Electrical Power and Energy Systems 53 (2013) 733–741

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# MCHO – A new indicator for insulation conditions in transmission lines

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ARTICLE INFO

*Article history:*
Received 15 December 2012
Received in revised form 30 April 2013
Accepted 29 May 2013

*Keywords:*
Leakage current
Capacitance
Permittivity
Transmission line
Detection and diagnosis

ABSTRACT

Conventionally monitoring operating conditions of a power transmission line is accomplished by periodic inspections along this line. This monitoring allows corrective maintenance by finding faults during the inspection. But in more efficient maintenance, predictive techniques that are characterized by real-time monitoring should be employed. Such predictive techniques allow for verifying the working status of the line by using normal working models to detect faults and fault models for diagnosis. This paper presents a study that used a mathematical model appropriate for application to predictive maintenance of transmission line segments at low cost, without the need for sensors distributed along the line, and presenting a new indicator of transmission line operation conditions. By tracking the leakage current of transmission lines, this model allows for estimating the current line insulation status. Once the current line insulation status is known, it is possible to compare it against other future status and verify the progress of the insulation conditions of that line. The model uses a new indicator, called MCHO, which can detect and diagnose both normal and abnormal operating conditions of a power transmission line. This new indicator is the capacitance of the harmonic frequencies of the transmission line leakage current. The model was validated through measurements obtained on a stretch of transmission line.



## 1. Introduction

The pollution from insulators, vandalism, fires, urban encroachment by building on the right of way of the line can cause faults and resultant outages in transmission lines (TLs). These events can reduce the level of isolation of the line, causing an increase in its leakage current ($I_L$). The evolution of these events is gradual, which presumes the possibility of observing these developments up until the occurrence of the fault. Added to these events has been the phenomenon of aging and natural wear of the line that must be considered when checking the level of isolation thereof. There are methods for real-time detection of faults in TLs, some analyze the line voltage and current, observing the phase between them for locating faults [1]. Other methodologies analyze the characteristics of voltage and current phasors to estimate the state of the transmission lines [2,22]. There are some methods that analyze temporal samples of the voltage and current for measuring the impedance of the transmission line and allow the use of systems for estimating the location of faults [3]. These methods, however, do not have the power to estimate the state of insulation of the transmission line nor predict a fault. On the other hand, work such as that of [4] observed the change in the behavior of $I_L$ in the occurrence of flashover. Other works such as [5,6], found that through the harmonic decomposition of the leakage current in contaminated insulators, there is a maximum level of magnitude for certain frequencies, and they signal the malfunction of the insulation. Kanashiro (1996) [7]included in his article the climatic effects added to marine and industrial pollution. In these latest studies it has been found that monitoring the insulation or operating conditions of a TL may be performed through observation of the $I_L$ current. This paper uses this finding to develop models to be employed in the detection and diagnosis, thus, to allow for developing a predictive and automatic protection methodology in TLs. This article presents a proper model aimed at the detection and diagnosis of fauls in TL by analyzing the $I_L$. Through this model, a new indicator of the state of operation of TL's, able to characterize

☆ Thanks to Eletronorte for funding through the On-line Monitoring Project for transmission lines, from which all actual data analyzed in this study were collected.
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0142-0615 
http://dx.doi.org/10.1016/j.ijepes.2013.05.052

their normal operation and failure modes, is proposed. Another aspect that is influenced by natural wear of a TL is its load carrying capacity and therefore the financial return it can offer. Currently this TL wear is estimated. With the characterization of the operating conditions of the power line, real wear can be considered in calculating the financial return of a TL.

## 2. Development of an adequate detection and diagnosis model

The methods for fault detection applied to continuous monitoring and associated with time, enable developing methods to predict faults [8,9]. The detection of faults for prediction should compare, continuously and in real time, the normal system behavior with actual behavior, as suggested by Fig. 1. The signal resulting from this comparison is called a residual. For diagnosis, signal patterns of failure modes and the signals of the residual can be used, as suggested by Fig. 1.

To use this methodology, the use of normal operation and failure mode models is necessary.

### 2.1. Models for detection and diagnosis problems

The model to be obtained through the studies presented in this article, is to be employed in the detection of incipient fault by model-based method. This method is based on parametric or non-parametric analytical models, with a precision which allowed performing an analytical redundancy [10]. According to [12] the analytical redundancy is based on the comparison between actual measurements and signals generated by a mathematical model of the system. The analytical model of the behavior of failure modes for the inputs of the system and the fault detection and diagnosis is performed by checking the residual, as shown in Fig. 2. The residual is the difference found between the actual measurements and those calculated by the model [11]. A significant residual does not always represents a failure, it might be unexpected behavior which can be described by correlating the model parameters. If this correlation is lost, then it is because a new element was introduced into the system.

