Mr. Chartier in the experiments reported in [13] and [16]. More specifically, the GPS receiver is a wideband correlation receiver that multiplies the receiver input (noise and signal) by a predetermined code and integrates the product over the duration of a navigation message bit (i.e., 20 ms) to detect signals with power as much as 29 dB *smaller* than the noise input. By correlating with an identical code embedded in the signal, the input noise power is effectively reduced to a level at which the signal can be received. Our goal, then, was specifically to study the issue of whether corona noise could interfere with the operation of a typical GPS receiver.

In addition, we note that there are several other important differences between Mr. Chartier's 900-MHz experiment and the one reported here. Of greatest importance is the fact that he used a "high gain" (i.e., 25 dB) parabolic antenna oriented toward the transmission line conductors. The fact that the antenna had "high gain" probably enhanced the corona noise input to the receiver. We, on the other hand, used an array of electrically small "low gain" antennas (specifically a circularly polarized cross-dipole antenna with a gain of less than 2 dB) typically incorporated into GPS receivers. The "low gain" of this array did not enhance the corona noise input nearly as much as did the "high gain" antenna used by Mr. Chartier. In fact, he said in [13] that "the use of a parabolic antenna with a gain of 25 dB will itself increase the overall sensitivity of the measurement system (authors' note: compared to a conical log spiral antenna with a gain of 4 dB) by 21 dB." We believe that the difference in antennas along with the fact that in [13] no noise was detected in fair weather conditions (approximately 20 to 25 dB less noise than during foul weather) means that it would be very difficult to even detect corona noise at 1575 MHz without a high gain antenna.

The fundamental question asked by Mr. Chartier was whether we have proven that there is no situation for which radio noise from conductor corona or spark discharges could interfere with the proper operation of a GPS receiver. The short answer to this question is no. Our goal was not that ambitious. Our conclusion was that "it is *unlikely* that power line conductors will interfere with the use of the GPS satellite signals." We did not claim to have examined all possible situations for which power lines could interfere with the operation of these systems.

It is helpful, however, to introduce the results of additional measurements that are relevant to the discussion. These were not reported in the paper simply because we did not have information about the satellite constellation for these cases similar to that reported in Fig. 4 for the case we did describe. The first was made under a relatively noisy 500-kV transmission line with a two conductor bundle that is part of the AC Pacific Intertie. The second was made under a 345-kV transmission line that was expected to be noisy due to its single conductor bundle. Both measurements were conducted during significant rain and were under lines that would be expected to have higher radio noise levels than the 345-kV lines on the corridor reported in the paper. In both cases, there was no loss of lock on any satellite signal experienced by the GPS receiver when operated in the vicinity of the transmission line.

The discusser specifically asked about the configuration of the 345-kV transmission lines shown in Fig. 5 in order that calculations could be made of its radio noise and compared to the 500-kV case reported in the paper. As shown in Fig. 4, there were two 345-kV transmission lines 100 ft apart. The 13.2-kV and 120-kV lines will be assumed here not to contribute to the maximum radio noise on the corridor since corona noise from them (if any) is much smaller than from the 345-kV lines. Each 345-kV line was a double circuit line with two conductor bundles at heights of 87, 62.5, and 41 ft above earth and horizontal locations with respect to the tower center of ± 19.5, ± 27, and ± 20.5 ft. Each subconductor diameter is 1.196 in and the subconductor spacing is 18 in. The phasing of each circuit is ABC from top to bottom except for the inside circuit of the first line that is phased CBA. This line was modeled with WBNoise and found to have a maximum average stable foul weather noise at 10 MHz of 38.4 dB $(\mu \mathrm{V/m})$ in a CISPR receiver at 1 m above the ground. For comparison, the maximum average stable foul weather radio noise level at 10 MHz for the 500-kV line used for the theoretical calculations was 38.9 dB $(\mu \mathrm{V/m})$ in a CISPR receiver at 1 m above the ground. It can be concluded that the noise during our measurements was reasonably close to that used for the theoretical calculations. Further, since fair weather noise is approximately 20 dB less than foul weather noise, corona noise from any existing transmission line is not expected to affect the operation of a GPS receiver during fair weather. This is consistent with the fact that Mr Chartier in [13] could not detect corona noise at 900 MHz during fair weather.

