A GPS BASED FAULT LOCATION SCHEME FOR DISTRIBUTION LINE USING WAVELET TRANSFORM TECHNIQUE

F.Jiang(1), Z.Q.Bo(2), G. Weller(2), Philip S.M.Chin(1), M.A.Redfern(3)

(1) Department of Electrical Engineering, Singapore Polytechnic, Singapore
(2) GEC T/D Alsthom P&C Ltd., UK
(3) Department of Electronic and Electrical Engineering, University of Bath, UK

Abstract: This paper introduces a new scheme which applies Wavelet Transform and Global Positioning System(GPS) to locate the fault in a distribution system. In the proposed scheme, fault locators installed at each busbar in a distribution system are employed to capture and extract the fault generated transient. When a fault occurs in a system, fault generated transient travels outwards along the line. Arrival of fault transient detected by each locator is tagged with time referred to GPS base. The accurate location of fault can be achieved by comparing the time difference detected by the locators situated at different busbars. Typical simulation results are presented to examine the feasibility of proposed fault location scheme.

Key words: Global Positioning System(GPS), Fault Location and Wavelet Transform

1. INTRODUCTION

The Global Positioning System(GPS), with its ability to provide time synchronization to a 1.0μs accuracy over a wide geographic area covered by a modern power system, has been successfully applied in many power system applications. For instance, the precise time-tagging of fault data recorded by a GPS can be utilised to conduct the post fault analysis that ultimately leads to improved efficiency and greater reliability in system operation. So far the GPS based techniques have been mainly utilised in long EHV transmission system thanks to the bandwidth limitation of the conventional transducer that makes it very difficult to detect very high frequency signals generated by a fault transient associated with relatively short distribution lines.

This paper presents a new fault locator which is applicable in a power distribution system. In the scheme, the locator consisting of a specially designed fault generated transient detection device with a GPS receiver is connected to the power lines via a coupling capacitor. The fault locator is installed at each busbar in a distribution system to capture the fault generated transient signals. In operation, the transient based location techniques with the aid of GPS are employed to detect the high frequency voltage transient signals and record the instance of the initial travelling wave generated by the fault[1-3]. To attain the accurate instance of initial travelling wave, wavelet transform is applied to extract the transient components from the captured fault signals. The fault location is performed by comparing the differences between the instances in time for all locators in the system.

Extensive simulation analyses are conducted in the paper to prove the feasibility of the proposed scheme. An 11kV overhead distribution system as indicated in Fig.1 is selected to evaluate the performance of the new scheme. The system is composed of three 11kV feeders and four buses fed by four different supply sources. Like most of distribution systems, the neutral of system is solidly grounded. System faults with the build-in non-linear arc model are simulated using EMTP software. The proposed fault locators installed at each busbar detect the high frequency voltage transient signals and capture the instance of initial travelling wave associated with the transient signals. Based on the clock provided by the GPS, the instances of initial fault transient wave recorded by all locators will be compared each other to determine the fault location.

The analytic results turn out that the proposed fault location scheme is able to locate correctly the fault position for a complicated distribution system. Furthermore the performance of the proposed scheme is insensitive to fault type, fault resistance and fault inception angle. The proposed scheme will provide distribution system with a very high accuracy fault location and high speed protection.

2. PRINCIPLE OF FAULT DETECTOR

The schematic of the proposed fault locator is shown as in Fig.1 to explain its operational principle. Within the detector are analog interfacing unit, wavelet transform based transient detection unit and GPS clock. To acquire the system fault, the detector is connected to the system busbar via coupling capacitor. Upon the system fault, the fault generated transient travels in two directions towards the two ends of the fault feeder and then continues to travel to other healthy feeders. As the fault signal arrives at a system busbar, the instant of signal arrival is captured by transient detector and marked with time of GPS clock. Here GPS functions as a time base to synchronize the detectors situated at different locations. Taking account of the 11kV distribution system as shown in Fig.1, the fault locators are installed at busbars B1, B2, B3 and B4 respectively. When a fault happens on any part of the network, the fault initiated transient signal accompanied by power frequency fault component will be detected by fault locators at all four burbars at the different times. To localize the observed transient signal in accurate time, the variable sampling windows instead of fixed window used in Windowed Fourier Transform should be implemented to focus on the interested high frequency transient signals. In this regard, the wavelet transform is one of the most powerful means since it can provide the analysis of transient signals with variable sampling windows and meanwhile very good time resolution at high frequencies and good frequency resolution at low frequencies as well. In other words, the wavelet can be used as a mathematical microscope to amplify the specified components in captured signal without losing resolution[4-5]. In the signal process of this paper, three levels Daubechies discrete wavelet transform is used to effectively extract the transient signal from the captured fault waveform. By comparing the difference between times arriving at busbars, the fault location can be diagnosed precisely.

