Unconventional Distance Protection in Half-Wavelength Transmission Lines

Bernard F. Küsel, Felipe V. Lopes and Kleber M. Silva

Abstract— **In the last decade, many studies have been directed towards finding unconventional solutions for bulk power transmission over very long distances. In this area, the use of AC transmission lines little longer than a half-wavelength has been thoroughly discussed. Even though this solution has been widely studied in many aspects, the literature brings very little reports on specific analysis regarding the performance of protection schemes applied to it. Existing research shows that current and voltage waveforms originated from fault occurrences in transmission lines little longer than a half-wavelength are very different from those found in lines with conventional lengths and may compromise the use of conventional protection functions. In this paper, an innovative analysis is presented, where the performance of an unconventional distance protection formulation applied to a half-wavelength transmission line is evaluated.**

Keywords— **Half-wavelenght, bulk power transmission, power systems relaying, unconventional protection.**

I. Introduction

ELECTRIC power systems around the world present a constant increase in their demands, what implicates in a permanent need of expansion of their generation sources. Concomitantly, the possibilities of building new power plants close to the main load areas are scarcer every day, resulting in the need of searching for options farther away. Allied to this need, is the interest in taking advantage of potential natural energy resources, such as hydraulic, for which it is essential that the plants be built where it will be possible to get the best use the resource, in such way that these plants are often built very far from the large urban centers. In these cases, mostly the local demand is quite low and the main interest is to send all – or most – of the produced energy to major load centers. For this, there are usually two options: connect the plant to the nearest transmission grid and program the operation so that the energy gets where it should or; build a transmission line connecting the plant directly to points with higher demand. In cases of very large installed capacity, the need of high investments to improve the local grid usually leads to the second option.

Historically, only High Voltage Direct Current (HVDC) transmission has been considered for distances greater than 600 km. For this distance range, the HVDC solution has more competitive costs than conventional Alternating Current (AC) transmission systems in extra-high voltage. However, for distances of about of about 2500 km, another solution is presented as a strong competitor: an AC transmission line with an electric length[1] slightly longer than a half-wavelength[2] ($\lambda/2^+$) at the industrial frequency of 60 Hz. This solution provides several advantages such as not requiring reactive compensation nor intermediate substations, presenting high power transmission capacity and transient stability limit and having a much lower cost *per* length than a conventional line [1]–[6].

The first paper to present the idea of a $\lambda/2^+$ was published in the URSS in decade of 30 [7] and, later on, several researchers around the world conducted studies aiming to further investigate the solution. In [8], $\lambda/2^+$ simulation results considering the corona effect are presented, revealing that if corona losses are taken into account on transmission line model, the transient overvoltages due to short circuits are significantly reduced. In recent years, researchers presented further analysis on the line's steady state operation conditions [9], proposed the use of FACTS devices to provide multi-terminal capability to the $\lambda/2^+$ [3], [5] and studied the possibility of a field test using lines on the Brazilian interconnected power system [6].

Regarding studies related to the performance of protection schemes applied to half-wavelength transmission lines, researchers have shown that conventional functions fail to provide a reliable protection for the solution [10]–[13]. Besides that, Küsel showed that inter-harmonics components with considerable amplitude and low dumping may be present in fault signals depending on the fault location [14], what seriously compromises the phasor estimation process.

Chinese researchers have recently proposed an alternative formulation for the distance protection where the premise of an equivalent π circuit line model was used. The authors state that the proposed formulation would be used as primary protection function for a 650 km transmission line in 1000 kV that was under construction in China and show that it presents much lower errors than the conventional formulation. Despite the good results presented in the paper for a 650 km line, there is no assurance that the alternative formulation will perform well for a $\lambda/2^+$. In this paper, we present a performance analysis of the algorithm proposed in [15], show that its performance is compromised for lines longer that $\lambda/4$, and propose an improvement aiming to make it suitable for any line length.

This research has been financially supported by the Brazilian National Research Council (CNPq).

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Paper submitted to the International Conference on Power Systems Transients (IPST2015) in Cavtat, Croatia June 15-18, 2015.

[1]The electrical length of a transmission line can be different from the physical length when using reactive compensation.

[2]The length of a periodic electromagnetic wave at 60 Hz is approximately 5000 km. This concept is presented in more detail in Section II.

