protection. Ashutosh Kumar Tiwari, Soumya Ranjan Mohanty and Ravindra Kumar Singh [7] proposed mathematical morphology based fault detection technique for the protection of DG penetrated electrical power distribution system. Vinayesh Sulochana, Anish Fransis and Andrew Tickle [8] proposed transmission line fault detection and classification scheme based on morphology and radon processed artificial neural network. Zehui Liang et al. [9] proposed mathematical morphology and integral method based transmission line protection scheme against lightning strikes. Paulo A. H. Cavalcante et al. [10] proposed a scheme based on simplified multi-resolution morphological gradient (SMMG) for fault location on a three phase transmission line. The proposed scheme is dependent on sampled voltage signals collected from both the ends of a transmission line. Numerous advantages of six phase power transmission line over traditional three phase power transmission lines are: six phase transmission line generates less electric field, less necessity of right of way (ROW) and tower dimensions, increased line inductance and decreased line capacitance, preserved voltage stability, and increased reactive power limit at the far end voltage point [11-14].

In this paper, a mathematical morphology based fault identification scheme is proposed for the detection of six phase transmission line close-in and remote-end faults. At a variety of fault locations, the performance of scheme is discovered including faults at boundary locations. Distinguish explorations are done to analyze the impact of variation in fault parameters like fault type, fault location, fault resistance, ground resistance, and fault inception angle. Performance of the proposed scheme is tested from 1% of the line length up to 97.5% of the line length. Test results attained by the training of proposed technique validate the suitability of the proposed scheme under a diversity of fault circumstances.

II. SIMULATION OF SIX PHASE TRANSMISSION LINE

Test system under consideration is comprised of 400 kV, 50 Hz, six phase transmission line of length 200 km as demonstrated in Fig.1. The six phase transmission line is connected to a load of 100 MW at the receiving end side. MATLAB software is used for the modeling and simulation of test system for numerous types of faults.

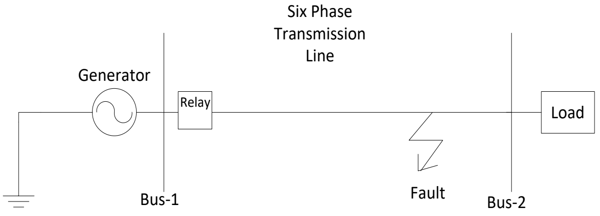

Fig.1. Single line diagram of six phase transmission line

III. MATHEMATICAL MORPHOLOGY

If f (p) is the signal [6] then its domain $D_f = \{x_0, x_1, \ldots x_p\}$ and s (q) is the structuring element having domain $D_q = \{y_1,$

$y_2,\ldots y_q\}$ and p > q, where p and q are the integers, then the dilation of f(p) by s (q), denoted by (f⨁s) can be defined as: -

$$y_d\,(p) = (f\oplus s)(p)=\max\{f(p-q)+s(q),0\leq(p-q)\leq p,q\geq 0\}. \quad (1)$$

The erosion of f (p) by s (q) denoted as (f⊖s) can be defined as: -

$$y_e\,(p) = (f\ominus s)(p)=\min\{f(p+q)-s(q),\ 0\leq(p+q)\leq p,q\geq 0\}. \quad (2)$$

IV. PROPOSED FAULT DETECTION SCHEME

Fig. 2 depicts proposed fault detection scheme [20].