This paper does not prove "that all gap discharges will not affect the performance of GPS receivers." However, it is almost impossible to prove this since, as the discusser states, natural gaps are "notoriously unstable." While it would have been possible and useful to measure the spectrum of the radiation from one or more of the gaps studied here, the information obtained would have been limited. More specifically, knowing that radiation from any given gap source was "small" at 1575 MHz would mean that interference to a GPS receiver was not possible. But by measuring these sources directly with a GPS receiver, we already knew that this interference did not occur. However, if the radiation from any given gap source was known to be "large" at 1575 MHz, the problem is not solved either. This is because even if it is shown to produce no interference, there are likely to be other gap sources that have higher radiation levels. To prove that no gap discharge will affect the performance of a GPS receiver, the largest gap source anywhere on the power system must be identified. It is not clear to us how this can be done.

The practical approach we used was to operate the GPS receiver close to (i.e., usually within 20 to 30 ft; a minimum distance for ground operation of a GPS receiver) a number of robust gap sources (in this case, seven). In no case did the GPS receiver lose lock on a single satellite. While this does not prove that gap discharges cannot interfere with a GPS receiver, it does support the claim made in the conclusion that "it is *unlikely* that power line conductors will interfere with the use of the GPS satellite signals." We claimed no more than to have performed "some practical measurements under transmission lines" that support this conclusion.

Discussion of "A New Protection Scheme for Fault Detection, Direction Discrimination, Classification, and Location in Transmission Lines"

M. Sanaye-Pasand

This paper is a sequel to an earlier paper[1] by the authors. The authors proposed a new transmission line fault protective scheme using synchronized phasor measurements through global positioning system

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[1]J.-A. Jiang, C.-S. Chien, and C.-W. Liu, *IEEE Trans. Power Delivery*, vol. 17, pp. 34-42, Jan. 2003

(GPS) satellites. The authors should be commended for their paper investigating the proposed scheme extensively by numerous simulation studies.

The discusser would like the authors to further clarify and comment on the following points.

1) The proposed protective scheme includes considerable number of components [e.g., phasor measurement unit (PMU), transmitter/receiver, GPS receiver, communication link, etc. which could make the whole system complex]. Reliability of the protective system might decrease due to its high complexity.
2) In the case that GPS signal is not available, how does the algorithm behave? What kind of backup is considered for protecting the transmission line?
3) The communication link transmission delay is considered and compensated in the algorithm. Is the algorithm able to compensate nonconstant communication link delays?
4) Have the authors compared this algorithm with other transmission line pilot relaying algorithms? It is suggested that performance of the proposed algorithm would be compared to performance of the phase comparison scheme in a sequel work.
5) According to section III, Fig. 4, the algorithm has to perform a considerable amount of calculations in each sampling interval. Different tasks such as fault detection, fault classification, modal transformation, online parameter estimation, and direction discrimination should be performed in approximately 0.5 ms (32 samples/cycle). Have the authors experienced which kind of hardware should be used to implement the whole procedure?
6) Performance of the algorithm for high-impedance faults is evaluated using a three phase to ground fault with 1-kΩ fault resistance. This kind of fault on transmission lines is not that usual. It would be better to consider a more usual fault (e.g., single-line-to-ground fault with some fault resistance).
7) The CT saturation effect is studied and the relay response is presented in Fig. 9. According to the paper, "the fault location is set at 0.95 p.u. of the protected line." For remote faults, current transformers usually do not get saturated if they are properly selected. According to Fig. 9, the ratio of the fault current to the load current is approximately ten. It might be better to test the algorithm with more close-in faults to study CT saturation effect.
8) Have the authors tested the algorithm with any evolving fault case (e.g., phase-to-ground a-g fault evolving to two phase-to-ground a-b-g fault in a few milliseconds)? How does the scheme behave during transmission line switching and energization? These cases are worth to be further addressed in future research.