Obtaining the residual is the first step for detecting a failure. A second step is to check whether or not this residual represents a failure. In the second step, the information from the residual can have a signature representing a pattern associating the residual signal with the cause of the fault and its location. From the foregoing, one can see the great importance of having a mathematical model of normal operation representing the system analyzed with a high degree of accuracy.

### 2.2. Identification of the signal for obtaining the residual in detection and diagnosis problems applied to TL's

It was described in the introduction that monitoring the insulation of operating conditions of a TL can be performed by observing the $I_L$. Moreover, according to [13], the capacitance associated with a resistance represents the TL dielectric losses, i.e. losses repre-

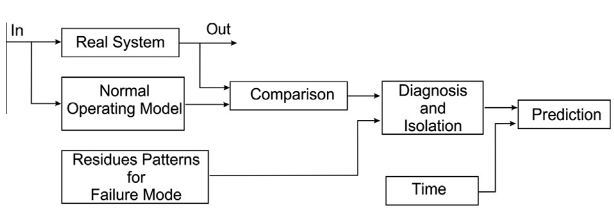


**Fig. 1.** Fault detection method using a normal operation model and the system fault modes.

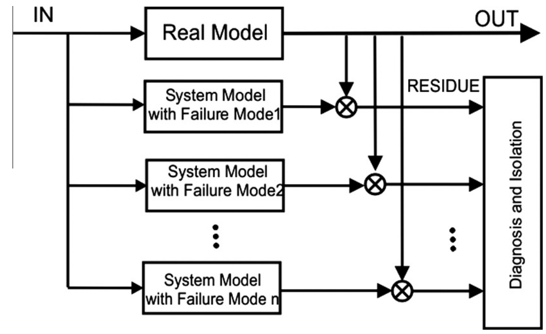


**Fig. 2.** Method of detection and diagnosis with residuals generated by dynamic models of fault modes.

sented by $I_L$, since it normally passes through the insulators. In other words, the behavior of $I_L$ is directly linked to the value of the capacitance of the line. In the detection of faults in transmission lines proposed in this paper, the residual is the result of the comparison of the measured $I_L$ signal with the $I_L$ signal obtained by the mathematical model of normal TL operation. This comparison allows for detection. The diagnosis can be obtained through the comparison against the fault models. On the other hand, the capacitance of a TL varies with environmental variables (EV's) and hence the behavior of $I_L$ as well. Therefore, for the development of the mathematical model of normal LT is necessary to characterize the $I_L$ also in relation to the EV's (temperature, relative humidity). This paper does not develop detection and diagnosis. It presents a promising detection and diagnosis tool.

### 2.3. Characterization of $I_L$

The experimental determination of $I_L$ is calculated using the theory of Gaussian surfaces. This theory holds that the algebraic sum of the current entering and leaving a closed surface is equal to zero [14]. On a TL section, this theory applies as shown in Fig. 3. This means that when monitoring a stretch of TL, its $I_L$ can be obtained from the vector sum of the output and input currents of this stretch.

$$I_L = I_{Guamá_{SS}} - I_{Utinga_{SS}} \tag{1}$$

In the literature, some methodologies are presented to determine the $I_L$ in insulators or lightning arresters. However, cannot be found concerning the determination of $I_L$ in a section of TL [21,23,24].

For monitoring of electrical and environmental variables, power analyzer and Remote Weather Station (RWS) was installed at each end of the monitored TL. The measurements performed by the analyzers are synchronized via GPS and every second. The RWS measurements are performed every 20 min. All these equipments are connected to the intranet of the company responsible for that section of the monitored TL. The database is built in real time with the aid of a personal computer (as shown in Fig. 4), equipped with a Core2Quad 2.0 GHz processor with 2 Gb RAM memory. The processing time for determining the $I_L$ measured in the TL and the $I_L$ calculated by the model is approximately 2 min and 10 s.

### 2.4. Capacitance and EV's – Experiment

The EV's that most influence the capacitance of the TL are: Temperature ($T_{amb}$), relative humidity ($U_{air}$) and wind speed ($S_{wind}$). To investigate the behavior of the capacitance with environmental variation, an experimental bench was constructed. A photographic record of this bench is shown in Fig. 5, whose schematic diagram is shown in Fig. 5.