II. Half-wavelength transmission main concepts

For a given transmission line, the voltage and current wavelength λ may be calculated as follows:

$$\lambda = \frac{2\pi}{\beta} \ , \tag{1}$$

where β is the imaginary part of the transmission line propagation constant γ:

$$\gamma = \sqrt{(R + j\omega L)\,(G + j\omega C)} = \alpha + j\beta \ , \tag{2}$$

where $\omega = 2\pi f$ is the angular power frequency, being f the power frequency, R, L, G and C are the line series resistance, series inductance, shunt conductance and shunt capacitance per unit of length, respectively, and α is the real part of γ, which represents the line attenuation constant.

For a hypothetical lossless transmission line, the real part of γ is equal to zero and $\beta = \omega\sqrt{LC}$. Therefore, from (1):

$$\lambda = \frac{2\pi}{\omega\sqrt{LC}} = \frac{2\pi}{2\pi f\sqrt{LC}} = \frac{1}{f\sqrt{LC}} \approx \frac{c}{f} \ , \tag{3}$$

where c is the speed of light in vacuum ($\approx$ 300 000 km/s).

From (3), considering $f = 60$ Hz, λ is equal to 5 000 km for lossless transmission lines and slightly less for lines with losses. Thus, a lossless line with exact half-wavelength would have 2 500 km, whereas actual lines with losses would be a few kilometers shorter. However, it is known that exact $\frac{\lambda}{2}$ km corresponds to a singular point of the transmission line operation, which can easily lead the power system to instability. Besides, the use of lines with lengths in between $\frac{\lambda}{4}$ and $\frac{\lambda}{2}$ km would require extremely complex control systems, affecting the main network power stations [2]. Thus, it is recommended that the transmission line should have, in practice, a length of about 2 600 km (or $\approx$ 190 electric degrees) [16].

A. Voltage and current fundamental phasor profiles

Considering a fully transposed line, a two-port network may be used to represent the voltage and current phasor values at any point x of the line extension assuming the sending end values are known [17]:

$$\begin{bmatrix} \widehat{V}(x) \\ \widehat{I}(x) \end{bmatrix} = \begin{bmatrix} \cosh(\gamma x) & -Z_C \sinh(\gamma x) \\ -\frac{1}{Z_C}\sinh(\gamma x) & \cosh(\gamma x) \end{bmatrix} \begin{bmatrix} \widehat{V}_S \\ \widehat{I}_S \end{bmatrix} , \tag{4}$$

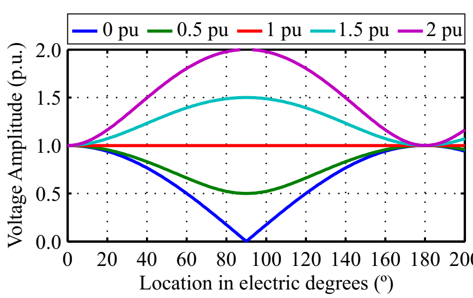
where Z_C is the line characteristic impedance, given by:

$$Z_C = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \ . \tag{5}$$

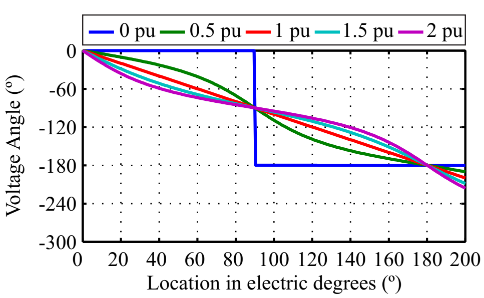
Using the line nominal voltage, V_N, as base voltage and the current related to the line characteristic power (P_C), I_C[3], as base current, expression (4) can be used to determine the currents and voltages along the transmission line for different load conditions. Figures 1 and 2 depicts the voltage and current profiles along and ideal $\lambda/2^+$ for a load flow of 0.5, 1, 1.5 and 2 times the line characteristic power P_C. It can be seen that, when the load flow is equal to P_C, the voltages and currents along the line are constant and equal to 1 p.u., what is a common effect for any transmission line. However, for different load conditions, some phenomena quite different from the ones observed in conventional lines are revealed:

- For any load condition, voltage and current amplitudes at the receiving end are exactly the same as the ones at the sending end with an angular displacement of 180°.
- For any load condition, the current at the central region of the line is equal to 1 p.u., even when only one of the terminals are closed.