Closure on "A New Protection Scheme for Fault Detection, Direction Discrimination, Classification, and Location in Transmission Lines"

Joe-Air Jiang, Ching-Shan Chen, and Chih-Wen Liu

We would like to thank the discusser for his interest in our paper[1] and for his valuable and constructive comments. We first offer comments of a general nature, and then respond to questions in the order asked.

Real-time wide area measurements from phasor measurement units (PMUs) allow for innovative solutions to traditional utility problems. The synchronized phasors from substations are then collected at a central location. By collecting these precise synchronized measurements, techniques for monitoring, protection, and control of the power system can be developed and implemented [1], [2]. For example, ABB is presently developing PMU-based products and advanced solutions. PMU functions are also being integrated into ABB protective relays [1]. Better relaying and fault location performance can be achieved using multiterminal synchronized measurements. Based on this trend, a new PMU-based protection scheme is presented for transmission line protection.

1) We agree with the discusser's opinion that reliability is one of the basic considerations for designing relays. Digital relays overcome this problem by constantly executing self-monitoring routines in the background of protection processing. If a failure occurs, an alarm is immediately issued, and a specific failure message can be communicated to the maintenance personnel. According to the descriptions about applications of global positioning system (GPS) to relaying and control in [2], we can say that the reliability of the GPS system is nearly ideal. When the GPS signal is interrupted or incorrect within a predefined time, an alarm signal will be sent, and the synchronized sampling method will be changed into a traditional version. It is also important to detect channel failures and promptly activate backup protection such as distance protection during such conditions, and to return to normal when channel quality is restored. The reliability of the proposed scheme can be further improved by adding redundant communication channels. In particular, the use of digital communications and numerical relays enabled us to provide a greatly enhanced relaying scheme together with network supervision and control.
2) When the protection scheme with GPS for data synchronization is proposed, the likelihood of the loss of GPS signals and antenna failure should be considered. In practice, when the GPS antenna is well sited, the loss of GPS signals is rare. Moreover, it is also possible to run the traditional ping-pong technique for propagation delay measurement as a continuous background task even when the GPS signal is lost [3]. Digital technology offers inclusion of many protection functions in a relay unit. When the GPS signal is not available, it is still possible to maintain protection by

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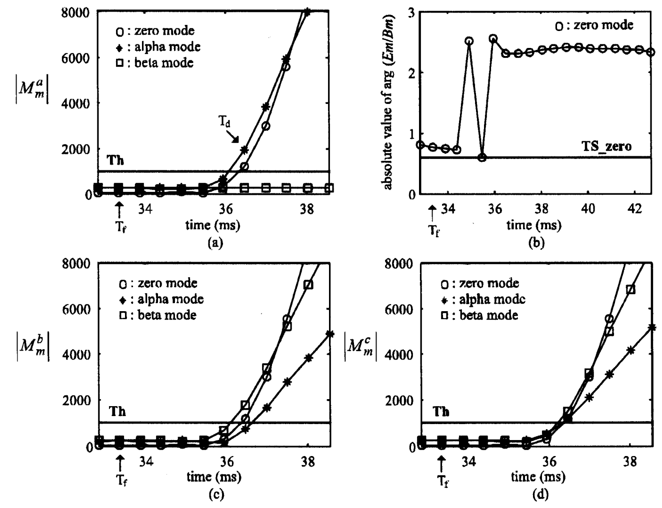

Fig. 1. Relay response for a phase-'a' to ground fault with a high fault resistance. (a) The behaviors of modal fault detection index $|M_m|$ under phase-'a' basis. (b) The response curves of $\text{abs}[\arg(E_m/B_m)]$. (c) and (d) are the behaviors of modal fault detection index under phase-'b' and -'c' basis, respectively.

