Settings-Free Strategy for Correlation-Based One-Ended Traveling Wave Fault Location Methods

R. L. A. Reis, F. V. Lopes, K. M. Silva, A. M. Britto, A. D. Rajapakse, W. L. A. Neves

***Abstract*—This work presents a new settings-free strategy to minimize the dependence of some user-defined adjustments in single-ended correlation-based traveling wave fault location (SEC-TWFL) techniques. Basically, the short-circuit point is estimated considering increments of the data window length used in the correlation process of forward and backward signals, whose limits are extended from suggested values reported in the literature. As a result, the greater gathering of fault location estimations taken from the variety of window lengths indicates the most likely disturbance point and the associated search field, whose auxiliary information help the utility maintenance crew in finding the fault distance in the field. The validation of the proposed solution is carried out by means of several Alternative Transients Program (ATP) fault simulations in a series-compensated 500 kV/60 Hz double-circuit transmission network, modeled with real parameters. The obtained results attest the benefits about the immunity of previous adjustments on SEC-TWFL routines.**

***Keywords*—Correlation-based functions, fault location, sensitivity analysis, transmission lines, traveling waves.**

I. Introduction

TRANSMISSION line (TL) fault location applications appear as one of the first functions to be used during disturbance analysis procedures for power system utility crews. Among the existing techniques, traveling wave (TW)-based algorithms have shown to be the most fastest and reliable solutions, since they just need to correctly identify the first fault-induced transients [1].

Two-ended TW-based fault location approaches have increasingly been used in a larger scale worldwide. However, problems on communication and time synchronization means may take place, affecting the performance of these kind of methods [2]. Such characteristics associated with the required cost to monitor two TL buses have attracted the attention of protective relay manufacturers and researches towards developments on single-ended TW-based solutions [3]. In this context, although one-terminal routines are easier to apply in the field as they do not require communication paths, the need of sophisticated filtering techniques to properly distinguish fault-induced reflected from refracted surges are still commonly reported as a limiting factor, which highlights the need of studies regarding computational implementations to deal with such aspects [2], [4].

The correlation of forward and backward TWs was one of the first computational strategies among single-ended TW-based techniques to estimate the short-circuit distance. However, impacts of low frequencies in the correlation function, the chosen filtering techniques, the fault classification process, high fault resistances, and mainly in the adjustments of data window lengths used to correlate the forward and backward TW relaying signals had led such methods to be replaced by other routines over the years [5], [6]. Nevertheless, the reliable identification of fault-induced reflections is still a challenge, even counting on the use of both impedance- and TW-based methods (hybrid algorithms), especially due to the well-known limitations of the phasor-based algorithms [4], [7]. In this way, following the advances in digital signal processing procedures, the resumption of computational studies on correlation-based strategies for one-terminal TW-based fault location applications was inevitable [3], [8].

Traditionally, single-ended correlation-based traveling wave fault location (SEC-TWFL) techniques reported in the literature use distinct filtering strategies and adjustments [3], [5], [6], [9], whose performances are susceptible to errors depending on the user-defined parameters. Recent works have carried out sensitivity analysis to determine the key settings of such routines to make them more robust, proposing new recommended adjustments to be applied [10]. However, they still depend on the evaluated power grid and the data window length of the monitored TW relaying signals. As a consequence, different performances may still be achieved by these algorithms as a function of their adjustments, which highlights the need of SEC-TWFL functions independent of some setting parameters, such as the length of the used observation window.

Therefore, sensitivity analysis and computational studies are carried out in this work to enhance the performance of SEC-TWFL algorithms by eliminating their dependence on the user-defined window length setting. Such a new proposed computational correlation strategy is obtained through determining the most likely fault location result from a range of different observation window lengths. Basically, for each short-circuit scenario, the fault point is

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estimated considering increments of the referred data window length, whose limits are extended from suggested values reported in the literature. As a result, the fault location estimations are statistically analyzed, and the greater gathering of such estimations taken from the variety of data window lengths indicates the most likely short-circuit point and the associated search field, whose auxiliary information is crucial for the utility maintenance crew in finding the fault distance in the field.

The validation of the proposed computational strategy is carried out by means of several Alternative Transients Program (ATP) fault simulations on a series-compensated 500 kV/60 Hz double-circuit transmission network located in the north region of Brazil, whose topology and parameters are realistically modeled. The obtained results show better performances of the proposed solution compared to other routines reported in the literature, and with no dependence to previously adjust the fault location function, making it more immune to possible errors in such procedure.