[3]Calculated as $I_C = P_C/V_N$

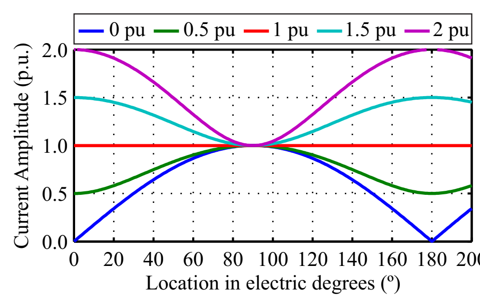


(a)

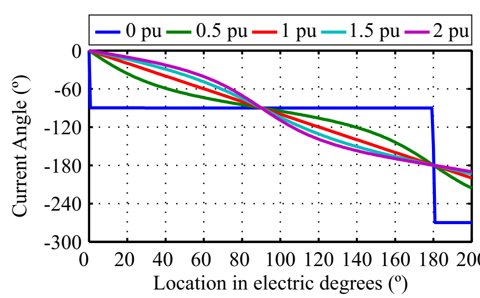


(b)

Fig. 1. Voltage phasor profiles along a $\lambda/2^+$ for different load flow conditions: (a) amplitude and (b) angle.



(a)



(b)

Fig. 2. Current phasor profiles along a $\lambda/2^+$ for different load flow conditions: (a) amplitude and (b) angle.

- The voltage amplitude at the central region of the line is proportional to the line load, in such way that, when there is power transfer greater than P_C, there will be voltages greater than the rated one.
- It can be concluded that the line consumes all the reactive power it generates.

Despite the third item seem to be an unfavorable matter for the use of this line, as they are usually planned to have a very high characteristic power, it is quite unlikely that a power flow greater than P_C may actually happen.

Further details on the operational characteristics of the $\lambda/2^+$ can be found in specific references such as [1]–[7].

III. System and simulations description

The transmission line proposed by Dias et al. [5] was used as a test case in this paper. The line was designed to transmit AC power up to 8 GW at rated voltage of 1000 kV through 2 600 km using two ground wires and a bundle of 12 conductors per phase. The transmission line tower structure is shown in Figure 4 and the relative position of the conductors in each bundle is presented in Table I. This configuration was obtained by an optimization procedure proposed by the authors that focuses on increasing power transmission capability to achieve the maximum permissible utilization of the line by bundle configuration geometry and phase displacement regarding a series of constraints. Additional information on the process is available in the original paper.

The single-line diagram of the studied power system is depicted in Fig. 3 and the line electrical and electromagnetic parameters are presented in Table II. The Thévenin power system equivalent parameters were obtained from studies concerning the integration of the Belo Monte generation power plant to the Brazilian power grid and the transformers were represented using typical parameters. Aiming to evaluate the protection scheme for external faults, 200 km lines with the same parameters were included before and after the $\lambda/2^+$. As the analysis performed in this paper were all based on fundamental frequency components, there was no need to use more rigorous models of the power system devices or a detailed soil representation, in such way that a constant ground conductivity was considered [2].

The system simulations were conducted using the ATP software, where the transmission lines where modeled as perfectly transposed with constant distributed parameters (Clark model: types -1, -2, -3). The voltage sources were set so that, in pre-fault condition, the line carried its characteristic power P_C and the voltage in Bus B1 was equal to 1 p.u. 0°. The fault voltages and currents fundamental phasors at the line terminals were obtained from the ATP steady-state solution, hence there was no need for a phasor estimation process. An auxiliary routine was developed to change the fault location in small steps, simulate all the cases in batch mode and organize the results from the ATP output files (.lis extension) in a single text file of easy reading for most analysis softwares. All the analysis are based on primary voltages and currents in order to avoid the instrument transformers inherent errors influence in the results.

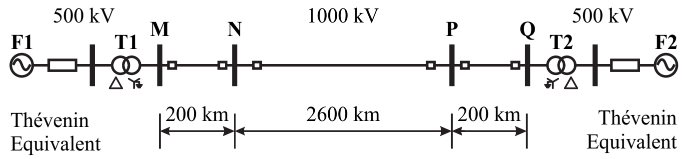


Fig. 3. Simulated power system single-line diagram.

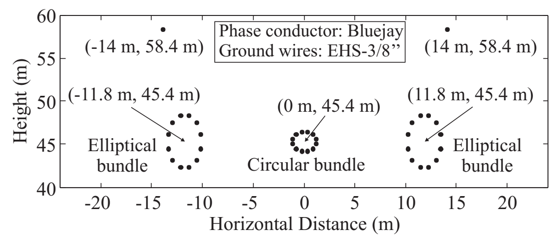


Fig. 4. Transmission line tower structure.

