Fuzzy-Based Orthogonal Decomposition Approach for Fault Diagnoses in Distribution Feeders of Smart Cities

Rogerio Flauzino, Ivan Nunes da Silva, Danilo Spatti
University of São Paulo
Department of Electrical Engineering (USP/EESC/SEL)
São Carlos, SP, Brazil
raflauzino,insilva@sc.usp.br

José Francisco R. Silva, Mateus A. Lourenço, Inacio R. N. Dantas
ELEKTRO – Power Distribution Company
Rua Ary Antenor de Souza, 321, CEP 13053-024
Campinas, SP, Brazil

***Abstract*—Smart Cities are the new goal for Smart Grid applications. In this context it can highlighted several researches introducing modern concepts of projecting, modelling, and simulating. This paper presents a new approach for fault diagnoses in distribution feeders inserted into a Smart City. The ability to handle load variations, several kind of permanent or temporary faults and non-linearities are performed by a hybrid combination of Fuzzy Systems and Orthogonal Decomposition. Results are shown to validate the approach.**

***Index Terms*—Fault Identification, Fuzzy Systems, Smart Grid, Smart City.**

I. Introduction

The concept of intelligent city (Smart City) comprises different structural, social, economic, environmental and technological elements, but generally refers to communities with modern energy resources, architectural and infrastructure. They are characterized also by ample capacity for sustainable innovation, greater efficiency in various processes, and the high degree of connectivity through the application of information and communication technologies [1-3].

In this conjuncture, within the context of power systems, the Smart Cities consist of a set of intelligent networks (Smart Grids) composed of different topologies. The Smart Grids (SG) can be understood as the union between the different elements of the electrical systems with the information and communication technologies, enabling many new features to electrical networks, among which we highlight the following: [4-8]:

- Minimization of operation and maintenance costs;
- Bi-directional flow of information;
- Improvement of the quality of delivered energy;
- Optimization of the operation of its elements;
- Automatic system recovery;
- Real-time monitoring of the network and its load;
- Increased monitoring of customer demand by distribution companies;
- Control and detailed monitoring of consumption by the customer;
- Provision of updated information and control options for consumers;
- Increased deployment and integration of distributed resources, increasing the use of renewable energy;
- Minimization of operation and maintenance costs.

Nevertheless, the implementation of Smart Grids, and consequent formation of Smart Cities, from the electric power point of view, has required coordinated efforts of government and private sectors. The current situation of some countries regarding the modernization of their networks is described below briefly.

In the United States, for example, in 2007, a law was passed to encourage greater independence; the guidelines also covered strategic issues in relation to Smart Grids, such as efficiency and energy security [9]. In 2009, it was announced the availability of 3.4 billion dollars for modernization of the electric networks in the country, with prospects of increasing energy efficiency and maximize performance of energy networks [10]. In 2010, the National Institute of Standards and Technology (NIST) published a document describing the conceptual model of Smart Grids and defines standards for their applications [6].

Although the constituent countries of the European Union have grids with very different specific characteristics, from 2005 it created the European Technology Platform for Electricity Networks of the Future in order to propose some general rules for adoption aiming the implementation of smart grids by the countries of this region. In 2006, 2007 and 2010 were presented normative documents from this group in order to define objectives and strategies for the development of Smart Grids as well as to establish the research and development priorities for its implementation [11].

In addition, among the countries of the European community have already begun the process of implementing its Smart Grids, we highlight Portugal, more precisely Portuguese city of Evora, due to investments made by EDP utility (Energias de Portugal). In Évora, the inhabitants already have smart meters that allow tracking and monitoring energy consumption via internet, which they also have possibility to find information related to the project and about the Smart Grids [12].

Another important country in research and development related to solutions for Smart Grids is China because of its economic expansion and the consequent need for electricity. The Chinese government has focused on distributed generation from renewable sources as a way to complement the efforts to meet its energy demand. In 2007, East China Power Grid Company initiated a process to evaluate the feasibility of developing Smart Grids signaling the need to create high-tech equipment and innovation by the research groups of the country [13]. In 2008 and 2009, the Shanghai Municipal Electric Power Company and the North China Power Grid Company also launched smart grid projects, mainly focusing their projects on smart metering, distribution automation and customer interaction [14].