II. Fundamental Principles of SEC-TWFL Methods

The fundamental principle behind SEC-TWFL methods consists in detecting the reflected surge from the short-circuit point, which is accomplished by a correlation process between forward (S_f) and backward (S_b) signals. Such relaying waveforms are respectively defined as [5]:

$$S_f = v(x,t) + Z_s i(x,t), \tag{1}$$

$$S_b = v(x,t) - Z_s i(x,t), \tag{2}$$

being v and i the aerial mode voltage and current measured at a particular point x of the TL, respectively, t the time, and Z_s the TL surge impedance. Essentially, S_f consists in the TWs moving from the monitored bus to the fault location (assuming that the local TL bus is situated at the left side of the grid), and S_b consists in the TWs moving in the opposite direction. The v and i can be derived from the classical solution of the differential equations of a lossless TL, which are [2]:

$$v(x,t) = f_f\left(t - \frac{x}{\upsilon_{tw}}\right) + f_b\left(t + \frac{x}{\upsilon_{tw}}\right), \tag{3}$$

$$i(x,t) = \frac{1}{Z_s}\left[f_f\left(t - \frac{x}{\upsilon_{tw}}\right) - f_b\left(t + \frac{x}{\upsilon_{tw}}\right)\right], \tag{4}$$

whose f_f and f_b are the forward and backward TW relaying functions, and υ_{tw} is the TW propagation speed. In this paper, the υ_{tw} is estimated by imposing an energization maneuver in the left terminal of the phase-domain frequency-dependent line model, recording the surges monitored in such a terminal. In these cases, the effects of TW dispersion and attenuation as a function of frequency are minimized when the aerial mode TW velocity is computed, reducing the dependence of TL distributed parameters with frequency [11].

The correlation function (ϕ) is computed by means of a data window containing information of fault-induced transient patterns generated by TWs reaching the monitored TL bus (template signal), in which similar TW patterns are expected to be created when fault-induced reflected surges reach the monitored TL end [5], [6]. The ϕ function is obtained according to:

$$\phi(\tau) = \frac{1}{\Delta k}\sum_{k=1}^{\Delta k} S_b(k\Delta t + \tau)\cdot S_f(k\Delta t), \tag{5}$$

being k the k-th sample, Δt the sampling period, Δk the user-defined data window length, and τ the time delay between S_f and S_b. The best match between S_f and S_b relaying signals consists in the maximum peak at the $\phi(\tau)$ output, indicating the time instant τ in which the incident and its respective TW reflected from the short-circuit point present similar waveform shapes [5]. On the other hand, since the fault-induced reflected waveshapes mismatch from other surges present in the grid, the correlation function output is not sensitized. As long as this particular τ value is estimated, classical one-terminal TW-based fault location formulations can be used, such as [12]:

$$d_1 = \frac{\upsilon_{tw}\cdot\tau\cdot\Delta t}{2}, \tag{6}$$

being d_1 the fault distance estimated by means of a single-ended application.

Classical SEC-TWFL methods typically remove S_f and S_b mean values present in the corresponding Δk sampled windows prior to compute ϕ. This process is used to minimize the effects of low frequencies that may appear superimposed to the respective relaying signals [5], [6], [9]. However, this procedure is not able to completely remove all the associated low frequencies in S_f and S_b, affecting the reliability of the correlation function output, and consequently the d_1 fault distance estimation [10]. To deal with such scenario, the use of a higher frequency spectrum in the relaying signals improves the process of computing ϕ, considering frequencies from 20 kHz, as suggested in [10], for example. Here, such cutoff frequency is taken into account during the subsequent analysis.

It is worth mentioning that a correlation process is a common way used by other filtering strategies in TW-based routines to estimate τ. Basically, in such cases, the voltage and/or current waveforms are correlated against template signals pre-defined by protective devices or algorithms, whose signals are usually determined as some filter coefficients (taken from differentiator-smoother technique [4] or wavelet transforms [8], for example). As a consequence, the best match between the template signal and the evaluated electrical quantity provides a maximum peak in the filter output, indicating a TW identification. This process is similar to the one described in Eq. (5) in SEC-TWFL functions, but the template signal in such techniques is defined from the voltage and current waveforms measured in the power grid.