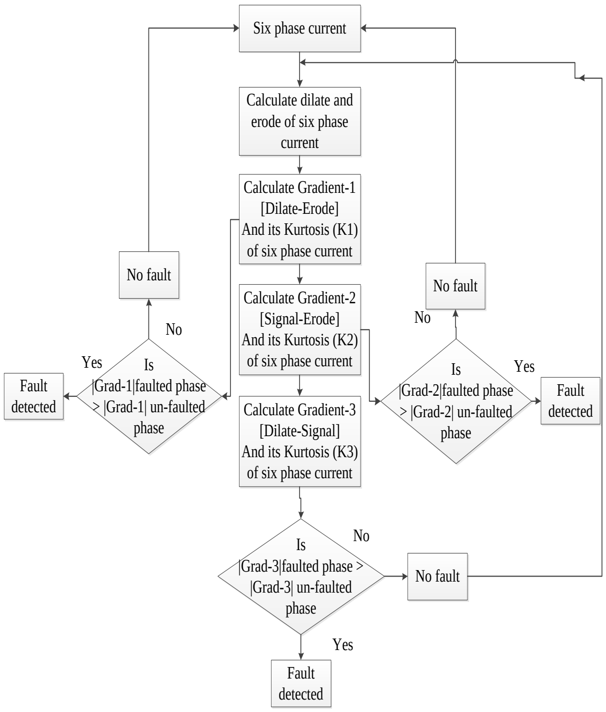

Fig. 2. Proposed fault detection scheme

Gradient-1 (grad1), gradient-2 (grad2) and gradient-3 (grad3) are the three types of mathematical morphological filter coefficients [10]. Following the calculation of these three coefficients, trip decision has been taken. Following six phase fault current decomposition using mathematical morphology filter, if magnitude of gradient-1, 2 or 3 of the faulted phase is found larger than the magnitude of gradient-1, 2 or 3 of a healthy phase, the relay detects the fault and issue trip command for the tripping of faulty phase (s). For numerous types of faults, the proposed scheme is tested with various fault parameters variation.

V. TEST RESULTS AND DISCUSSIONS

To scrutinize the performance of mathematical morphological based fault detector, the proposed scheme is tested for various fault cases with variation in fault type, fault location, fault resistance, ground resistance and fault inception time.

5.1 *Phase-'AD-g' close-in fault*

The proposed scheme is examined for close-in relay phase-'AD-g' fault occurring at 1% from the relay location with fault inception time of 0.0133 seconds having $R_f = 10\Omega$, $R_g = 15\Omega$. The six phase current for the period of phase-'AD-g' fault is shown in Fig. 3. The process of fault detection using mathematical morphological filter during phase- 'AD-g' fault occurring at 1% from bus-1 at FIT = 0.0133 seconds with $R_f = 10\Omega$ and $R_g = 15\Omega$ can be seen from Fig. 4 to Fig. 5. Fig. 4 to Fig. 5 clarifies the magnitude of gradient-1, 2 and 3 of phase-A and D for the duration of phase-'AD-g' fault and from Fig. 4 and 5 it is clearly observed that the magnitude of gradients-1, 2 and 3 of phase-A and D during phase-'AD-g' fault is higher than the magnitude of gradients-1, 2 and 3 of other phases. Table I summarizes the response of the proposed scheme for phase-'AD-g' fault occurring at 1% from relay location. As viewed from Table I, the magnitude of gradient-1, 2 and 3 of faulted phase (Phase-A and D) is more than the magnitude of gradient 1, 2 and 3 of un-faulted phase and this explains that the proposed mathematical morphological based fault detector in actual fact detects phase-'AD-g' fault occurred at 1% from the relay location.

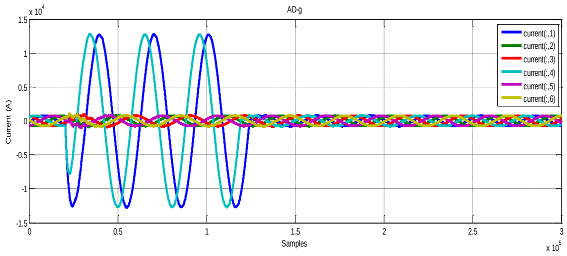

Fig. 3. Six phase current during phase-'AD-g' fault at 1% from bus-1 at FIT = 0.0133 seconds with $R_f = 10\Omega$ and $R_g = 15\Omega$