TABLE I
RELATIVE POSITION OF THE CONDUCTORS IN THE BUNDLE [5].

N	Coordenadas (m)	
	Circular Bundle	Elliptical Bundle
1	(0.31 , −1.15)	(0.43 , −3.00)
2	(0.84 , −0.84)	(1.17 , −2.20)
3	(1.15 , −0.31)	(1.60 , −0.80)
4	(1.15 , 0.31)	(1.60 , 0.80)
5	(0.84 , 0.84)	(1.17 , 2.20)
6	(0.31 , 1.15)	(0.43 , 3.00)
7	(−0.31 , 1.15)	(−0.43 , 3.00)
8	(−0.84 , 0.84)	(−1.17 , 2.20)
9	(−1.15 , 0.31)	(−1.60 , 0.80)
10	(−1.15 , −0.31)	(−1.60 , −0.80)
11	(−0.84 , −0.84)	(−1.17 , −2.20)
12	(−0.31 , −1.15)	(−0.43 , −3.00)

TABLE II
SYSTEM PARAMETERS

Transmission Line

Impedances and Admittances

Zero Sequence			Positive Sequence		
R_0 (Ω/km)	X_0 (Ω/km)	B_0 (μS/km)	R_1 (Ω/km)	X_1 (Ω/km)	B_1 (μS/km)
0.2856	1.2374	3.4873	0.0048	0.1689	9.8727

Electromagnetic Parameters

$\gamma(\text{km}^{-1})$	$0.000018 + j0.001291$
$Z_C(\Omega)$	$130.81 - j1.858$
P_C(MVA)	7 643.90
v(km/s)	291 913.71
λ(km)	4 865.23
$\lambda/2$(km)	2 432.61
2600 km (electric degrees)	192.4

Power System

Sources Equivalent Impedances

Source	Zero Sequence (Ω)	Positive Sequence (Ω)
S1	$1.6820 + j9.0760$	$0.1635 + j6.7338$
S2	$2.9695 + j15.0000$	$0.5625 + j11.7463$

Transformers Parameters

Transformer	X_T (%)	Voltage (kV)	Total Power (MVA)
T1	12.0	500/1 000	$5 \times 2\ 000$
T2	12.0	500/1 000	$5 \times 2\ 000$

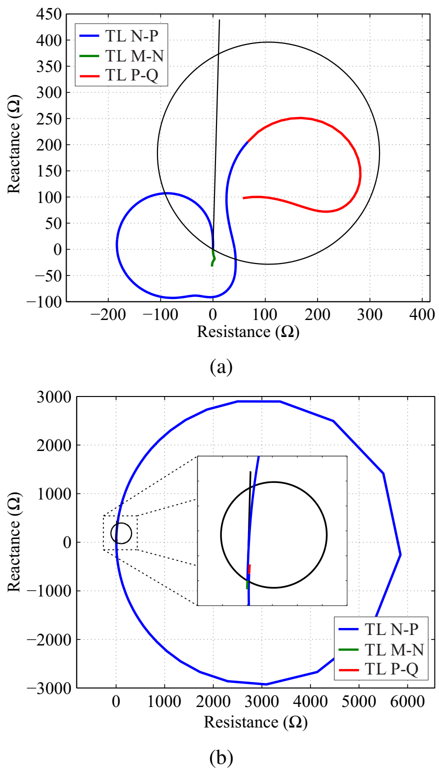


Fig. 5. Apparent impedance calculated by the relay unit Z_{AG} for simulated (a) AG and (b) ABC faults along the system lines.

IV. Conventional distance protection in $\lambda/2^+$

To present the performance of the conventional distance protection in $\lambda/2^+$, single and three-phase faults were simulated along the three transmission lines and the voltages and currents measured at Bus N were used as inputs for a relay installed at that point, which calculated the apparent impedance using the signals relation presented in Table III.

Figures 5(a) and 5(b) depict the apparent impedance calculated by the relay unit Z_{AG} for simulated AG and ABC faults along the lines, respectively. As a reference, a mho unit with an impedance-reach of $Z_N = 0.85 \cdot 2\ 600 \cdot (R_1 + jX_1)$ and maximum torque angle of $\tau = 60°$ was added to the figure. In both cases, two serious problems are highlighted:

- For a great part of the line extension (internal faults), faults are identified as external (or even reverse) and would not lead the relay to trip.
- Faults on the downstream line (P-Q) are identified as internal faults and would lead the relay to trip in first Zone.