To estimate the τ value and consequently determine d_1, the correlation function described in Eq. (5) depends on the length Δk of the used data window. As a result, the template signal can present more or less information about the power network and the short-circuit as a function of the setting Δk. To illustrate this scenario, S_f waveform is shown in Fig. 1 with respect to different values of Δk, considering a BC fault applied at 93.11% (208.34 km) of the grid described in section IV. As it is presented in such figure, for a bigger

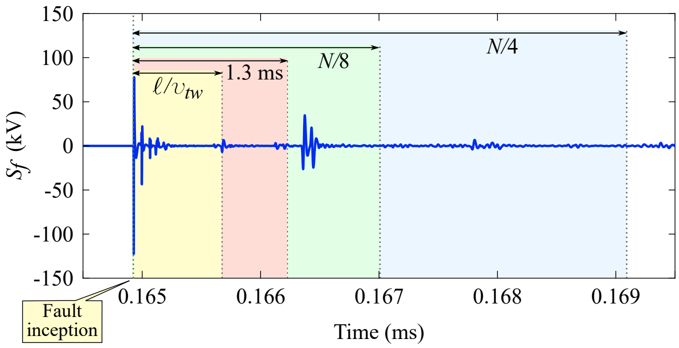

Fig. 1. S_f waveform for a BC fault as a function of Δk.

data window length, more information about the fault-induced TW patterns can be used as a reference to the correlation procedure. On the other hand, if lower values of Δk are taken into account, it is possible that some of the first TWs presented in the network may not be inserted in the template signal, leading the correlation process to misoperate depending on the disturbance characteristics.

SEC-TWFL methods reported in the literature define the parametric setting Δk, as the ones presented in Table I, in which *Method 1*, *Method 2* and *Method 3* are the SEC-TWFL fault location techniques reported in [3], [5] and [6], respectively. In *Method 3*, ϕ is computed by the sum of two correlation functions, but one with a bigger Δk length, and the other one with a smaller Δk value. This procedure is used to increase the final correlation function output.

Sensitivity analysis were carried out in [10] to check the viability of such predefined parametric setting and its impact on the performances of SEC-TWFL routines. From the performed studies, a set of new recommended settings of Δk for each evaluated method was proposed. These values are also shown in the last column of Table I. However, the referred parametric settings are still a field to be adjusted by the user and can be different depending on the power system. As a consequence, distinct performances of such SEC-TWFL methods may be achieved according to their settings, which may be also subjected to human errors during such adjustment process, or even by the considered network.

Hence, a setting-free strategy is attractive to the industry and researches during the application of SEC-TWFL algorithms, since the performance of such methods would be more immune to errors during the adjustment procedures and could be applied to different grids, eliminating the need to previously carry out studies for each power system in order to define Δk. These studies are the main focus of this work, which aims to address the best computational practices to make SEC-TWFL techniques independent of user-defined adjustments in Δk value.

TABLE I
LENGTH Δk OF THE USED DATA WINDOW REPORTED FOR EACH EVALUATED SEC-TWFL METHOD

Method	Δk (Reported setting)	Δk (Recommended setting)
1	$N/2$[1]	$N/2$
2	1.3 ms	$N/4$ (shorter TL) 1.3 ms (longer TL)
3	ℓ/v_{tw} (long window)[2] $\ell/4v_{tw}$ (short window)	ℓ/v_{tw} and $\ell/4v_{tw}$ (shorter TL) 1.3 ms and $\frac{1.3}{4}$ ms (longer TL)

[1] N is the number of samples per cycle.
[2] ℓ is the TL length.

III. Proposed Correlation Strategy

To eliminate the need of adjustments in Δk during the application of SEC-TWFL functions in order to provide a setting-free procedure, a computational correlation strategy is proposed. Basically, it consists in estimating the fault location by means of increments in Δk length to compute ϕ, whose limits are extended from the suggested values described in Table I.

The process starts by computing ϕ as in Eq. (5) with the lowest value typically defined for the short window length used by *Method 3* for Δk ($\ell/4v_{tw}$ - see Table I). Afterwards, Δk is incremented by a step of $\ell/4v_{tw}$ and a new ϕ function is computed. In the literature, it is usual to consider values up to $N/2$ for Δk [3], but tests to check the viability of using higher values are still scarce. Here, such upper limit is extended up to $1.2N$ in order to investigate if bigger observation window lengths bring advantages to the correlation task, and to provide more information about the power grid and fault-induced transients through the relaying signals to the correlation procedure. As a result, ϕ is defined as a function of Δk, which is computed for each increment value. This procedure is summarized in Eq. (7), which is derived from Eq. (5), as:

$$\phi(\Delta k, \tau) = \left[\frac{1}{\Delta k} \sum_{k=1}^{\Delta k} S_b(k\Delta t + \tau) \cdot S_f(k\Delta t) \right]_{\Delta k = \frac{\ell}{4v_{tw}}, \ldots, 1.2N} . \quad (7)$$

