

The influence of corona effect on traveling wave based transmission line protection distance to fault error calculation

Abstract: The future of smart grid protections is related to identification of fast electromagnetic transient in the electric grid. Many algorithms are developed over the world; however some physical processes are common for the overhead transmission line which makes influence to the algorithms reliability. The aim of the article is to show the corona influence on the traveling wave based line protection distance to the fault measurement error. Transmission line model with corona effect was used as the digital filter. Distance to the fault calculation errors dependence on applied voltage trigger level for different overhead line was presented. The influences of environmental conditions to the measurement error were investigated.

Streszczenie. Celem artykułu jest pokazanie wpływu zjawiska korony na błąd pomiaru na podstawie fal wędrownych odległości wystąpienia uszkodzenia linii. Przedstawiono dla różnych linii napowietrznych zależność błędów obliczeń odległości do miejsca uszkodzenia od przyjętego poziomu napięcia wyzwalającego. Badano wpływ warunków środowiskowych na błąd pomiaru. (Wpływ zjawiska korony na błąd obliczeń na podstawie fal wędrownych odległości do miejsca uszkodzenia linii przesyłowej).

Keywords: smart grid, protection, electromagnetic transient, traveling wave, corona effect.

Słowa kluczowe: inteligentne systemy elektroenergetyczne, ochrona, stany nieustalone, fala wędrowna, zjawisko korony.

Introduction

Selectivity, sensitivity, fast working, electronic device reliability are specifications for the numerical relay protection devices or intelligent electronic device IED. Globally these conditions could be divided in to the two parts: reliability of IED algorithm and reliability of device. Secured object mathematical model, IED and its settings definition are included to the concept of algorithm.

Another IED algorithm could be based on traveling wave approach. The registrations of traveling waves propagated from fault are used. The time difference of multiple wave reflections is calculated in [1].

The registrations of propagated wave are performed in the both side of line [2]. The time stamps are fixed at the traveling wave arrival moments. Then the distance to the fault would be proportional to difference of time value.

Another fault identification method for high voltage transmission and distribution networks could be applied. This method concern to adaptation of traveling wave processes to registration values [3], [4]. Corona effect makes influence on traveling wave propagation along overhead line for all traveling wave processes registration methods mentioned above.

Corona model

The corona process begins then the voltage, applied to electrode system, reaches the corona inception voltage u_0 . The corona inception electric field strength value could be calculated using equation:

$$(1) \quad E_0 = 30.3 \cdot M \cdot \delta \cdot \left(1 + \frac{0.298}{\sqrt{r_0 \cdot \delta}} \right);$$

where $\delta = \frac{p}{760} \cdot \frac{293}{T}$ - coefficient, which evaluate environmental conditions; r_0 - radius of conductor; M - evaluate the convolution of conductor.

The additional charge accumulation around the line conductor during corona is non linear process and depends on applied voltage. The corona is described as $q-u$ characteristic; though the experimental approximation is quite complicated, however some results are published [5], [6]. The implementation of corona characteristic for

each maximum applied voltage u_m as depicted in Fig. 1 is complicated. The corona $q-u$ characteristic approximation at AMDKB points are used by authors [6]. The coefficients are calculated at points $q_{max} \rightarrow u_{max}$ from experimental results.

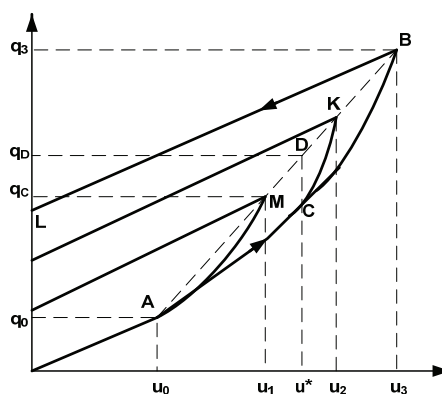


Fig. 1. $q-u$ characteristic

The electric field strength at streamer zone is evaluated using different approach. The electric field strength $E^+ = 5 \text{ kV/cm}$ for the positive corona, $E^- = 8 \text{ kV/cm}$ for the negative corona is used according to experimental results [6].

Transmission line model

Transmission line model based on equations:

$$(2) \quad \begin{cases} -\frac{du}{dx} = L \cdot \frac{di}{dt} + R \cdot i; \\ -\frac{di}{dx} = C \cdot \frac{du}{dt} + G \cdot u; \end{cases}$$

where L - line inductance; C - line capacitance; G - line conductance; R - line resistance.

The combination of equation (2) with corona model [5] yields the nonlinear equations system with two variables depending on time and coordinate.

The investigation [6] proposes divided transmission line in to the j nodes with connected dynamic capacitor C_d at each node. The transmission line model is depicted in Fig. 2.