Given that this behavior is caused by how the impedance is calculated, the use of different impedance characteristics or pilot protection schemes will not be enough to ensure reliable and safe operation of the protection relay.

The uncommon way the impedance-loci behave when using conventional distance protection on $\lambda/2^+$ may be explained by the fact that, in its formulation premises, the line is modeled as short (as depicted in Figure 6(a)) and the capacitive effect is neglected. As the studied line is extremely long and, consequently, presents strong capacitive effect, this premise is certainly not appropriate.

TABLE III
CONVENTIONAL DISTANCE RELAY INPUT SIGNALS.

Unit	Voltage Signals	Current Signals
Z_{AG}	$\widehat{V}_a$	$\widehat{I}_a + K_0\widehat{I}_0$
Z_{BG}	$\widehat{V}_b$	$\widehat{I}_b + K_0\widehat{I}_0$
Z_{CG}	$\widehat{V}_c$	$\widehat{I}_c + K_0\widehat{I}_0$
Z_{AB}	$\widehat{V}_a - \widehat{V}_b$	$\widehat{I}_a - \widehat{I}_b$
Z_{BC}	$\widehat{V}_b - \widehat{V}_c$	$\widehat{I}_b - \widehat{I}_c$
Z_{CA}	$\widehat{V}_c - \widehat{V}_a$	$\widehat{I}_c - \widehat{I}_a$

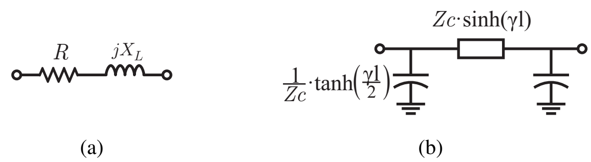


Fig. 6. (a) Short line model: used as premise for conventional distance protection; (b) Long line model: used as premise for unconventional distance protection.

V. Unconventional distance protection

A possible solution for the problem presented in section IV would be to reformulate the distance protection on the premise that the line is long, considering the equivalent π line model (as depicted in Figure 6(b)). An alternative formulation that considers exactly this idea was proposed by Xu et al. [15] to be used as main protection scheme at a 1 000 kV 650 km line in China.

A. Algorithm description

To briefly describe the algorithm proposed in [15], the following variables must be defined:

$$k_1 = \frac{\cosh(\gamma_0 d)}{\cosh(\gamma_1 d)} \qquad k_2 = \frac{\sinh(\gamma_0 d)}{\sinh(\gamma_1 d)} \tag{6}$$

and

$$K_U = k_1 - 1 \qquad K_I = \frac{k_2 Z_{C0} - Z_{C1}}{3Z_{C1}} \tag{7}$$

where γ_0 and γ_1 are the zero and positive sequence line propagation constants, respectively, Z_{C0} and Z_{C1} are the zero and positive sequence line characteristic impedances, respectively and d is the fault location.

The algorithm is based on two stages:

Stage 1: Calculate each of the relay units apparent impedance based on the signals presented in Table IV.

Stage 2: Correct each of the impedances using the following expression:

$$Z^*_{mn} = Z_1 \gamma_1 \,\text{atanh}\left(\frac{Z_{mn}}{Z_{C1}}\right), \tag{8}$$

where Z_{mn} is the impedance calculated using the expressions in Table IV and Z^*_{mn} is the corrected impedance.

Despite its simplicity, the algorithm presented in [15] has a major inconvenience: the parameters K_U and K_I depend on the fault location; an unknown parameter *a priori*. For the 650 km line used in their paper, the authors suggest using constant

TABLE IV

UNCONVENTIONAL DISTANCE RELAY INPUT SIGNALS.