On the other hand, considering all Δk increments in Eq. (7) can lead to a time-consuming task to estimate the fault location. To speed up the correlation function calculation, after $\Delta k = N/2$, the increments are defined following a relationship of $\frac{i}{i+1}N$, being $i = 2, 3, ..., 20$. This is due to the fact that, for bigger data window lengths, the fault-induced reflected TWs from the short-circuit point may be attenuated, and the samples saved in S_f and S_b windows may contain more information about TW reflections and refractions from other parts of the network. However, although they are important to ϕ, there is no need to maintain steps of $\ell/4v_{tw}$ in such evaluated period if the fault-induced surges may present themselves as attenuated TWs.

The fault location d_1 is computed for each considered Δk value in ϕ, and the obtained estimations are statistically analyzed. Basically, the greater gathering of such fault point estimations taken from the variety of data window lengths indicates the most likely short-circuit distance and the associated search field, whose auxiliary information is crucial for the utility maintenance crew in finding the fault location in the field. By statistically analyzing as a boxplot, the final fault distance is determined as the median value of d_1, and the associated search field consists in the d_1 occurrences within the lower and upper percentiles, i.e., the fault locations estimated in 25% and 75% of the evaluated scenarios, respectively. The whiskers and the outliers are not considered to address the corresponding search field, since they consist in values outside the respective interquartile range. Therefore, the median value of all evaluated estimations considering the different data window lengths is the final fault distance, and the interquartile is the associated search field.

To illustrate the process of estimating the fault location and the associated search field, the same BC short-circuit taken into account in Fig. 1 is considered, whose obtained results are shown in Fig. 2. It is worth mentioning that the value of ℓ is used to provide only a starting point for the fault location estimation process (as used by *Method 3*), but a different minimum size of Δk may also be used if ℓ is not known nor estimated with acceptable accuracy, such as 0.975 ms, for example.

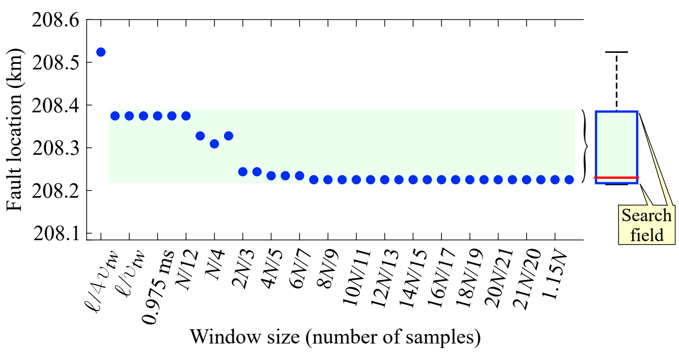

Fig. 2. Process of estimating the fault location and the associated search field.

From the fault location estimations presented in Fig. 2, the search field is defined by the interquartile range (distance between the bottom and top of the box), whose limits are defined from $\Delta k = 1.3$ ms, in this case study. These limits were obtained as 93.04% (208.21 km) and 93.12% (208.37 km), respectively. The obtained d_1 median value is approximately at 93.06% (208.23 km). Regarding the median value, the fault location estimation begins to converge around a final value from a data window length of $2N/3$, in this evaluated scenario. It is worth mentioning that, in Fig. 2, the final fault distance is represented in red color (median value), and the associated search field is represented in green color (interquartile). For other fault situations or power systems, these limits can be different, as well as the initial Δk data window length in which the interquartile is generated. However, irrespective to the grid and the short-circuit type, the proposed strategy provides the most likely fault location estimation and the associated search field, without the need to previously adjust the used SEC-TWFL technique.

IV. Analysis Methodology and Results

To investigate the viability of the proposed correlation strategy on SEC-TWFL techniques, short-circuit simulations were carried out on a 500 kV/60 Hz double-circuit series-compensated TL located in Brazil, whose power grid is shown in Fig. 3. The substation names and network parameters are not shown in the figure for confidentiality reasons. The system is modeled in ATP/ATPDraw and the faults were applied at the circuit 2 (C2) of the double-circuit TL interconnecting both 500 kV Buses 1 and 2, which is 223.76 km long. There is also a DC $\pm$ 800 kV lines connecting Bus 5 to Bus 11 and Bus 12. The TLs are modeled using a modal-domain frequency-dependent model (JMartí) with parameters adjusted to represent the range from 0.1 Hz to 1 MHz, with 10 points per decade. Then, the TW propagation speed was estimated by a TL energization maneuver, resulting in approximately 298,744 km/s.