3. MODELLING OF DISTRIBUTION SYSTEM

Fig.1 shows graphically the configuration of the distribution system for illustrating the performance of proposed fault locator. This 11kV system has four busbars supplied by different sources and connected through three feeders. The precise fault location is attained by four locators at each busbar. For the simplicity, only one fault locator at busbar B2 is given in Fig.1.

The response of the fault locators to the system fault is examined by use of the EMTP. Faults at different locations are simulated with the non-linear arc built-in the model. It is important to notice that embodying non-linear arc into the simulation model is crucial for the application of the proposed fault location algorithm. This is because the high frequency signals generated by arc can be employed to detect the fault at zero cross voltage. Meanwhile the initial fault generated signal at zero voltage fails to produce substantial high frequency noise.

Study shows that the frequency of fault generated transient(tens to hundreds kHz) is much higher than power frequency(50Hz/60Hz). Also the transient signal is nonstationary and remains for less than one power cycle. Thereby wavelet transform is utilized to extract the transient signals. Here the WT acts as a band-pass filter of high performance which is not affected by power frequency fault. Moreover it has become evident[1] that the fault generated transient is not sensitive to the fault type, fault path impedance and system sources. On contrary, these are the factors that affect significantly the performance of a conventional impedance based fault location method. More importantly, the problem of voltage zero fault inception that limits the performance of the traditional travelling wave based fault detector[6] has been overcome by detecting the fault arc generated transient.

4. EVALUATION OF PROPOSED LOCATOR

In this section, simulation studies will be presented to verify the correct response of proposed fault locator to different type of system faults at the various locations. All results are obtained by virtues of three levels Daubechies discrete wavelets. Furthermore, the error analysis is also carried out to examine the applicability of proposed locator in practical operation.

Fig.2 indicates the transient voltage signals extracted by each fault locator at four busbars when a phase 'a'-to-earth fault occurs at location 'F1' as shown in Fig.1. It is clearly seen from the figure that the fault generated transient reaches different busbars at the different time. The relationship between the tagged time is shown as:

$$T3>T4>T1>T2 \qquad \dots (1)$$

Where T1, T2, T3 and T4 are the times when transient arrives at busbars B1, B2, B3 and B4 respectively.

Observing eqn.(1) and the system configuration in Fig.1, it is predictable that the fault occurs on feeder 1. The distance of fault location from busbar B2 can be figured out by using eqn (2). The fault position detected by the locators is shown in table 1.

$$D_{F1\text{-}B2} = \frac{(T_2 - T_1)\times v}{2} + \frac{L_{B1-B2}}{2} \qquad \dots (2)$$

where $D_{F1\text{-}B2}$ is the distance from fault position to busbar B2, $L_{B1\text{-}B2}$ is the length of feeder 1 and $v(=281km/ms)$ is the velocity of electro-magnetic wave travelling on the line.

Fig. 3 illustrates graphically the response of fault locator to a phase 'a'-to-earth fault occuring at location 'F2'. The figure visualises the travelling times of fault transient from fault point to each busbar. Time relation can be derived as:

$$T3>T1>T4>T2 \qquad \dots (3)$$

As a result, this fault occurs on the feeder 3. The distance of fault referring to busbar B2 can be determined in terms of eqn.(4) and is given in table 1.

$$D_{F2\text{-}B2} = \frac{(T_2 - T_4)\times v}{2} + \frac{L_{B2-B4}}{2} \qquad \dots (4)$$

where $D_{F2\text{-}B2}$ is the distance from fault position to busbar B2 and $L_{B2\text{-}B4}$ is the length of feeder 3.