Unit	Voltage Signals	Current Signals
Z_{AG}	$\widehat{V}_a + K_U\widehat{V}_a$	$\widehat{I}_a + K_I\widehat{I}_0$
Z_{BG}	$\widehat{V}_b + K_U\widehat{V}_b$	$\widehat{I}_b + K_I\widehat{I}_0$
Z_{CG}	$\widehat{V}_c + K_U\widehat{V}_c$	$\widehat{I}_c + K_I\widehat{I}_0$
Z_{AB}	$\widehat{V}_a - \widehat{V}_b$	$\widehat{I}_a - \widehat{I}_b$
Z_{BC}	$\widehat{V}_b - \widehat{V}_c$	$\widehat{I}_b - \widehat{I}_c$
Z_{CA}	$\widehat{V}_c - \widehat{V}_a$	$\widehat{I}_c - \widehat{I}_a$

values for these parameters, what is a valid assumption, as they change only slightly for faults along the line extension, as presented in Figure 7. However, for the $\lambda/2^+$ this criteria cannot be used, once the parameters change very significantly depending on the fault location, as may be seen in Figure 7(b). Henceforth, to evaluate the algorithm performance, two case scenarios were considered:

- Case 1: Parameters k_1 and k_2 are calculated for a fault at the end of transmission line, as proposed in [15].
- Case 2: Parameters k_1 and k_2 are calculated for the exact fault location, considering the hypothetical situation where it is known *a priori*.

B. Algorithm applied to a 800 km long transmission line

Prior to presenting the algorithm performance on $\lambda/2^+$, results on its performance for faults along a 800 km 500 kV test system are shown. Figures 8(a) and 8(b) depicts the apparent impedances calculated by a relay installed on one of the line terminals for single and three-phase faults along its extension, respectively. For the impedance calculation, the conventional and the unconventional formulations were used, where for the unconventional one, the two cases were considered.

One can see that, for both fault types, the use of the conventional formulation leads to a strong underreach in the relay units. When the alternative formulation proposed in [15] is used and k_1 and k_2 are calculated considering $d = 800$ km (Case 1), it may be observed that the relay underreach is significantly reduced for single phase faults and that the apparent impedance assume values exactly the same as the line positive sequence impedance for three phase faults. When considering the hypothetical situation where the fault location is previously known and used to calculate k_1 and k_2 for each short circuit case (Case 2), one can see that the apparent impedance assume values exactly the same as the line positive sequence impedance for both single and three phase faults. The results strengthen the fact that the parameters k_1 and k_2 only influence the relay ground units.

C. Algorithm applied to a $\lambda/2^+$

After confirming the good results presented by the algorithm when applied to a 800 km line, the unconventional formulation was used to calculate the apparent impedance for signals from faults along the $\lambda/2^+$ described in Figure 3.

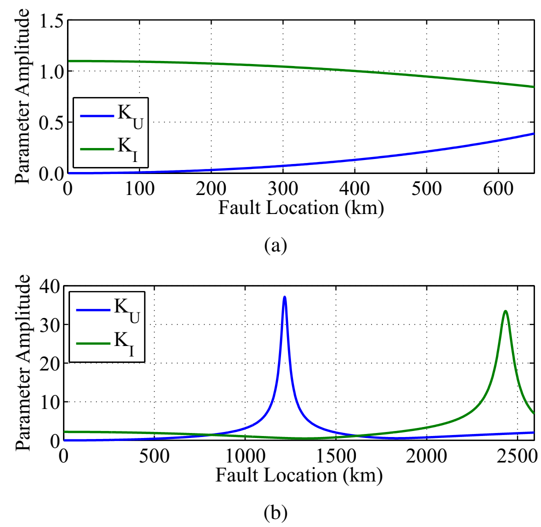


Fig. 7. K_U and K_I for fault along a (a) 650 km length line and a (b) 2 600 km length line.

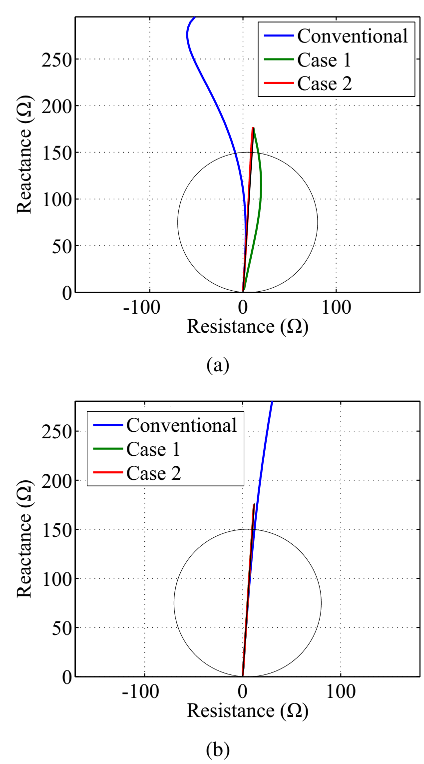
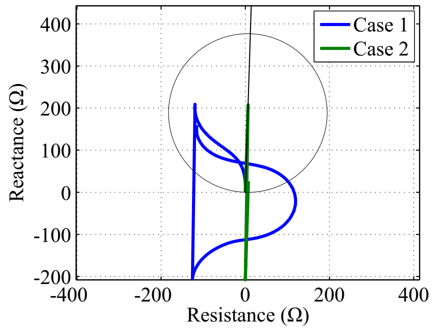
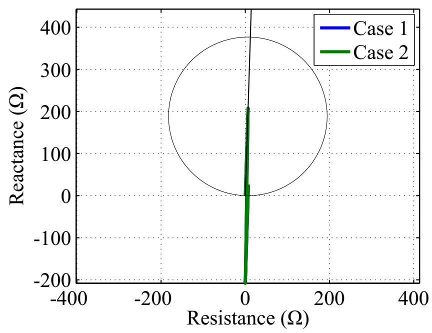