In each simulation, voltage and current signals measured at Bus 1 are used as input data to the evaluated SEC-TWFL methods, considering a sampling rate of 1 MHz. Regarding the voltage sensors, it is usually reported that conventional coupling capacitor voltage transformers (CCVTs) present poor frequency responses at a wider bandwidth, with most of the CCVT digital models reported in the literature validated for frequencies up to few tens of kHz [13]. Such features may affect the proper measurement of fault-induced reflections and refractions in the voltage signal, and, consequently, in SEC-TWFL routines. However, researches and practical applications are moving towards the development of alternative solutions to compensate the CCVT dynamics at such spectrum, by measuring the capacitive stack currents to reconstruct the corresponding voltage waveform [14], or by means of optical voltage transformers [15], for example. Since the main goal here is investigating the advantages of a setting-free SEC-TWFL solution, it is considered that the voltage signals are accurately represented in the CCVTs secondary sides, i.e., they are measured with acceptable accuracy at the monitored TL bus. Then, ideal CCVTs are taken into account during the evaluations. Regarding the current transformers (CTs), they typically present a flat frequency response over a wider spectrum, representing high frequency components with acceptable accuracy [16]. Thus, ideal CTs are also considered in this work during the evaluation process.

To allow comparative analysis with the proposed correlation strategy, *Methods 1*, *2* and *3* were also taken into account with their reported and recommended settings described in Table I. In this context, 72 ATP fault simulations were carried out for each evaluated SEC-TWFL algorithm, varying their parameters, such as fault resistance, inception angle, type and location, resulting in a total amount of 648 evaluated short-circuit scenarios[1]. The fault parameters are presented in Table II.

The obtained results are analyzed according to the estimated absolute errors, which is defined as $\varepsilon = |d_1 - \tilde{d}_1|$, being d_1 the actual short-circuit distance and $\tilde{d}_1$ the estimated fault point. The obtained errors for *Methods 1*, *2* and *3* are named as ε_{M_1}, ε_{M_2} and ε_{M_3}, respectively.

[1]For *Method 1*: 72 fault cases considering the proposed correlation strategy, 72 scenarios for the reported setting and 72 cases for the recommended setting described in Table I. The same quantities are used for both *Methods 2* and *3*, resulting in a total amount of 648 evaluated fault cases.

