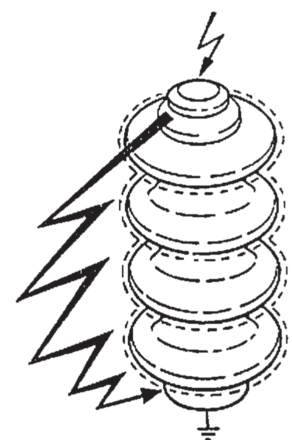
Arcing faults characterization using wavelet transform with special focus on auto-reclosure of transmission lines

Johann Jäger,* Gina Idárraga Ospina,**
Eduardo Agustín Orduña López, Ernesto Vázquez Martínez,*****
* Friedriech Alexander Universität Erlangen_Nürnberg - Alemania
** Universidad Nacional de San Juan - Argentina
*** Universidad Autónoma de Nuevo León - México
gidarraga@gmail.com , eorduna@iee.unsj.edu.ar
evazquez@gama.fime.uanl.mx



RESUMEN

Las líneas de transmisión juegan un papel fundamental en la operación de los sistemas eléctricos de potencia pues permiten que la electricidad llegue desde las plantas generadoras hasta los usuarios finales. En este artículo se caracterizan las fallas por arco, se analizan las señales transitorias generadas por las fallas por medio de ondoletas (Wavelet Transform, WT) y se muestra su aplicabilidad a líneas de transmisión de un solo polo con auto-cierre. Una red de 500kV con fallas por arco fue modelada y analizada. Varias condiciones reales fueron evaluadas analíticamente y posteriormente verificadas mediante simulaciones usando los programas de cómputo ATP/EMTP. Finalmente fue justificada la viabilidad del auto-cierre de un solo polo (single-pole auto-reclosing, SPAR) y la prevención de auto-cierre en fallas permanentes, buscando reducir las interrupciones.

PALABRAS CLAVE

Fallas por arco, análisis transitorio, auto-cierre, ondeletas.

ABSTRACT

Transmission lines have a fundamental role in electrical power system operations since they assure the continuity of the service from the generation plants to the final users. In this work the arc faults are characterized, the transitory signals generated by faults are analyzed using Wavelet Transform (WT) and its applicability to single-pole auto-reclosing of transmission lines is shown. A network of 500kV which is being under arc faults was modelled and analyzed. Several real life considerations have been evaluated analytically and subsequently verified based on transient simulations using ATP/EMTP. Finally, the feasibility of single-pole auto-reclosing (SPAR) during transient faults, and preventing reclosing for permanent faults was justified, looking to outage reduction.

KEYWORDS

Arcing faults, transient analysis, auto-reclosures, Wavelet Transform.

INTRODUCTION

The large majorities of overhead lines faults are transient and can be cleared by momentarily deenergizing the line. It is, therefore, feasible to improve service community by automatically reclosing the breaker after fault relay operation. High-speed reclosing on tie lines, if successful, also assists in maintaining stability. When closing at high speed, the dead time required to deionize the fault arc must be considered. This time is based on 40 years of operating experience,[1] and it depends of rated line-to-line voltage. On a 345-kV system, for example, the dead time is approximate of 20.5 cycles (0.34 seconds). Single-pole tripping and reclosing requires longer dead time because the two phases that remain energized tend to keep the arc conducting longer.

Around 80 or 90 % of the faults occurring on transmission lines are transients and, in the same percentage, they are line-to-ground faults.[1] Consequently, a correct identification of permanent and transient faults its necessary in order to increase the possibility of single-phase auto-reclosure (SPAR) during transient faults and to avoid automatic reclosing on permanent faults. This will reduce, significantly, the outage time and provide continuity in the service to the consumers. SPAR depends on different parameters such as voltage level, primary and secondary arc current, and transient recovery voltage across the arc path.

When a single-pole tripping occurs in the system, a primary arc is formed and it remains until breaker opens and cuts the fault current. Once the breaker open the secondary arc appears due to the mutual coupling between the faulted phase and the healthy phases. In general, primary arc could be represented by an ideal short circuit, or a linear resistance of low value. However, in order to know the transients due to by arcing faults, the arc is represented as accurately as possible. For that reason, the arc modeling is one of the most important research topics in circuit breaker design. A summary of distinct arc models and their applications can be found in reference.[2] In general, every arc model is based on voltages and currents waveform.[3,4,5]

This paper describes the modelling and simulation of an arc, as based of a frequency characterization of arcing faults. Considerations have been evaluated analytically and then verified based on transient simulations using ATP/EMTP, followed of a WT analysis. The results allow identifying correctly the presence of either transient or permanent fault.