Fig. 8. Apparent impedances calculated by a Z_{AG} relay unit at a 800 km 500 kV transmission line for (a) AG and (b) ABC faults along its extension considering 3 formulations: conventional; unconventional with k_1 and k_2 calculated for a fault at the end of transmission line (Case 1) and; unconvetional with k_1 and k_2 calculated for the exact fault location (Case 2).

The obtained results for AG and ABC fault are depicted on Figures 9(a) and 9(b), respectively. One can see that, for single phase-to-ground faults, it is not a good approach to calculate k_1 and k_2 considering a fault at the end of the line (case 1), once the behavior of the obtained results seems to be quite unpredictable. For the three phase faults results, where there is no influence of the parameters k_1 and k_2, one can see that the apparent impedance assume values exactly the same as the line



(a)



(b)

Fig. 9. Apparent impedances calculated by a Z_{AG} relay unit at Bus N (a) AG and (b) ABC faults along the $\lambda/2^+$ extension considering 2 formulations: unconventional with k_1 and k_2 calculated for a fault at the end of transmission line (Case 1) and; unconvetional with k_1 and k_2 calculated for the exact fault location (Case 2).

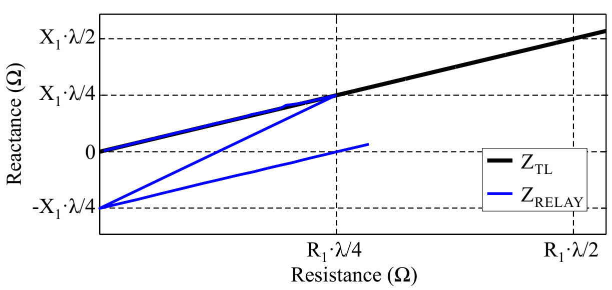
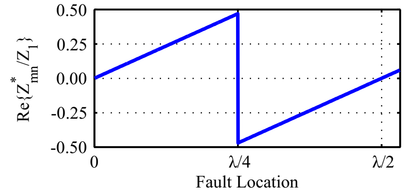


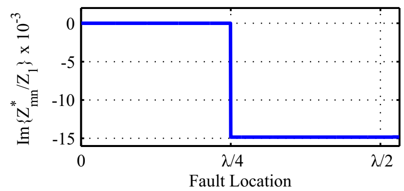
Fig. 10. $\lambda/2^+$ positive sequence impedance and apparent impedance calculated by a Z_{AG} unconventional distance relay unit at Bus N from internal faults considering k_1 and k_2 calculated for the exact fault location (Case 2).

positive sequence for faults until a certain point, from where the impedance is displaced. When the exact fault location is used to calculate the parameters k_1 and k_2 for single phase faults, the apparent impedance behaves exactly the same as the three phase fault case.

By plotting the results in a more convenient way (Figure 10), it is noticed that the displacement phenomenon occurs for faults located beyond $\lambda/4$ and that the displacement may be represented by an error impedance equal to $Z_{error} = R_1\lambda/4 + jX_1\lambda/2$. Hence, it can be concluded that the unconventional formulation can not be promptly used for lines longer than a quarter wavelength (about 1250 km). However, the formulation may be adapted by identifying variables capable of pinpointing with high reliability that a given impedance is displaced ($d \geq \lambda/4$) and adding Z_{error} to it.



(a)



(b)

Fig. 11. (a) Real and (b) imaginary parts of the *per unit* corrected apparent impedance.