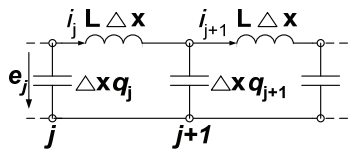


Fig. 2. Transmission line divided to j nodes

The further calculations are made using finite difference method based digital filter. The line resistance and conductance are neglected. The voltage and current at node j and time step n are calculated using digital filter:

$$(3) \quad \begin{cases} u_{j+1}^n = u_j^n - \frac{L \cdot \Delta x}{h} \cdot (i_j^{n+1} - i_j^n); \\ i_{j+1}^n = i_j^n - \frac{\Delta x}{h} \cdot (q_{j+1}^{n+1} - q_{j+1}^n); \end{cases}$$

where h - time step; Δx - line length between two nodes.

Calculation results

The overhead transmission lines were studied. Line parameters are shown in Table 1. The traveling wave dissipation due to corona effect causes distance to fault calculation error for differential [2] and protection algorithm described in [1]. The calculated distance to the fault errors via incepted voltage are depicted in Fig. 3, 4 and 5. The calculation were made according equations (1-3).

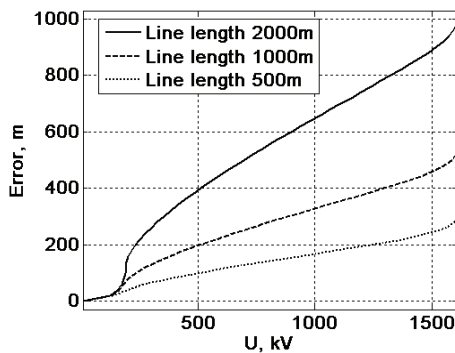


Fig. 3. Distance to fault measurement error due to corona effect for overhead transmission line with parameters described in Table 1 case 1

Table 1. Overhead transmission line parameters and environmental conditions

Case \ Param	1	2	3
H, m	19	19	19
r_{eq}, m	0.006	0.006	0.0027
δ	1.0	1.172	1.172
u_0, kV	195	224	125

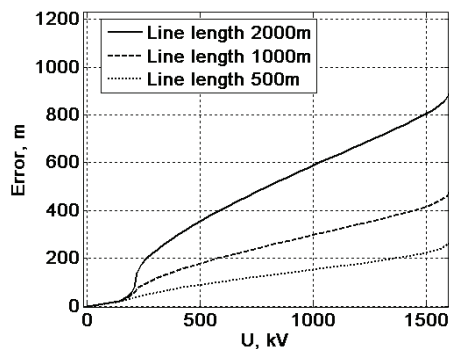


Fig. 4. Distance to fault measurement error due to corona effect for overhead transmission line with parameters described in Table 1 case 2

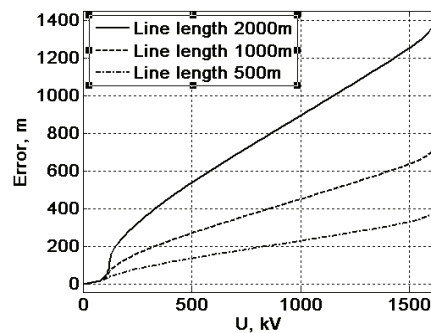


Fig. 5. Distance to fault measurement error due to corona effect for overhead transmission line with parameters described in Table 1 case 3

The study has shown that calculated distance to fault error depends on voltage trigger level. The higher trigger value, the higher distance to fault error value. The transmission line corona inception voltage u_0 should be considered defining trigger level as depicted in Fig. 4 and 5. The higher voltage u_0 leads to lower traveling wave front dissipation.

The most unpredictable is environmental conditions, described by coefficient δ . If we assume δ is normally distributed with mean value $\delta_{mean} = 1$ and dispersion $\sigma_\delta = 0.15$ than calculations yields the family of curves, depending on δ and inception voltage. Such family of curves could be created for each line type and conductor diameter. The traveling wave front dissipation or distance to fault calculation errors, via environmental conditions δ at trigger voltage $u_{max} = 500kV$ are depicted in Fig. 6 as the histogram.