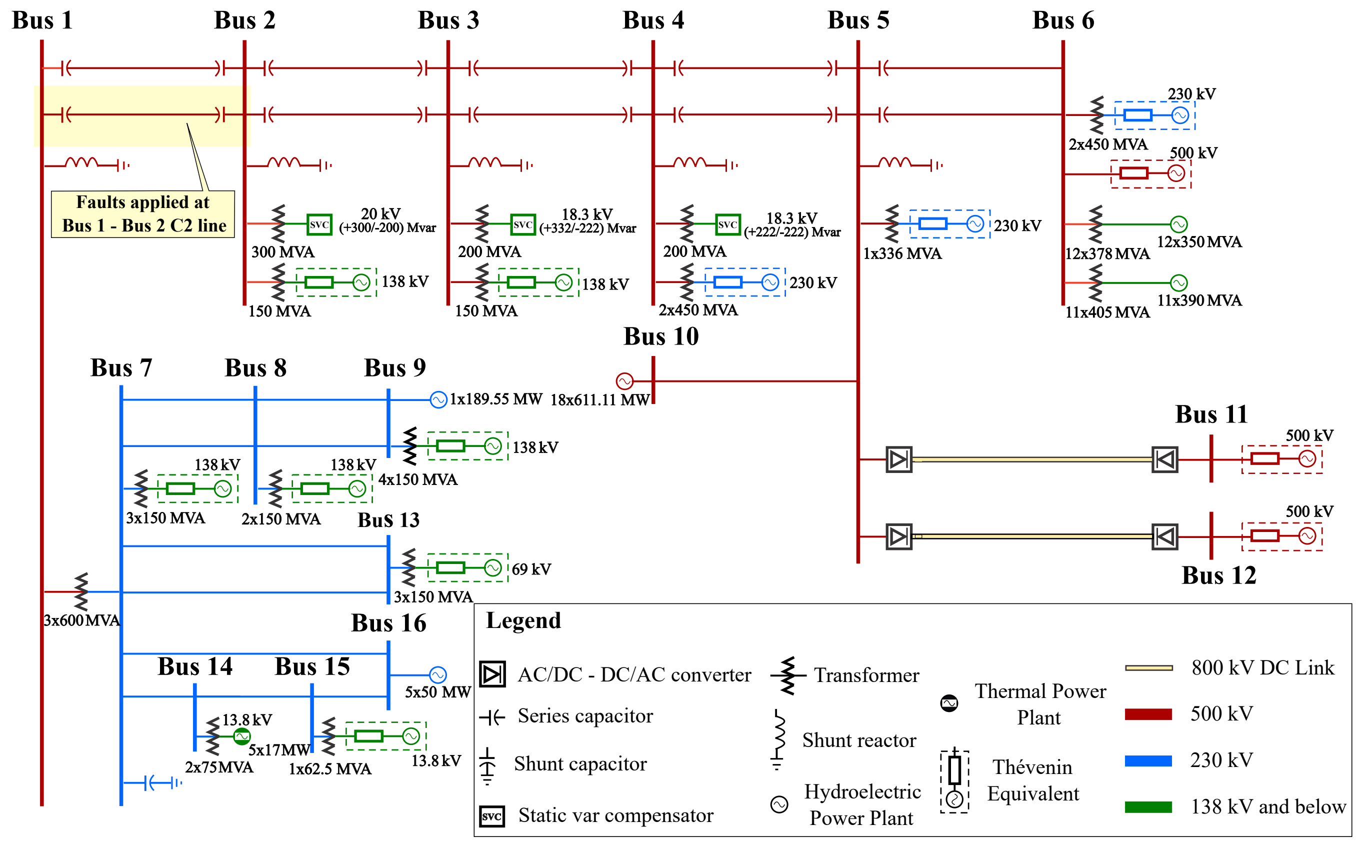

Fig. 3. 500 kV/60 Hz power network used in the analysis.

TABLE II
FAULT PARAMETERS USED DURING THE SIMULATION STUDIES

Simulation variables	Values
Fault location (km)	10, 111.36, 208.34
Fault type	AG, BC, BCG, ABC
Inception angle (°)	30, 60, 90
Fault resistance (Ω)	1, 40

TABLE III
NUMBER OF NON-CONVERGENT FAULT SCENARIOS FOR EACH CONSIDERED SEC-TWFL TECHNIQUE

Method	Number of non-convergent cases		
	Proposed strategy	Recommended setting	Reported setting
1	1	1	1
2	3	8	10
3	3	7	11

A. Obtained Results

The comparison between the proposed correlation strategy for SEC-TWFL applications against the use of recommended and reported settings described in Table I are depicted as stack bars in Fig. 4, in which the absolute errors are plotted as a function of the considered fault parameters. In the following analysis, only the estimated errors smaller than approximately 1 km (three tower spans) were taken into account (convergent cases), whose limit is typically reported as within the range of accuracy for TW-based functionalities. Errors bigger than this threshold were considered as non-convergent situations, whose number of cases for each evaluated SEC-TWFL technique is presented in Table III. In Fig. 4, there is no bar if an evaluated case is a non-convergent scenario.

From the obtained results shown in Fig. 4, the proposed setting-free strategy has presented a better performance compared to the use of Δk recommended and reported settings, especially for *Methods 2* and *3*. Particularly, most of the fault cases classified as non-convergents for such routines were properly identified by using the proposed correlation procedure. In fact, by incrementally varying the observation data window for each short-circuit case, it is possible to have information about the greater gathering of fault location estimations as a function of Δk, which provides more accurate and robust results about the disturbance point. On the other hand, if such strategy is not carried out, depending on the user-defined adjustment, the fault location can be even estimated outside a certain range of accuracy (search field), as in the case illustrated in Fig. 2 for lower values of Δk. For *Method 1*, similar results for the different strategies were obtained.