VI. Proposed correction method

The proposed method to identify and correct the displaced impedance is based on the analysis of the *per unit* apparent impedance Z^*_{mn}, which can be obtained through the following expression:

$$Z^{pu}_{mn} = \frac{Z^*_{mn}}{Z_1} = \frac{Z^*_{mn}}{(R_1 + jX_1)L} = \Re\{Z^{pu}_{mn}\} + j\Im\{Z^{pu}_{mn}\} \ , \tag{9}$$

where L is the $\lambda/2^+$ length.

We observed that, for bolted faults in lines with conventional lengths, $\Re\{Z^{pu}_{mn}\}$ is the normalized distance between the relay and the fault location, whereas $\Im\{Z^{pu}_{mn}\}$ assumes neglectful values. However, for lines with longer lengths, we noticed that $\Re\{Z^{pu}_{mn}\}$ and $\Im\{Z^{pu}_{mn}\}$ values presented a Δr and Δi displacements, respectively, for faults that occurred and distances greater than $\lambda/4$, as presented in Figure 11. Once this behavior is caused by the displacement Z_{error}, Δr and Δi may be obtained in analytical form:

$$Z^{pu}_{error} = \frac{Z_{error}}{Z_1} = \frac{\frac{\lambda}{2}\left(\frac{R_1^2}{2} + X_1^2\right)}{(R_1^2 + X_1^2)\,L} + j\frac{\frac{\lambda}{4}\,(R_1 \cdot X_1)}{(R_1^2 + X_1^2)\,L} = \Delta r + j\Delta i \ . \tag{10}$$

From the knowledge of Δr and Δi, a strategy to correct the apparent impedance calculated by the unconventional distance protection formulation was developed, consisting on the following simple set of rules:

$$Z^{**}_{mn} = \begin{cases} Z^*_{mn}, & \text{if } |\Im\{Z^{pu}_{mn}\}| < 0,5 \cdot \Delta i \\ Z^*_{mn} + Z_{error}, & \text{if } |\Im\{Z^{pu}_{mn}\}| \geq 0,5 \cdot \Delta i \end{cases} \tag{11}$$

where Z^{**}_{mn} is the final apparent impedance, which will be used as input for the protection system.

The use of this strategy in the same cases presented in Section V-C results in the apparent impedances depicted in Figure 12 for any fault type. The displacement is corrected the way it was meant, leading the apparent impedance to assume values exactly the same as the line positive sequence impedance for faults in any point of the line extension.

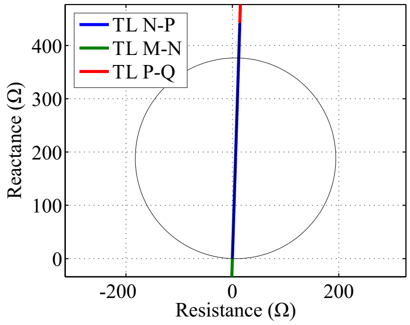


Fig. 12. Apparent impedance calculated by a relay installed at Bus N for any fault type along the three lines extension considering the unconventional distance protection formulation proposed in [15] combined with the correction method proposed in this paper.

VII. Conclusions

This paper begins presenting a brief review on the main principles of the half-wavelength transmission line and the problems that arise when using conventional distance protection. Then, The performance of an alternative formulation for the distance protection proposed in [15] when applied to $\lambda/2^+$ is evaluated. The results reveal that the algorithm can not be promptly used in transmission lines with extension greater than $\lambda/4$, once a large impedance displacement takes place for faults beyond this point. To overcome this problem, a method to identify and correct the impedance displacement is proposed and tested. The results indicate that the method is suitable for any type of fault.

In summary, one can conclude that conventional protection schemes can not guarantee safety and reliability to the operation of relays in transmission lines little longer than half-wavelength. However, it was shown that with the use of unconventional solutions, maybe it can be possible to achieve this objective, which is critical for the technology future. Some of the challenges that must be overcome are:

- Develop a practical solution for the use of the parameters k_1 and k_2.
- Evaluate the correction method performance for intermediate solutions of k_1 and k_2 calculation.
- Evaluate the influence of electromagnetic coupling in parallel lines on the algorithm.

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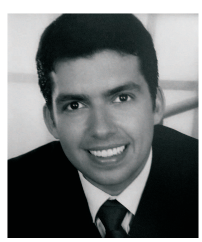

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