To investigate the response of the locator to the zero voltage fault, Fig.4 presents the time detection of locator when a phase 'b'-to-earth fault with inception angle close to zero occurs at point 'F3'. It can be seen that although the magnitudes of the fault arc generated transient are relatively low, the locators are capable of extracting the fault transient and producing the correct fault location as given in table 1.

The response of the locator to the high impedance fault is also examined in the study. Fig.5 describes the locator's operation when a phase 'a'-to-earth fault via a 300Ω fault path occurs at location 'F4'. It is apparent that the magnitudes of transient signals are comparatively low due to the high fault resistance. Nevertheless, the results in Fig.5 indicate that the performance of the locators doesn't change with the resistance of fault path.

Figs. 6 and 7 show the response of the locator to different fault type and locations. The results as given in table 1 prove that the proposed fault-locating scheme is able to diagnose fault location precisely in presence of different fault conditions.

5. CONCLUSION

This paper introduces a new approach that uses the WT technique and GPS system to locate the fault position in a distribution system. In the proposed scheme, the WT acts as a band pass filter which is able to effectively extract the fault generated transient signals. To measure the instants of fault transient arriving at each busbar, the running time of all fault locators is synchronised by GPS which can provide time base up to a 1μs accuracy. By comparing the difference between travelling times from fault point to all system busbars, the fault location can be determined by utilising the algorithm in the paper. The results arising from the simulation study shows that under different fault conditions, the proposed locator possesses remarkable performance in accurate fault location. In addition, its performance is not affected by the inception of fault, fault type and system configuration.

6. FUTRUE WORK

The research will be extended to investigate the response of the proposed protection relay on different simultaneous faults and study signal characteristic of other types of transients on the system with respect to 3D space, i.e. magnitude, frequency and time.

Reference:

[1]. Z.Q.Bo, " transient based protection", the journal of power system technology, No.2, 1996

[2]. H Lee, "Development of an Accurate Travelling Wave Fault Locator Using the Global Positioning System Satellites", 20th Annual Western Protective Relay Conference, October 19-21, 1993, Spokane, Washington, USA

[3]. Z Q Bo, J A S B Jayasinge, R K Aggarwal, A T Johns, "A New Scheme for Monitoring and Protection of Power Transmission System Based on Global Positioning System", Proceedings of the 31st UPEC, Sept. 1996, Crete, Greece

[4]. O. Rioul and M.Vetterli, "Wavelet and Signal Processing", IEEE singal processing Magazine, Vol. 8 No.4, 1991.

[5]. I. Daubechies, "The Wavelet Transform, Time-frequency Localization and Signal Analysis", IEEE Trans. Pattern Anal. Mach. Intell. 11(7), 1989.

[6]. P F Gale, P A Crossley, B Y XU, Y Z Ge, B J Cory, J R G Baker, "Fault location based on travelling wave", IEE Pul. 368, March 1993. pp.54-9.

Table 1. The response of proposed fault locator to various system fault under different conditions

Fault cases used in simulation study				Travelling time from fault to busbars B1, B2,B3 and B4 in ms				Analysis of fault location from bus B2 using proposed scheme		
No	Location	Fault type	Fault resistance	T1	T2	T3	T4	Actual (km)	detected (km)	Error (m)
1	F1	Phase 'a' to earth	0	5.012	5.005	5.048	5.034	4.0	4.0165	16.5
2	F2	Phase 'a' to earth	0	5.029	4.993	5.036	5.020	0.0	0.205	205
3	F3	Phase 'a' to earth	0	9.995	10.03	10.075	10.058	10.0	10.058	58
4	F4	Phase 'a' to earth	200Ω	5.012	5.005	5.048	5.034	4.0	4.0165	16.5
5	F5	Phase 'a' to phase 'b'	0	5.039	5.004	5.046	5.018	2.0	2.033	33
6	F6	Phase 'b' to phase 'c' to earth	0	5.048	5.012	5.019	5.040	5.0	5.0165	16.5