ARC MODELING

Physical arc models are based on the equations of fluid dynamics and obey the laws of thermodynamics in combination with Maxwell's equations. The arc-plasma is a chemical reaction and, in addition to the conservation of mass equation, describes the rate equations of the different chemical reaction. In general, the arc conductance is a function of the power supplied to the plasma channel, and the power transported from the plasma channel by cooling and radiation time.

The most common arc modeling uses black box models, also called P-τ models, where the arc is described by a mathematical equation that relates arc conductance and measurable parameters, such as arc voltage and arc current. Usually, black box models consist of one or two differential equations, and all of them are a solution of the general arc equation[6] as follows:

$$\frac{d\left[\ln\left(g\right)\right]}{dt}=\frac{F'\left(Q\right)}{F\left(Q\right)}\left(P_{in}-P_{out}\right) \qquad (1)$$

Where g is the arc conductance, represented by:

$$g=F\left(P_{in},P_{out},t\right)=\frac{i_{arc}}{u_{arc}}=\frac{1}{R} \qquad (2)$$

where:

Pin= the power supplied to the plasma channel
Pout= the power transported from the plasma channel
t = time
iarc= the momentary arc current
uarc= the momentary arc voltage
R= the momentary arc channel resistance

The classical black box models are the Cassie model and the Mayr model, both of them are solution of the general equation described below.

Cassie model

The Cassie model is well suited for studying the behavior of the arc conductance in the high-current time interval when the plasma temperature is 8000

K or more. The equation is:

$$\frac{d\left[\ln\left(g\right)\right]}{dt}=\frac{P_0}{Q_0}\left(\frac{u_{arc}^2}{u_0^2}-1\right) \tag{3}$$

The quotient Q_0/P_0 is called the arc time constant τ and can be calculated from the homogeneous differential (3) as:

$$\frac{d\left[\ln\left(g\right)\right]}{dt}=-\frac{P_0}{Q_0} \tag{4}$$

A solution satisfying homogeneous equation (4) is

$$g=g_0e^{-t/\tau} \tag{5}$$

The time constant τ in (5) can be interpreted as the arc time constant parameter with which the arc channels diameter changes.

Mayr model

The Mayr model describes the arc conductance around current zero. The model considers the cooling or loss of power of the arc channel to be constant. The equation is:

$$\frac{d\left[\ln\left(g\right)\right]}{dt}=\frac{\left(u_{arc}i_{arc}-P_0\right)}{Q_0} \tag{6}$$

At the instant of current zero, the power input uarciarc in the arc channel is zero, and the rate of change of the conductance of the arc channel is:

$$\frac{dg}{dt}=-g\,\frac{P_0}{Q_0} \tag{7}$$

This is the homogeneous differential equation, which solution is:

$$g=g_0e^{-P_0/Q_0t} \tag{8}$$

In this expression Q_0/P_0 is called the arc time constant τ .

Since Mayr and Cassie introduced their differential equations for describing the dynamic arc behavior, other black box models have been developed, such as the Avdonin model, the Hochrainer model, the Kopplin model, the Schwarz model, the Urbanek model and the KEMA model,[7] which are capable of simulating thermal breakdown of the arc channel

WAVELET TRANSFORM

Wavelet Transform (WT) was introduced early in the 1980s; it is a powerful tool similar to the Fourier Transform (FT) which is employed to transfer the time-domain signal into the frequency-domain for signal analysis; the theory behind WT and the comparison with FT has been documented in reference.[8]

Wavelet Transform algorithms process data at different scales so that they may provide multiple resolution in frequency and time; the objective of multiresolution analysis (MRA) is to develop representations of a signal *f*(*t*) in terms of wavelet and scaling functions, it is particularly useful for analyzing fault transients, which contain localized high frequency components, superposed to 60Hz power frequency. This property will be used to characterize arc faults waveforms.

The basic concept in Wavelet analysis is to select a proper wavelet, called mother wavelet and then perform an analysis using its translated and dilated versions. Technically, the mother wavelet must satisfy an admissibility criterion in order for a resolution of the identity to hold. The mother wavelet is scaler (or dilated) by a factor a and translated (or shifted) by a factor *b* to give (under Morlet's original formulation):

$$\psi\, a,\, b(t)=\frac{1}{\sqrt{a}}\,\psi\left(\frac{t-b}{a}\right) \tag{9}$$

These functions are often incorrectly referred to as the basis functions of the transform when there is no basis indeed. Time-frequency interpretation uses a subtly different formulation. Additional details of WT can be found in.[910]

SIMULATIONS

Simulations have been performed with the Electromagnetic Transient Program (EMTP),[11] using the parameters of a typical 500 kV system of 350 km transmission line already reported.[12] A diagram of the modeled system is presented in figure 1, a non linear fault arc model was included in the simulation, both primary and secondary models were modeled using the EMTP MODELS features.