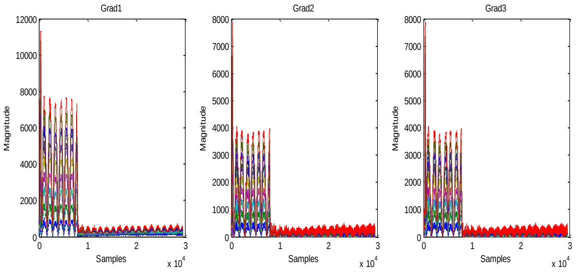

Fig. 4. Gradients-1, 2, 3 of phase-A during phase-'AD-g' fault

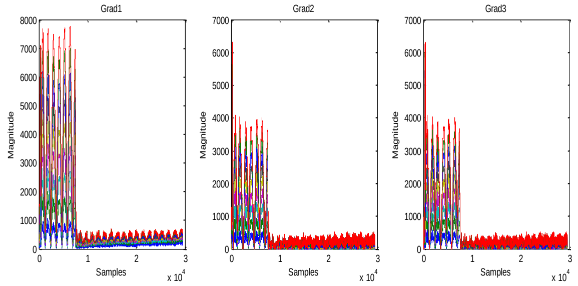

Fig. 5. Gradients-1, 2, 3 of phase-D during phase-'AD-g' fault

TABLE I. RELAY OUTPUT FOR PHASE-‘AD-G’ FAULT AT 1% FROM BUS-1 AT FIT = 0.0133 SECONDS WITH R_F = 10Ω AND R_G = 15Ω

	Phase					
Outputs	*A*	*B*	*C*	*D*	*E*	*F*
Dil	1.2722* 10^4	929.2 827	1.0302* 10^3	1.2759* 10^4	865.2 665	1.1426* 10^3
Erd	1.2712* 10^4	853.9 529	960.7 028	1.2732* 10^4	767.0 688	1.0743* 10^3
Grad1	1.1307* 10^4	1.5519* 10^3	1.4875* 10^3	7.7755* 10^3	1.4875* 10^3	1.3429* 10^3
Grad2	7.8811* 10^3	1.2593* 10^3	1.4458* 10^3	6.3013* 10^3	1.4448* 10^3	1.0005* 10^3
Grad3	7.8811* 10^3	1.2593* 10^3	1.4458* 10^3	6.3013* 10^3	1.4448* 10^3	1.0005* 10^3

5.2 Phase-‘ABEF-g’ remote-end fault

The proposed scheme is tested for remote-end phase-‘ABEF-g’ low resistance fault occurring at 95% from the relay location with fault inception time of 0.02833 seconds having R_f = 0.5Ω, R_g = 1Ω. The six phase current for the duration of phase-‘ABEF-g’ fault is shown in Fig. 6. The process of fault detection using mathematical morphological filter during phase- ‘ABEF-g’ fault occurring at 95% from bus-1 at FIT = 0.02833 seconds with R_f = 0.5Ω and R_g = 1Ω can be seen from Fig. 7 to Fig. 10. Fig. 7 to Fig. 10 describes the magnitude of gradient-1, 2 and 3 of six phases for the duration of phase-‘ABEF-g’ fault and from Fig. 7 to Fig. 10 it is clearly observed that the magnitude of gradients-1, 2 and 3 of phase-A, B, E and F during phase-‘ABEF-g’ fault is higher than the magnitude of gradients-1, 2 and 3 of other phases. Table II highlights the response of the proposed scheme for phase-‘ABEF-g’ fault occurring at 95% from relay location. As viewed from Table II, the magnitude of gradient-1, 2 and 3 of faulted phase is higher than the magnitude of gradient 1, 2 and 3 of un-faulted phase and this explains that the proposed mathematical morphological based fault detector in point of fact detects phase-‘ABEF-g’ fault occurred at 95% from the relay location which is mainly a remote-end low resistance fault.