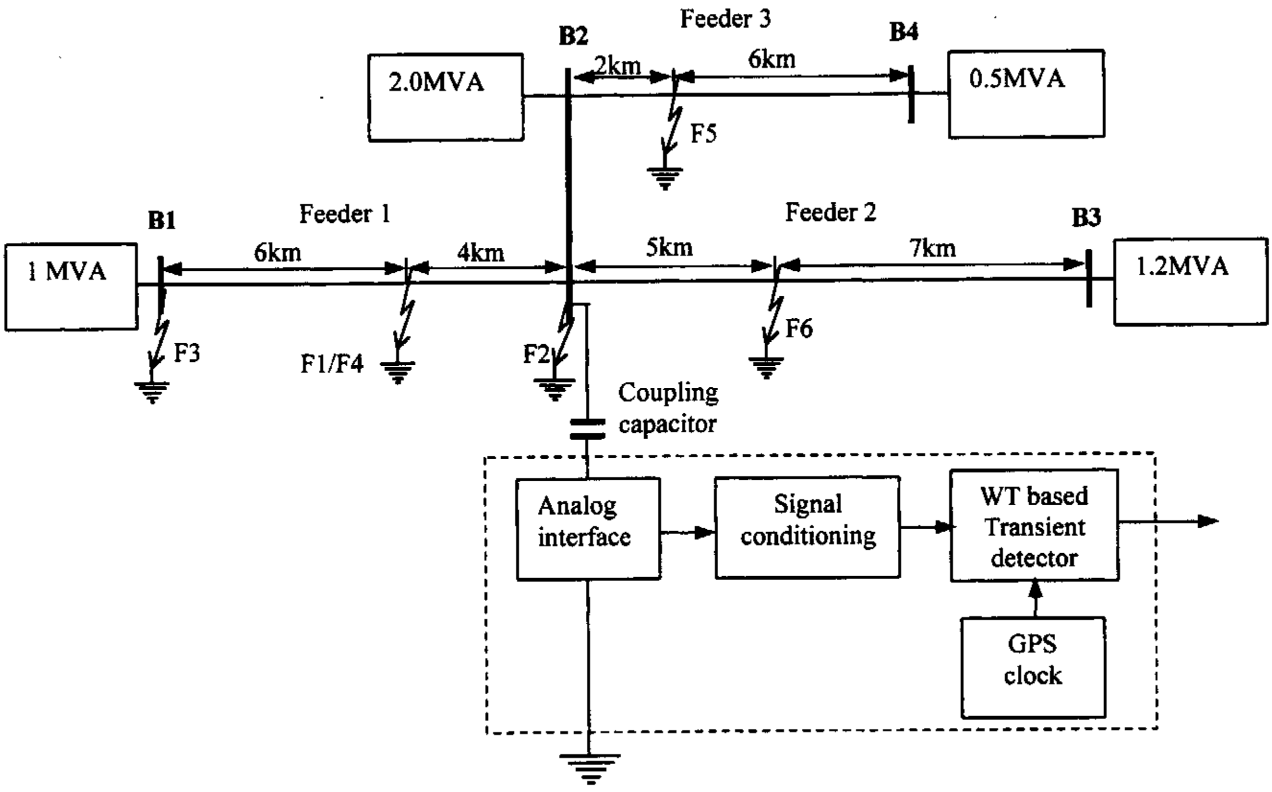

Fig. 1 Schematic of 11kV distribution system with one proposed fault locator at Busbar B2

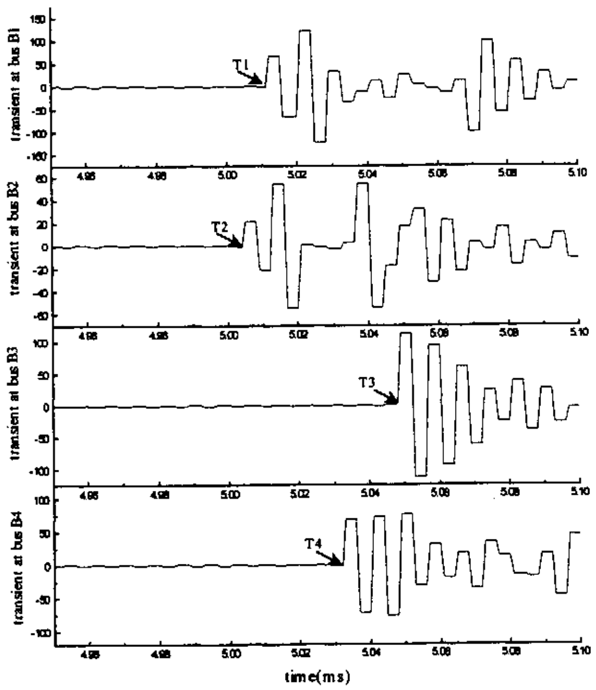

Fig.2 Response of the locators at B1,B2,B3 and B4 on a 'a'-to-earth fault at 'F1'on feeder 1 at 4km from busbar 2