When a fault occurs, the primary arc model, the primary arc characteristics are given[12] then, after circuit breakers open, the secondary arc is simulated using suggestions indicated in reference.[13]

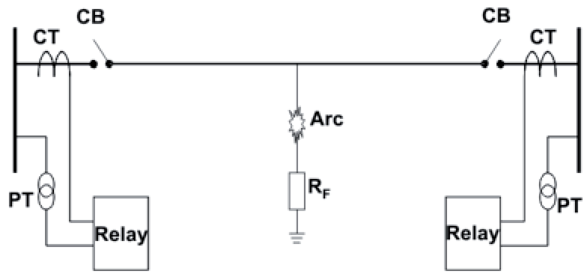


Fig. 1. Diagram of the modeled system.

Validity of the arc model

Transient and permanent single-earth faults were analyzed in order to probe the simulation model. The fault inception time is 0.1s, that is when the primary arc starts. Once the fault is detected, and the relay operates to open the faulted phase, the secondary arc starts at 0.2 s and continues until the final extinction occurs at 0.55 s.

Figure 2 shows the voltage and current waveform for a permanent a-earth fault; in figure 2a, the voltage shows the transients generated by primary arcs, with practically zero-current after operation relay (figure 2b). As expected, very significant high frequency traveling waves are produced on the waveform at fault inception and fade fairly rapidly due to the losses on the line. It is evident that the magnitude of the voltage is greater at the primary arc than latter; however it has important transient information. figure 3 shows the voltage and current waveform for a transient a-earth fault; in this case it is possible to see the transients generated by secondary arcs after the circuit breaker opening at 0.2s. This cases show that both arcs models, Cassie and Mayr, can simulate the arc transient behavior due a fault in a realistic form. Afterwards, the Wavelet Transform can be applied for detecting some characteristics in this type of transient signals.

WT Analysis

The discrete Wavelet Transform is applied to analyze and decompose a set of the arcing fault waveforms simulated shown above. The performance of signal extraction depends highly on the mother wavelet used; which was selected based on a previous analysis of the mother wavelets which waveform is similar to the phenomenon under

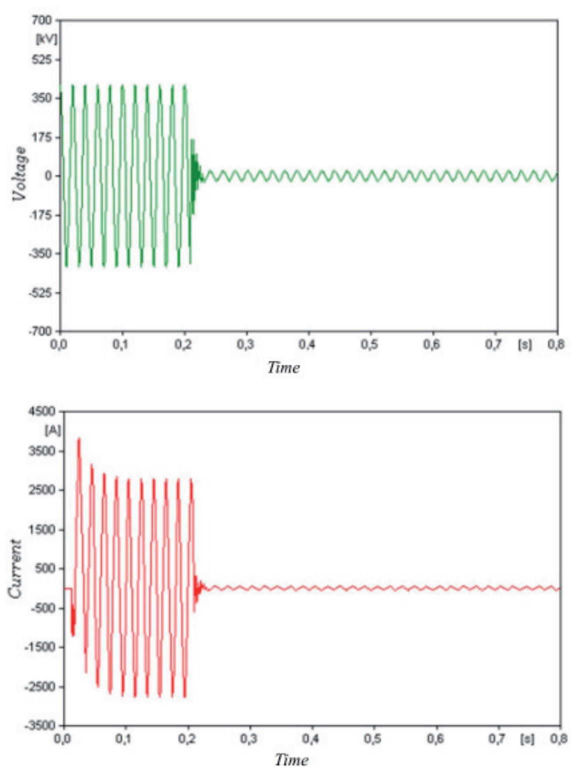


Fig. 2. Voltage and current waveforms of a permanent a-earth fault.