Regarding the results shown in Table III, only *Method 1* has presented the same number of non-convergent cases irrespective to a setting-free process (proposed strategy) or by using a predefined Δk setting. However, there is no

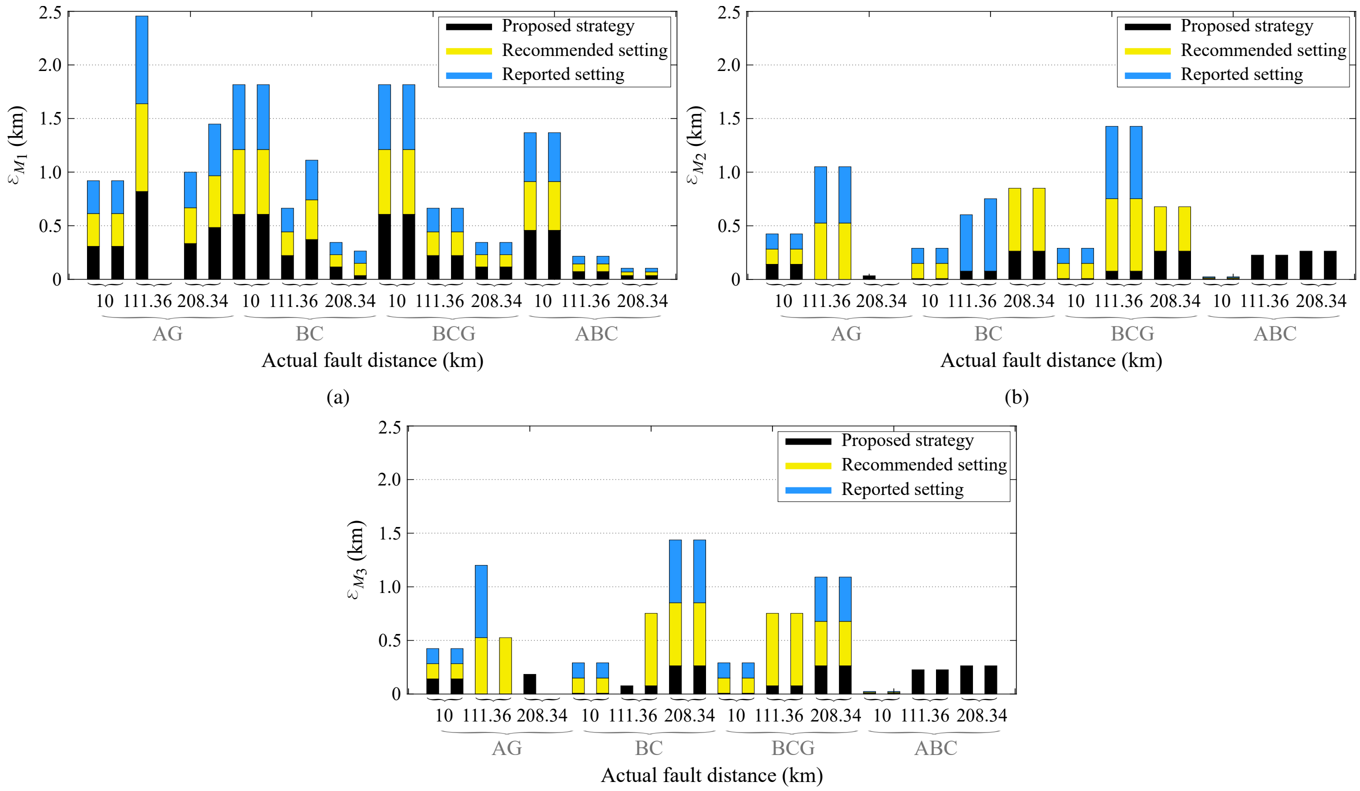

Fig. 4. Estimated absolute errors plotted as stack bars for: (a) *Method 1*; (b) *Method 2*; (c) *Method 3*.

guarantee if such user-defined adjustment works for every power network. Previous tests need to be carried out in each grid to proper set the Δk length prior to use this SEC-TWFL technique, which highlights the benefits of the proposed correlation procedure since these tests are no longer necessary.

From Fig. 4 and Table III, the smallest numbers of non-convergent cases were obtained by both the proposed solution and the use of Δk recommended setting for SEC-TWFL applications. To better compare the performance of such strategies, the estimated errors obtained from *Methods 1*, *2* and *3* by using the proposed solution were combined in a vector, as well as the ones obtained by using the recommended setting were combined in another vector. These vectors were compared to each other by means of a scatter plot, which is depicted in Fig. 5. The y-axis represents the errors obtained by the proposed solution, and the x-axis represents the ones obtained by the recommended setting.

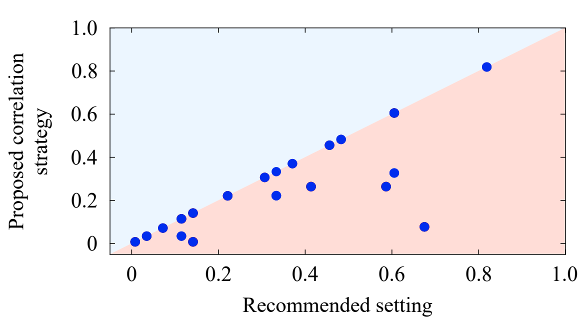

Fig. 5. Comparative analysis about the performance of the proposed correlation strategy and the use of Δk recommended setting.