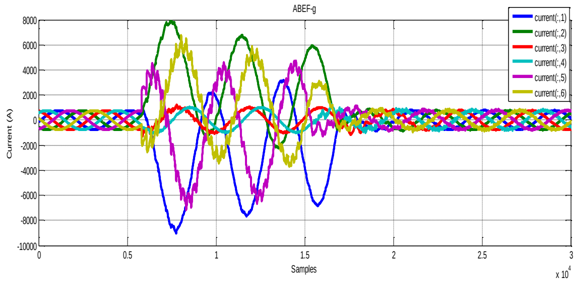

Fig. 6. Six phase current during phase ‘ABEF-g’ fault at 95% from bus-1 at FIT = 0.02833 seconds with R_f = 0.5Ω and R_g = 1Ω

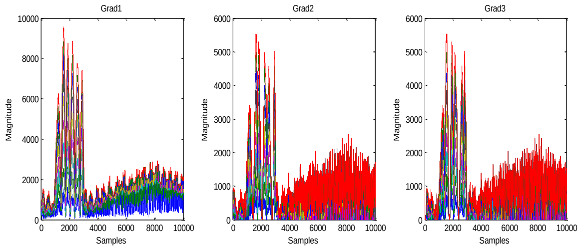

Fig. 7. Gradients-1, 2, 3 of phase-A during phase-‘ABEF-g’ fault

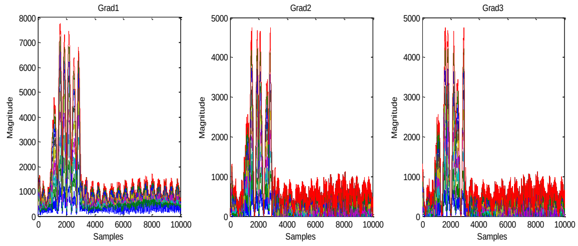

Fig. 8. Gradients-1, 2, 3 of phase-B during phase-‘ABEF-g’ fault

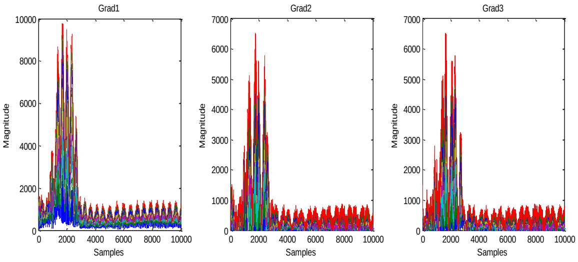

Fig. 9. Gradients-1, 2, 3 of phase-E during phase-‘ABEF-g’ fault

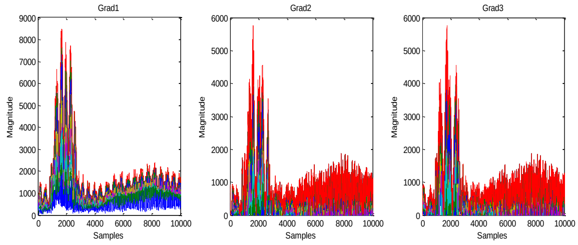

Fig. 10. Gradients-1, 2, 3 of phase-F during phase-‘ABEF-g’ fault

TABLE II. RELAY OUTPUT FOR PHASE-‘ABEF-G’ FAULT AT 95% FROM BUS-1 AT FIT = 0.02833 SECONDS WITH R_F = 0.5Ω AND R_G = 1Ω

	Phase					
Outputs	*A*	*B*	*C*	*D*	*E*	*F*
Dil	3.1552* 10^3	7.8973* 10^3	1.5010* 10^3	1.2483* 10^3	4.5779* 10^3	6.6614* 10^3
Erd	3.0995* 10^3	7.7891* 10^3	969.8 007	966.1 331	4.3562* 10^3	5.9316* 10^3
Grad1	9.5591* 10^3	7.7628* 10^3	2.3589* 10^3	1.9644* 10^3	9.7774* 10^3	8.4613* 10^3
Grad2	5.5240* 10^3	4.7516* 10^3	1.8681* 10^3	1.3764* 10^3	6.5126* 10^3	5.7584* 10^3
Grad3	5.5240* 10^3	4.7516* 10^3	1.8681* 10^3	1.3764* 10^3	6.5126* 10^3	5.7584* 10^3