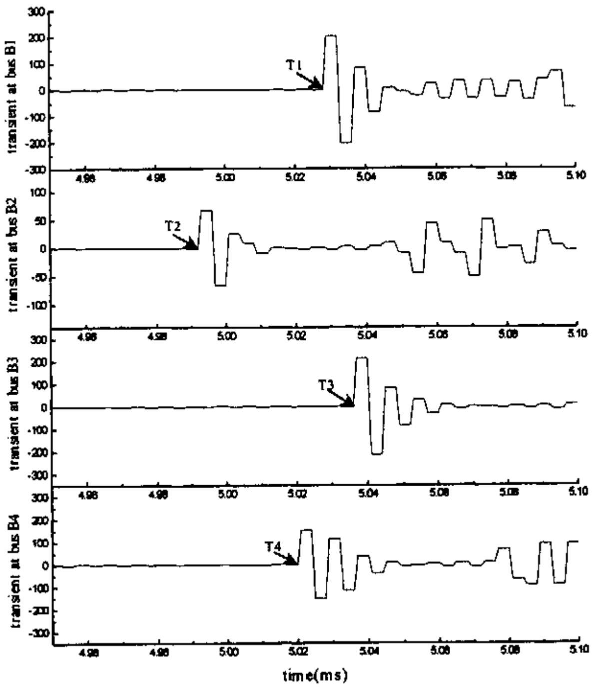

Fig.3 Response of the locators at B1,B2,B3 and B4 at 'F2' on a 'a'-to-earth fault on busbar 2

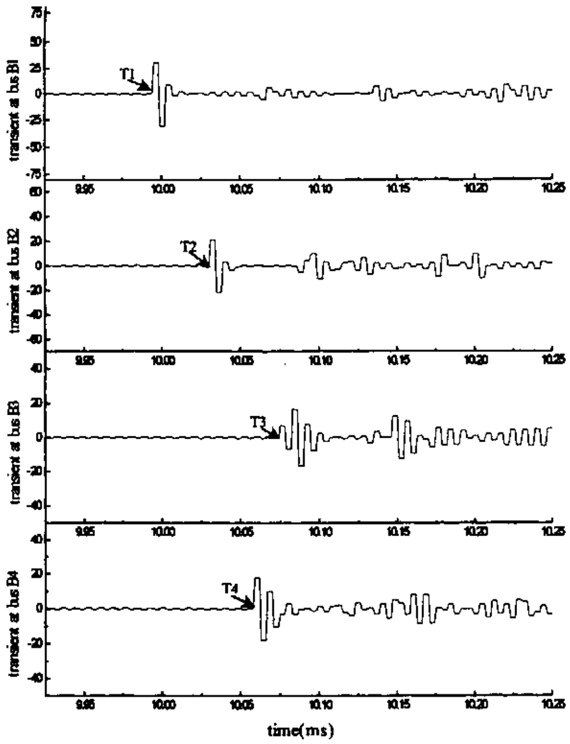

Fig.4 Response of the locators at B1,B2,B3 and B4 on a 'b'-to-earth zero voltage fault at 'F3' on busbar 1

