Online Chafing Fault Diagnosis and Characterization in Twisted Pair Cables based on Multi-Carrier Reflectometry and Genetic Optimization Algorithms

Wafa **BEN HASSEN,** Moussa **KAFAL**, and Esteban **CABANILLAS;** CEA, LIST, F-91191 Gif-sur-Yvette, France,
wafa.benhassen@cea.fr, moussa.kafal@cea.fr, Esteban.cabanillas@cea.fr

ABSTRACT

Nowadays, the predictive diagnosis of an isolation damage in wiring and interconnect systems is an economic and human requirement. This paper proposes to study and develop methods and models to detect such faults and characterize them based on inverse problems combined with optimization-based algorithms and the well-known reflectometry based techniques. To do so, an unshielded twisted pair cable with an isolation damage is modelled using the finite element method and tested using reflectometry. The proposed methodology is validated by numerical results based on an electronic card including Xilinx Zynq 7010 FPGA to inject/receive Orthogonal Multi-Tone Time Domain Reflectometry (OMTDR).

KEYWORDS

Transmission line networks, soft faults, fault detection and location, fault characterization, reflectometry methods, optimization based algorithms.

INTRODUCTION

During its normal daily operation, the Embedding Wiring Interconnect System (EWIS) is severely stressed leading to the appearance of faults. Wiring faults are mainly categorized into two main families, they can be either hard (i.e. open and short circuit), or soft faults (i.e. shielding damage, pinching, etc.) [1], [2]. Intermittent faults, which can be either hard or soft, are not permanent faults and occur in very short duration [3]. Online network diagnosis is a very recent and interesting field of study aiming at monitoring the heath of an operating network under test (NUT). Online diagnosis offers the possibility of performing the diagnosis concurrently to the normal operation of the network, i.e., when voltage is on for supply wires and while communication is running for signal cables. This last condition requires harmlessness: diagnosis must not interfere with communication signals, and useful signals must not trigger any false alarm [4], [5]. In fact, the injection of high frequency signals into live cables may lead to the appearance of new Radio Frequency (RF) signals that may propagate into the neighboring wires due to the cross-talk phenomenon and variations of loads present at the extremities of the EWIS. Moreover, advanced transport systems design (i.e. electric aircraft, etc.) should bow to strict security and safety norms with respect to Electromagnetic Compatibility (EMC) constraints. In this context, Multi-Carrier Reflectometry (MCR) [5], [6] Multi-Carrier Time Domain Reflectometry [7] and its variant Orthogonal Multi-Tone Time Domain Reflectometry were proposed [8], [9]. In OMTDR, the frequency band is divided into several frequency sub-bands to control the signal bandwidth and avoid prohibited bands. The reflected part of the signal is correlated with the injected one to enable online and reliable diagnosis in such EWISs.

Beyond online diagnosis, soft fault location has been recently extensively studied. The low amplitude signature has made their monitoring critically difficult. They are usually characterized by weak reflectiveness, which produce echoes that can pass unnoticed compared with those caused, e.g., by junctions within an EWIS, particularly when noisy conditions are present, e.g., in live testing [10]. Although several methods have been developed for the sake of a precise soft fault detection and location [11], [12], fault characterization aiming at estimating the fault parameters such as width, length, impedance, etc., is equally or even more important. This permits estimating the fault's severity thus allowing to predict its evolution with time and therefore planning a predictive maintenance. The literature related to soft fault characterization are those accomplished by NASA team where complex physics-based models for specific cables and Bayesian inference-based algorithms are deployed. Although those models were precise, they are highly complex and are not fitted to online wiring systems diagnosis and prognosis [13].

Accordingly, this paper aims at detecting, locating and characterizing chafing faults in lively operating twisted pair cables using MCTDR and genetic optimization algorithms. To do so, a three-dimensional numerical modelling of twisted pairs is developed and validated by a distributed parameters model for a stranded twisted pair including the pitch of twist and frequency dependent effects such as proximity and skin effects. After that, a three-dimensional chafing fault is developed and integrated in the cable model where the shield or/and the insulation are damaged. OMTDR reflectometry, a powerful variant of MCTDR, is performed to evaluate the response of the chafing fault. The Genetic Algorithm (GA) is then applied to characterize the chafing fault by estimating its length, impedance and distributed per-unit-length parameters. The proposed method will be validated by numerical results using an electronic card including Xilinx Zynq 7010 FPGA to inject/receive OMTDR signals into the twisted pair cables.

PROPOSED METHODOLOGY: SOFT FAULT DIAGNOSIS AND CHARACTERIZATION BASED ON GA

An incipient fault diagnosis and characterization algorithm is developed, in this paper, as shown in the flow chart of Fig. 1. After detecting the incipient fault based on reflectometry, it is proposed to estimate its per-unit length parameters such as the resistance, the capacitance, the inductance, its length and its position. For this, the developed algorithm proposes to solve an inverse problem based on the genetic algorithm.

Compute the reflectometry response of a healthy version of the NUT

The first stage of the algorithm proposes to compute the reflectometry response of a healthy model of the considered EWIS given by V_{sim}. This will later form a