5.3 Phase-‘ABCDEF-g’ remote-end fault

The proposed scheme is examined for remote-end phase-‘ABCDEF-g’ low resistance fault occurring at 85% from the relay location with fault inception time of 0.03166 seconds having $R_f = 10\Omega$, $R_g = 15\Omega$. The six phase current for the period of phase-‘ABCDEF-g’ fault is shown in Fig. 11. The procedure of fault detection using mathematical morphological filter for the period of phase- ‘ABCDEF-g’ fault happening at 85% from bus-1 at FIT = 0.03166 seconds with $R_f = 10\Omega$ and $R_g = 15\Omega$ can be seen from Fig. 12 to Fig. 17. Fig. 12 to Fig. 17 illustrates the magnitude of gradient-1, 2 and 3 of six phases for the period of phase-‘ABCDEF-g’ fault and from Fig. 12 to Fig. 17 it is noticeably observed that the magnitude of gradients-1, 2 and 3 of all six phases during phase-‘ABCDEF-g’ fault increases. Table III summarizes the response of the proposed scheme for phase-‘ABCDEF-g’ fault occurring at 85% from relay location. As inspected from Table III, the magnitude of gradient-1, 2 and 3 of all six faulted phase raises and this clarifies that the proposed mathematical morphological based fault detector in point of fact detects phase-‘ABCDEF-g’ fault occurred at 85% from the relay location which is essentially a remote-end low resistance fault.

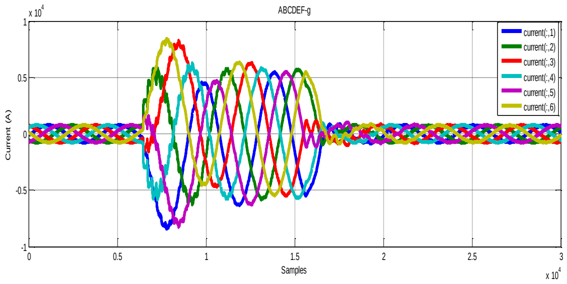

Fig. 11. Six phase current during phase ‘ABCDEF-g’ fault at 85% from bus-1 at FIT = 0.03166 seconds with $R_f = 10\Omega$ and $R_g = 15\Omega$