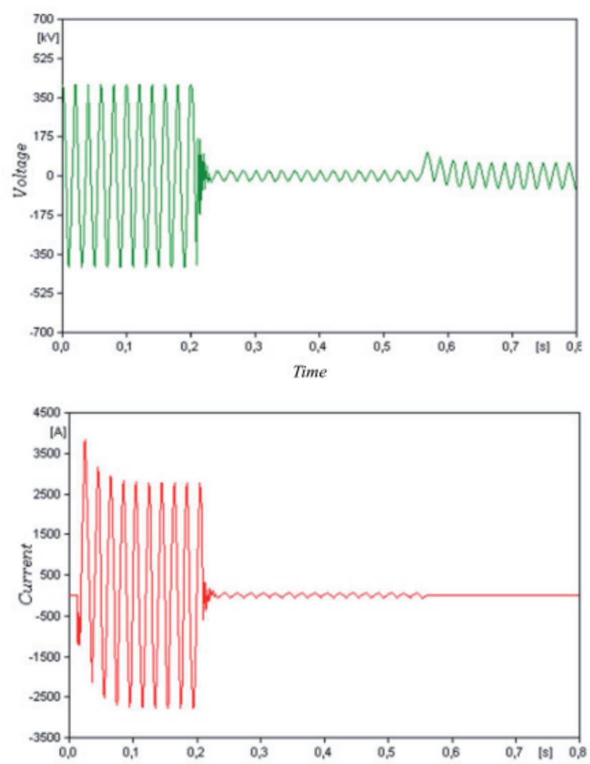


Fig. 3. Voltage and current waveforms of a transient a-earth fault.

analysis. We found that coif2, coif3, Db4, Db5, sym4 and sym6 are the best options for the signals under study. However, Db4 was the choice in this research because it is currently the most reported as one with the best behavior for transient analysis. The software used is the Wavelet toolbox of Matlab.

The current signal for the permanent fault showed in figure 2a was decomposed using Db4 to level 3 (figure 4a). The wavelet multiresolution is used for decomposing each signal into low frequency approximation and high frequency details. The obtained coefficients d_4, d_3, d_2 and d_1 corresponds to the frequency bands of 0-75Hz, 75-125Hz, 125-250Hz, and 250-500Hz respectively. The fault inception is identified in all coefficients at the beginning, and the transient due to secondary arc can be seeing in d_2 and d_1. For sinusoidal signal, during the faults and after fault clearing, the output is zero in all coefficients.

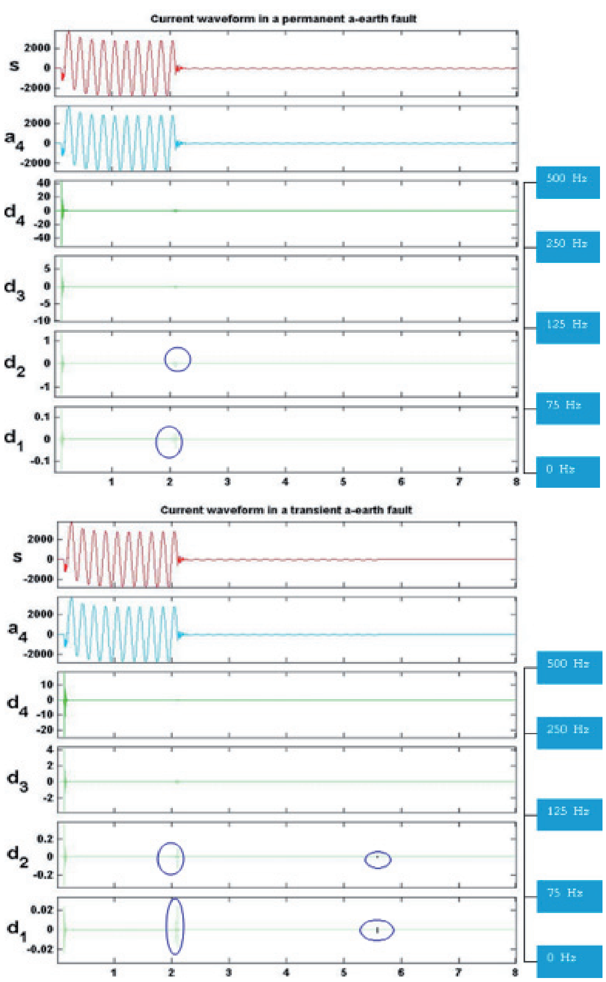


Fig. 4. Levels in the voltage signal in a (a) permanent fault and (b) transient fault.

In the same way, figure. 4b show the wavelet transform results of the transient fault showed in figure 3b: The secondary arc characteristics are evident in the wavelet levels form d_1 and d_2. Additionally, there is another transient once breaker opens.

According the arc behavior describes above, the presence of secondary arc in current waveform is an evidence that a transient fault is happened. In permanent faults there is a secondary arc too, but the effect is minimal due to lack arc in the faulted line. From figure 4, the presence of a secondary arc can be detect using wavelets levels d_1 or d_2; however, in order to apply the spectrum analysis results to the SPAR (figure 4), we need to define a threshold (α) to discriminate between transient faults ($d_1 < \alpha$) and permanent faults ($d_1 < \alpha$). This is the next step in the actual research, where frequency characterization of switching operations and lightning strokes will be required.