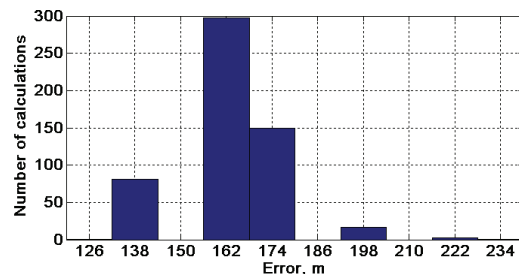


Fig. 6. Distance to fault measurement error histogram. Environmental coefficients mean value $\delta_{mean} = 1$ dispersion $\sigma_\delta = 0.15$, trigger voltage $u_{max} = 500kV$. Line parameters according case 3 in Table 1, line length 500 m

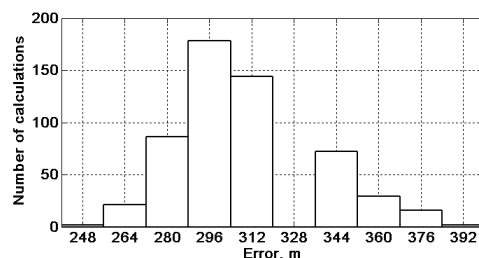


Fig. 7. Distance to fault measurement error histogram. Environmental coefficients mean value $\delta_{mean} = 1$ dispersion $\sigma_\delta = 0.15$, trigger voltage $u_{max} = 500kV$. Line parameters according case 3 in Table 1, line length 1000 m

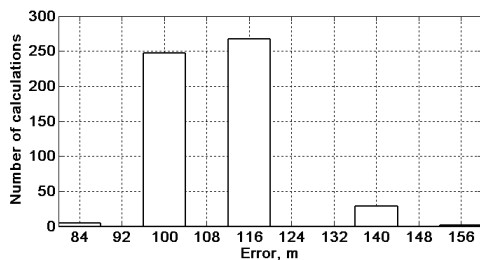


Fig. 8. Distance to fault measurement error histogram. Environmental coefficients mean value $\delta_{\text{mean}} = 1$ dispersion $\sigma_{\delta} = 0.15$, trigger voltage $u_{\text{max}} = 500\text{kV}$. Line parameters according case 2 in Table 1, line length 500 m

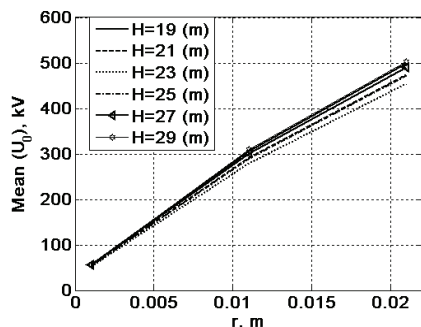


Fig. 9. Corona inception voltage mean value dependence on wire radius. Environmental coefficients mean value $\delta_{\text{mean}} = 1$ dispersion $\sigma_{\delta} = 0.15$

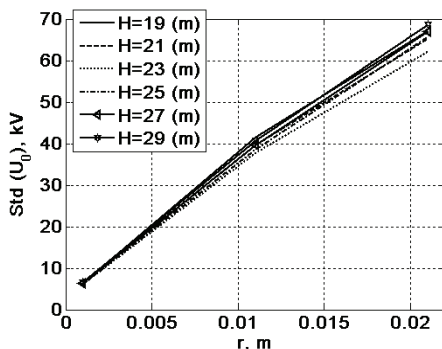


Fig. 10. Corona inception voltage standard deviation dependence on wire radius. Environmental coefficients mean value $\delta_{\text{mean}} = 1$ dispersion $\sigma_{\delta} = 0.15$

The lower corona inception voltage value leads to higher distance fault measured error as it could be seen by comparing results depicted in Fig. 6 and 8. The dispersion of fault measurement error highly depends on variation of environmental conditions as depicted in Fig. 6, 7 and 8.

The decrease of defined trigger level leads to decrease of traveling wave based protection distance to the fault measurement error. It is obvious, that the high trigger value is not sufficient due to probability to dismiss the first traveling wave. Low trigger level leads to triggering of protection algorithm in many non fault situations. So, the trigger value coordination should observe the protected line corona inception voltage value, especially, the

dependences of corona inception voltage on environmental conditions. The Fig. 9 shows the corona inception voltage mean value dependence on line wire radius due to changes of environmental conditions and wire height. The Fig. 10 shows corona inception voltage dispersion due to environmental conditions variation and variation dependence on wire radius.

The wire height over the ground could vary due to relief. The highest corona inception voltage mean and standard deviation dispersion is along radius $r = 0.02$ as depicted in Fig. 9 and 10.

Conclusions

1. The front of traveling wave is dissipated and the process is nonlinear. The corona effect described coefficients are different not only for different line types, but also for the different environmental conditions.
2. Probabilistic methods should be used for the evaluation of reliability of traveling wave based IED algorithms.
3. Higher overhead line wire radius makes higher standard deviation of the corona inception voltage due to changes of environmental conditions.
4. Corona inception voltage mean value and deviation should be observed for traveling wave based line protection trigger value coordination.
5. The increase of protection trigger level dramatically increase distance to the fault calculation error which could reach 40%.

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