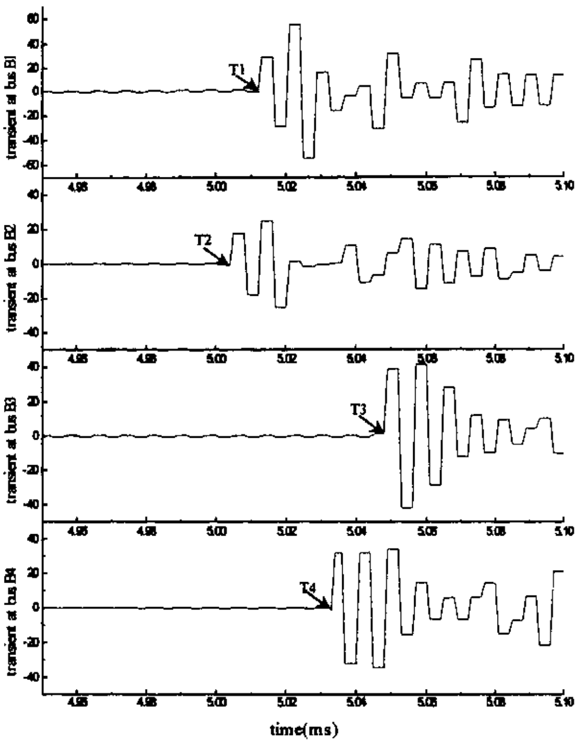

Fig.5 Response of the locators at B1,B2,B3 and B4 on a 'a'-to-earth high impedance fault at 'F4' on feeder 1 at 4km from busbar 2

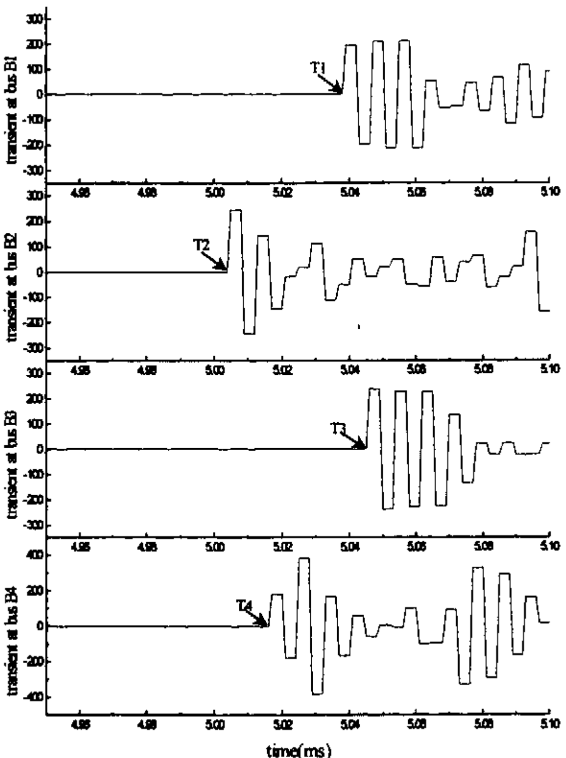

Fig.6 Response of the locators at B1,B2,B3 and B4 on a 'a'-to-'b' fault at point 'F5' on feeder 3 at 2km from busbar 2

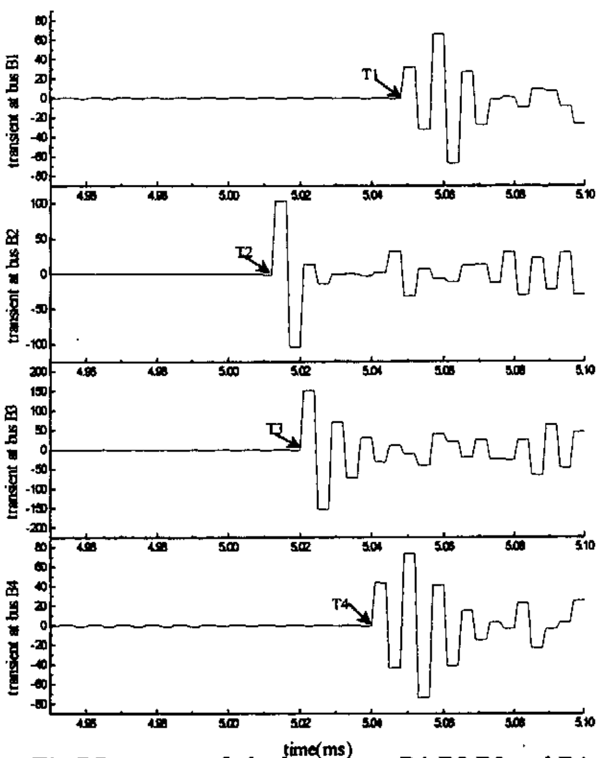

Fig.7 Response of the locators at B1,B2,B3 and B4 on a 'b'-to-'c' fault at 'F6' on feeder 2 at 5km from busbar 2