From the obtained results shown in Fig. 5, a higher number of errors are presented in the bottom half (red part) of the graph, which indicates bigger errors obtained when using the recommended setting compared to those with the proposed solution. As a result, the use of a predefined setting may not be the best practice to be used in SEC-TWFL methods, since it still needs careful studies prior to be applied in a particular grid. It should be noted that the recommendations described in [10] and presented in Table I were reported for a simplified network, which is quite different from the realistic power system model used here during the evaluations.

Regarding specifically to the obtained search fields, they were not bigger than one tower span (approximately 300 m) in all the convergent fault cases. As a consequence, the proposed computational correlation strategy has provided the most likely short-circuit point within a narrow range of possibilities, irrespective of the evaluated SEC-TWFL method. Such auxiliary information would certainly help the utility maintenance crew in quickly find the fault location in the field.

Therefore, from the carried out studies, the proposed correlation strategy has shown to be more effective than the classical solutions reported in the literature for SEC-TWFL offline applications [3], [5], [6], [10]. Besides, it addresses a setting-free strategy to make SEC-TWFL techniques more immune to errors during the adjustment process, pointing out the feasibility to be applied in different power networks without the need to previously carry out studies in each particular grid to define the Δk length. Hence, such studies can contribute to optimize the use of SEC-TWFL algorithms with no dependence of adjustment processes nor commissioning tests in different grids.

B. Comparison With Other Types of One-Ended TW-based Fault Location Methods

Here, the performance of the proposed correlation strategy for the evaluated SEC-TWFL methods is compared with other types of single-ended TW-based fault location techniques, such as the one reported in [4], considering the same simulation variables presented in Table II. The method reported in [4] works with only current TWs, and it will be named hereafter as *Method 4*, just to follow the same nomenclatures used along this paper, being the associated errors defined as ε_{M_4}.

Basically, an array with the estimated errors ε_{M_1}, ε_{M_2}, ε_{M_3}, and ε_{M_4} for each evaluated routine was built, considering only the convergent cases. The mean values (μ) and the standard deviation (σ) of the obtained errors for each evaluated TW-based fault location technique are presented in Table IV.

TABLE IV
OBTAINED ERRORS FOR EACH EVALUATED ONE-ENDED TW-BASED FAULT LOCATION TECHNIQUE.

Method	Estimated errors	
	μ	σ
1	0.33	0.25
2	0.16	0.13
3	0.16	0.21
4	0.15	0.52

From the obtained results presented in Table IV, the lowest μ was estimated by *Method 4*, although the use of pre-estimations from other auxiliary techniques and TW data captured from previous network disturbances may need to be used for improving its performance. However, for such a method, the number of non-convergent cases was 7, presenting a bigger value than the ones obtained with the proposed strategy applied to SEC-TWFL. The lowest values of σ were obtained by the SEC-TWFL algorithms. In fact, the need to detect only the first fault-induced incident surge in such routines may avoid errors in distinguishing reflected from refracted TWs.

It is worth mentioning that the values presented in Table IV consist in the estimated fault distance errors, i.e., only the median values were taken into account to compute μ and σ. Such fact disregards one of the main advantages of the proposed strategy in providing an accurate associated search field to help the utility maintenance crew in finding the fault point in the field. Thus, the proposed correlation strategy appears as a promising solution to improve SEC-TWFL techniques performances, providing more accurate fault location estimations associated with a narrow search field, being independent of some user-defined parametric settings.

V. CONCLUSIONS

In this paper, a setting-free correlation strategy is proposed to enhance the performance of SEC-TWFL techniques by eliminating their dependence on some adjustment procedures. Basically, the fault location is estimated considering increments of the data window length typically used by the forward and backward relaying signals to compute the correlation functions. As a result, the greater gathering of the fault distance estimations taken from the variety of window lengths indicates the most likely short-circuit point and the associated search field.

Several ATP fault simulations were carried out on a realistic model of a series-compensated 500 kV/60 Hz double-circuit TL, varying the short-circuit parameters, such as location, type and resistance. From the obtained results, the proposed strategy has shown to be more robust than the classical solutions reported in the literature, with the advantages to be more immune to errors during the adjustment process of Δk, and with no need to previously carry out studies in each particular power system to determine such data window length.

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