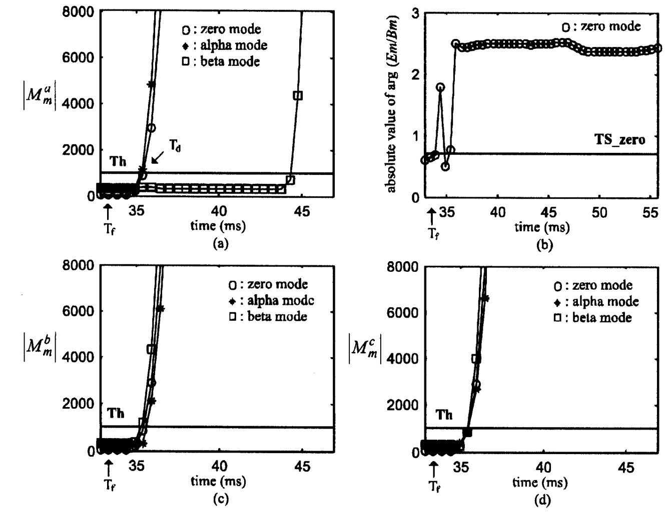

Fig. 2. Relay response for an evolving fault. (a) The behaviors of modal fault detection index $|M_m|$ under phase-'a' basis. (b) The response curves of $\text{abs}[\arg(E_m/B_m)]$. (c) and (d) are the behaviors of modal fault detection index under phase-'b' and -'c' basis, respectively.

using the nonunit elements, distance relays, or directional overcurrent, as backup protection within the same relay and alternatively enabled on communication channel failure. This diversity of operation principles in the same unit enhances the overall relay performance without a significant cost increase.

3) Communication time delay produces a phase shift between the local and remote signals in unit protection systems. One of the widely used techniques to align the signals is known as the "ping–pong" technique, which measures the time delay between the sampling pulses at two different locations. Once the delay between the two sampling pulses is measured, the two signals corresponding to these two sampling pulses are time aligned. The ping-pong technique assumes that the forward time delay is equal to the return time delay [4]. However, the proposed relaying scheme uses an external reference signal (i.e., GPS signal, to synchronize the line measurements at both ends). This method removes the need to measure and compensate for the communication delay. Therefore, the effect of nonconstant channel delay on the protection algorithm can be ignored.
4) The authors would like to point out that the work presently being carried out is preliminary research. Extensive simulations under various system and fault conditions are performed to verify the performance and correctness of the proposed relaying algorithm. The studies of the proposed scheme compared with other transmission line pilot relaying algorithms are not considered here. We agree with the discusser's opinion that perhaps a future work may undertake a comparative study.
5) Since the proposed algorithm is performed in a sequential method, the various tasks such as fault detection, direction discrimination, and fault classification are not executed simultaneously in each sampling interval. Moreover, the online parameter estimation is performed at a predetermined interval before a fault occurs. The algorithm also can be implemented in a lower sampling rate such as 16 or 12 samples per cycle but may take more relaying response time. Now, the algorithm is only programmed using MATLAB in a personal computer to check its correctness. In the future, we will implement the algorithm using C language or assembly language on a digital signal processor (DSP) board. With the advancements of high-speed DSPs, we believe that the algorithm can be real time executed.
6) We agree that a three-phase to ground fault with 1 kΩ fault resistance on transmission lines is not usual. Following the discusser's comment, the authors show a relay response for a phase-'a' to ground fault. The fault resistance is 300 Ω, and fault position is set at 0.5 (p.u.). As shown in Fig. 1(a) and (b), the proposed relaying scheme correctly detects the fault and discriminates the fault as an internal fault. From the patterns shown in Fig. 1(a), Fig. 1(c), and Fig. 1(d), it is obvious that the fault type is phase-'a' to ground fault.
7) The discusser seems to misunderstand the definition of fault location used in this paper. As shown in Fig. 5 in this paper, the power flow direction is from bus A to bus B and the fault position of 0 p.u. is defined at receiving end (i.e., bus B). For more detail descriptions, the discusser can refer to our previous research [9]. Fig. 9 shows a relay response for a fault occurring at 0.95 p.u. of the protected line, and the fault does not belong to a remote fault. Moreover, the ratio of the fault current to the load current is about 15 rather than 10. We agree that current transformers (CTs) will not get saturated if they are properly selected. In this paper, we purposely make CTs saturation to test performance of the algorithm under this situation.
8) It is very important that the faulted-phase selector is capable of changing the decision in the event of an evolving fault. Fig. 2 depicts an evolving fault response in which a phase to ground a–g fault subsequently evolves into a two phase to ground a–b–g fault approximately 10 ms after initial fault inception. From Fig. 2, we observe that the scheme will fast detect the fault, discriminate the fault as an internal fault, and correctly identify the faulted phase (a-phase) after the a–g fault occurrence. After time of 10 ms, the beta-mode signal in Fig. 2(a) is also greater than the predefined threshold. At this time, the fault type will be identified as two phase to ground fault and then a three-phase tripping command is issued. Thus, the scheme can work well in case of evolving faults.