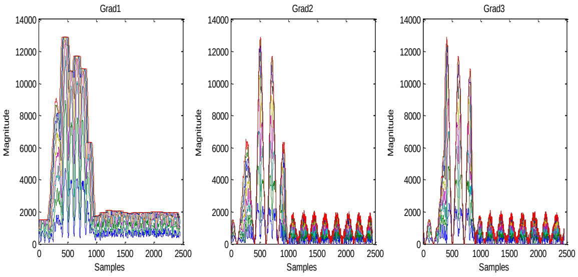

Fig. 12. Gradients-1, 2, 3 of phase-A during phase-‘ABCDEF-g’ fault

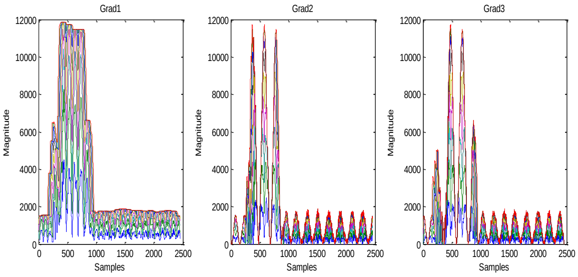

Fig. 13. Gradients-1, 2, 3 of phase-B during phase-‘ABCDEF-g’ fault

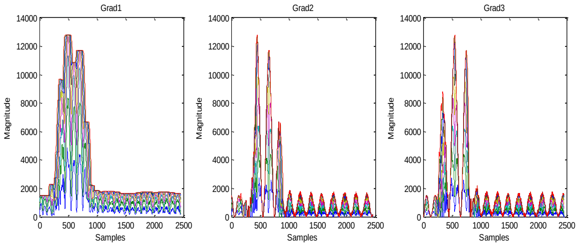

Fig. 14. Gradients-1, 2, 3 of phase-C during phase-‘ABCDEF-g’ fault

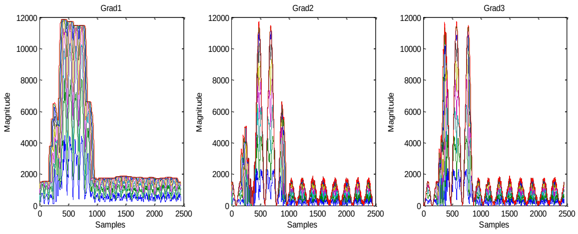

Fig. 15. Gradients-1, 2, 3 of phase-D during phase-‘ABCDEF-g’ fault

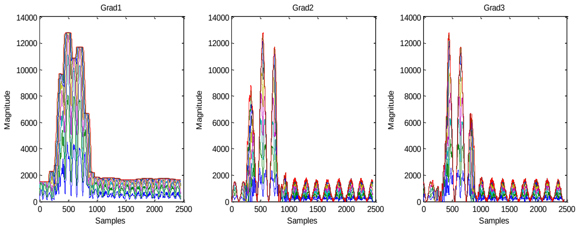

Fig. 16. Gradients-1, 2, 3 of phase-E during phase-‘ABCDEF-g’ fault

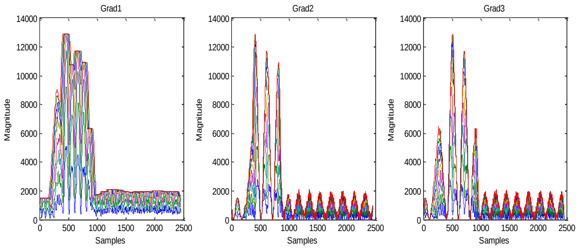

Fig. 17. Gradients-1, 2, 3 of phase-F during phase-‘ABCDEF-g’ fault

TABLE III. RELAY OUTPUT FOR PHASE-‘ABCDEF-G’ FAULT AT 85% FROM BUS-1 AT FIT = 0.03166 SECONDS WITH $R_F = 10\Omega$ AND $R_G = 15\Omega$

	Phase					
Outputs	*A*	*B*	*C*	*D*	*E*	*F*
Dil	5.4351* 10^3	5.7897* 10^3	8.1342* 10^3	6.0585* 10^3	5.4672* 10^3	8.3995* 10^3
Erd	5.0707* 10^3	5.3053* 10^3	7.5893* 10^3	5.4177* 10^3	5.0268* 10^3	7.9739* 10^3
Grad1	1.2881* 10^4	1.1848* 10^4	1.2776* 10^4	1.1848* 10^4	1.2776* 10^4	1.2881* 10^4
Grad2	1.2881* 10^4	1.1743* 10^4	1.2776* 10^4	1.1743* 10^4	1.2776* 10^4	1.2881* 10^4
Grad3	1.2881* 10^4	1.1743* 10^4	1.2776* 10^4	1.1743* 10^4	1.2776* 10^4	1.2881* 10^4

VI. CONCLUSION

In this paper, a mathematical morphology based boundary protection scheme is proposed for six phase transmission line. The proposed scheme exploits dilation and erosion coefficients of six phase fault current measured at the relay location (Bus-1). The proposed scheme effectively detects both close-in and remote-end faults that occur on six phase transmission line. The proposed scheme is tested for numerous categories of boundary faults with fault parameters variation. Simulation results show that both close-in and remote-end faults are correctly detected by mathematical morphology based fault detection scheme.

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