Another aspect that must be considered before to develop a new SPAR algorithm is the fault evolution process. There are situations where transient arc fault change to permanent fault (the fault begin as a tree contact, but the conductor fall down after a short time); the reclosure will be unsuccessful in these cases. It mean that reclosure action should be done only if fault current remain in a reduce level after operation relay. Important work has been done to minimize the secondary arc current effect, for feasible single-pole auto-reclosing actions during transient faults.[14]

CONCLUSIONS

In this paper, Wavelet Transform were used for a frequency characterization of arcing faults, as first step toward SPAR algorithm in overhead transmission lines. The proposed characterization is based in the arc transient behavior, where the presence of secondary arc in current waveform is evidence that a transient fault is happened. Initially, the validation of the arc model, through simulations in EMTP program, was done, and then the current signal for transient and permanent fault was analyzed using the discrete Wavelet Transform. The results proof that secondary arc transient can be identified using wavelets levels, based on transient behavior during permanent and transient faults. Using threshold logic in the wavelet levels (d_1 or d_2 in figure 4), we can implement a new SPAR.

REFERENCES

1. J. Lewis Blackburn. Protective Relaying. Principles and Applications. Bothell, Washington.
2. WG 13.01, Applications of black box modeling to circuit breakers, Electra, no. 149, pp. 41-71, August 1993.
3. Pieter H. Schavemaker, Lou Van der Sluis, An improved Mayr-type arc model based on current-zero measurements, IEEE Transactions on Power Delivery, vol. 15, no. 2, April 2000.
4. D.W.P. Thomas, E.T. Pereira, C. Christopoulos, A. F. Howe, The simulation of circuit breaker switching using a composite Cassie-modified Mayr model, IEEE Transactions on Power Delivery, vol. 10, no. 4, October 1995.
5. Ivan M. Dudurych, T.J. Gallagher, Eugeniusz Rosolwski, Arc effect on single-phase reclosing time of a UHV power transmission line, IEEE Transactions on Power Delivery, vol. 19, no. 2 April 2004.
6. Van der Sluis, L. Transients in Power Systems. John Wiley and Sons LTD, 2001.
7. O. Mayr, Beitrage zur Theorie des Statichen und des Dynamischen Lichtbogens, Archiv für Elektrotechnik, vol. Band 37, no. Heft 12, pp. 588-608, 1943.
8. D.C. Robertson, O.I. Camps, J.S. Mayer and W.B. Gish, Wavelet and Electromagnetic Power System Transient, IEEE Transactions on Power Delivery, vol. 11, pp. 1050-1056, 1996.
9. G. Strang, and T. Nguyen. Wavelet and Filter Banks. Wellegsleg-Cambridge Press, 1997
10. C. Sidney Burrus, and R.A. Gopinath. Introduction to Wavelets and Wavelet Transform. A Primer. Prentice Hall, 1988.
11. Alternative Transient Program (ATP) - Rule Book. Leuven EMTP Centre, 1987.
12. G. Herold. Elektrische Energieversorgung III. J. Schlembach Fachverlag, Erlangen. 2002
13. Làslò Prikler, Mustafa Kizilcay, Gàbor Bàn, Pèter Handl, Improved secondary arc models based on identification of arc parameters from staged fault test records, Proceedings of the 14th PSCC, Sevilla, 24-28 June 2002. Session 24, Paper 3, Page 2.
14. Ramold. M, Idárraga G.M., Jäger J. Transient shunt reactor dimensioning for bulk power transmission systems during normal and faulty network conditions. PowerCon 2006, Chongquing-China, 23th October 2006.

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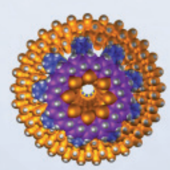

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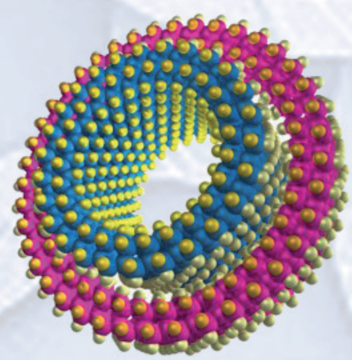

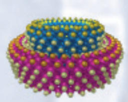

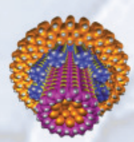

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