Reclosing a faulted line or transmission line energization would result in a high inrush current. These cases should be recognized by the relay. Through preliminary simulation studies, if a faulted line is reclosed, the proposed scheme can correctly detect the fault again. When a transmission line is energized, the value of the fault detection index will be greater than the predefined threshold and then decays with time.

Under this condition, the behavior of the scheme is similar to an external fault case. Utilizing the fault detector incorporated with appropriate threshold setting and the fault direction discriminator, the scheme does not issue a tripping command. Indeed, these cases need to be further investigated and are now under progress through extensive simulations. We hope to report the results in the future. In addition, a technique to discriminate between the line charging inrush current and the current resulting on closing or autoreclosing a faulted line is proposed in [5]. We also can use the technique to supplement our proposed relaying scheme. If the case is recognized as closing a faulted transmission line, the breaker should be tripped again. However, if the case is identified as closing on line energization, the relay does not trip the breaker and then our scheme takes over its normal function.

Once again, we would like to thank the discusser very much for his insightful and valuable comments on our paper.

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Discussion of "Frequency Characteristics of Wavelets"

Chen Xiangxun

In the above paper,[1] wavelet transform (WT) is to measure the local similarity between waveforms of the signal and the wavelet [1], [2]. It is a misunderstanding that any wavelet is suitable for any signal and any applications. Choosing or designing the right wavelet is crucial for a successful WT application. This is the problem that many authors in power community have not paid attention to, but the author of the paper and a few others [3], [4] did pay attention to. However, the criterion for choosing the right wavelet depends on the application. For example, compressing data and extracting feature by WT require different wavelets. Not one criterion including the number of coefficients or the bandwidth characteristics of a wavelet suggested in this paper is suitable for all applications.

The number of coefficients and the bandwidth characteristics at different scales of a wavlet are not certainly related. There are many wavelets, which correspond to various bandwidth characteristics but with the same number of coefficients. Furthermore, frequency characteristic of a wavelet includes magnitude spectrum (MSP) and phase spectrum (PSP). A variety of wavelets has the same MSP but different PSPs. It can be proved [5] that the number of the effective WT coefficeints (i.e., the energy distribution at WT-domain depends not only on the MSP but also more strongly on PSP). The bandwidth characteristic only involves the MSP. Obviously, it is not complete to characterize the frequency characteristic of a wavelet by its MSP.

Even for MSP, it is also not complete to characterize MSP by bandwidth characteristic. For a given bandwidth, we have a variety of MSP with different decay toward high frequency (DHF) and different decay toward low frequency (DLF). The DHF corresponds to the regularity of the wavelet and the DLF to the number of vanishing moments [6]. Both of them are important for various applications of wavelets.

As for minimizing the energy leakage at WT-domain, we have two choices. One is to make the energy concentrate on a few scales. The other is to make the energy concentrate on a few coefficients at given scales [7]. The two choices correspond to different requirements on the wavelet. It seems that choosing a wavelet from the point of view of bandwidth may not be the best way.

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Closure on "Frequency Characteristics of Wavelets"

Chethan Parameswariah and Mickey Cox

We thank Dr. Xiangxun for his reply and interest in our paper[1] "Frequency Characteristics of Wavelets." We agree that a proper choice or design of wavelet depends on the application; a specific wavelet may be an excellent candidate for one application and be a poor choice for a different application. In our opinion, this issue has not received sufficient attention and this is what we intended to understand and clarify in our paper by looking at one particular property—the coefficients of wavelets and the energy distribution.

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