Intelligent Grid Diagnostics with MIMO Power Line Modems

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Index Terms

Grid diagnostics, machine learning, multiple-input multiple-output (MIMO) power line communication (PLC), precoding, beamforming

Extended Abstract

Power Line Communication (PLC) receives widespread attention for the purposes of communication and control of smart-grid operations due to its ability to exploit the existing medium of power lines for data transmission [1], [2]. As with typical communication systems, PLC modems also continually estimate the channel state information (CSI) for internal functionalities, e.g., adaptive bit loading [3]. It has been previously shown that this estimated CSI also provides valuable insight into the health of the power cables in the network [4], [5]. An alternative technique to determine changes in the cable health is to monitor the access impedance using the PLC modems, either through hardware modifications or by exploiting the in-band full-duplex (IBFD) functionality [6], [7]. However, all these techniques require different extents of modifications to the legacy PLC modem chip-sets, i.e., altering the PHY/MAC implementation to access the estimated channel frequency response, or appending additional impedance measurement hardware and/or introducing IBFD operation to estimate the line impedance [8]. In this paper, we propose an alternative solution to achieve grid diagnostics purely as an add-on functionality to the legacy PLC modems without requiring any modifications to the existing chip-set implementation. Following the procedure proposed in this paper, we are also able to explore different types of faults and degradations that are detectable and assessable using information extracted from legacy PLC modems.

We first examine the parameters that are accessible from the native chip-sets of commonly used multiple-input multiple-output (MIMO) broadband PLC (BB-PLC) modems [9], [10]. Among the available parameters, the frequency dependent values of signal-to-noise ratio, tone-map, and the precoding matrix provide an indication into the CSI. However, while the former two are computed using CSI estimates, their final values are also impacted by the effects of power line noise. Therefore, we decide to focus on the precoder matrix instead, which is computed only using the estimated channel frequency response, to detect different faults and degradations commonly experienced in the electricity grid.

MIMO BB-PLC modems implement *Eigen-beamforming* over the available transmit ports [11]. Therefore, the precoding matrix, $\mathbf{F}$, is simply $\mathbf{F} = \mathbf{V}$, where $\mathbf{V}$ is the right-hand unitary matrix of the singular value decomposition of the estimated channel frequency response matrix, $\hat{\mathbf{H}}$ [12, Sec. 8.5.2], i.e.,

$$\hat{\mathbf{H}} = \mathbf{U}\mathbf{S}\mathbf{V}^H, \tag{1}$$

where $\{\cdot\}^H$ is the conjugate transpose operator. It is noticeable from (1) that while $\mathbf{V}$ provides an indication into the channel, the entire channel characteristics are not available at our disposal. Therefore, we investigate the performance of grid diagnostics using only the precoding matrix $\mathbf{F}$ by applying methods developed in our prior works [4], [5].

In our previous work, we have designed a machine learning (ML) based solution to detect water-tree degradations by training and testing the machine with several features extracted from $\hat{\mathbf{H}}$ [4], [5]. In this work, we apply the same principle to investigate its suitability in detecting low impedance faults typically observed in distribution networks. To this end, we feed our machine with selected features extracted solely from $\mathbf{F}$.

First results of our evaluation, seen in Fig. 1, show the detection and false alarm rates of identifying an asymmetric *line-to-line* low impedance fault between a random pair of conductors at a location that is also randomly chosen, by using different sets of features extracted from $\mathbf{F}$, for e.g., the n-th order moment of $F(i, j)$ across frequency, for $n \in \{1, 2, 3, 4\}$ and $i, j \in \{1, 2\}$, where $F(i, j)$ indicates the (i, j)th element of $\mathbf{F}$. We notice in Fig. 1 that by choosing the right features, we obtain up to 99% detection rate with a false alarm as low as 2%.

We also perform similar evaluations for different types of faults on the lines and determine the detection accuracy with various features extracted from $\mathbf{F}$. In addition, we also use the precoding matrix to predict the cable aging conditions as is

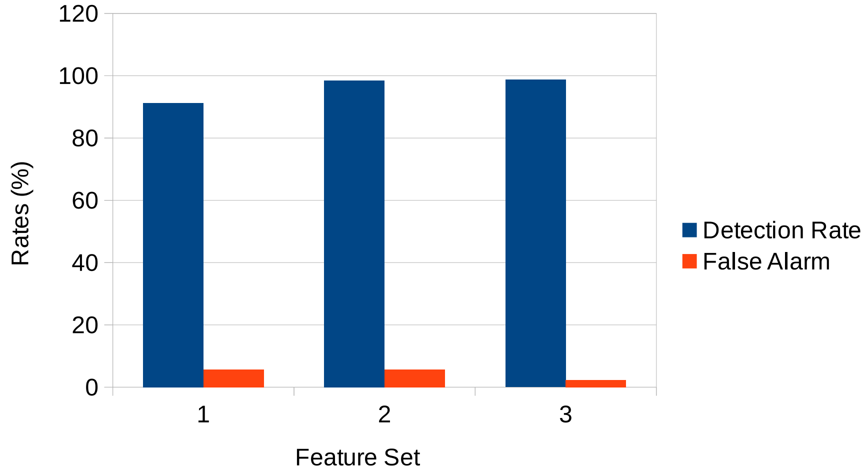

Fig. 1: Detection and false alarm rates of detecting a low impedance fault located at random on a 500 m cable.

performed in [5], where the cable degradation severity is estimated using ML-based regression, to examine if legacy PLC modem chip-sets could be used in their current form with only a trained machine augmented on it for the versatile tasks encountered in grid diagnostics.

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