The development of digital protection systems, as well as reliable and fast communication networks constituted a major technological breakthrough, which were adopted in an accelerated manner in electric power systems. However, many obstacles are still present and its study gets relevance when it is premised on the continuing evolution of electric power systems, especially those based on Smart Grid.

In this context, identification and fault location receive attention, since, given the possibility of their correct execution have, in principle, the isolation of sector belonging to the electric system that is faulty and, subsequently, given its location, restoration of electricity supply in time compatible with the requirements related to the set of customers affected by the outage.

In power distribution systems, on the other hand, due to its large branch, electrical unbalance and unique features, which are present only in these systems, fault location is not in a closed issue. In addition, we have that the identification of high impedance faults in such systems, when made by conventional techniques, does not provide reliable performance, which is highlighted by the related literature from the 1980s to the present day [15].

Thus, it is in the context of location of high impedance faults in distribution systems with Smart Grid that this work develops.

II. Proposal for Identification and Location of Faults

Approaches for locating faults in electric power systems can be modeled by two modules. The first of these modules is responsible for receiving the waveforms of voltage and current in order to extract features. With these results, the second processing block is responsible for locating the fault of high impedance. Schematically, this common model can be represented as shown in Fig. 1.

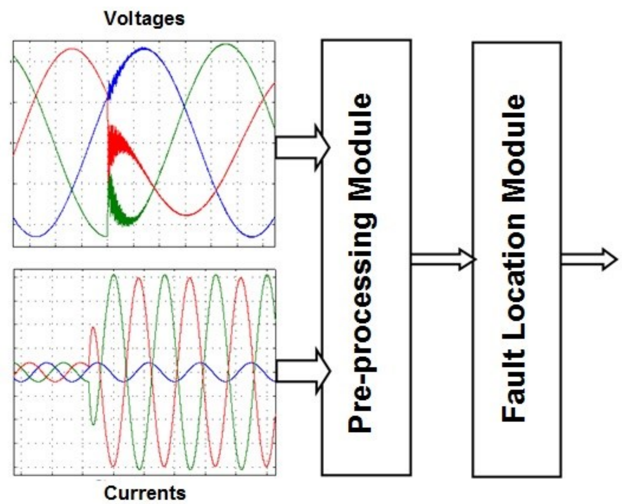

Fig. 1. Schematic diagram for the common model related to fault identification and location systems.

There are two work fronts for the structures identified in Fig. 1, that is, decomposition into orthogonal components which, from the waveforms of voltage and current, it is possible to extract components orthogonal to each other, i.e. uncorrelated, able to synthesize the electric system behavior under study. Therefore, we used this mathematical tool as pre-processing module to the fault location system model. The mathematical foundation of this tool can be found in [16].

The second work front consists of a proposition for the automatic adjustment of fuzzy inference systems. Thus, by means of computer simulations of high impedance faults and pre-processed data, through decomposition into orthogonal components, two fuzzy systems will be adjusted. The first fuzzy system estimates the distance, in relation to the substation, where the fault of high impedance occurred, whereas the second fuzzy system estimates the resistance of this fault.

The feeder employed in computer simulations has a nominal voltage of 13.8 kV and it is presented by the geographical layout of your primary network, as illustrated by Fig. 2. Computer modeling of this feeder was made using descriptive language ATP/EMTP. The primary network of this pilot feeder was modeled having a total of 2,764 primary branches. A summary of their characteristics is shown in Table I.

Tabela I. Parameters of the equivalent electrical system at the medium voltage bus of substation.

Parameter	Value
Positive sequence impedance (Z_1)	$1.9546 + j7.3245$ Ω
Zero sequence impedance (Z_0)	$1.9809 + j14.491$ Ω

Fig. 2. Map of primary branches of the modeled computationally pilot feeder.

Considering a three-phase system and that the available waveforms for the phase voltages and line currents are possible, and also considering the waveforms for $v_N(t)$ and $i_N(t)$, we can then obtain a total of 64 waveforms, i.e., 32 for voltages and 32 for currents. In order to better delineate each of these waveforms, it is shown in Fig. 3 a schematic diagram illustrating the process of decomposition into orthogonal components.

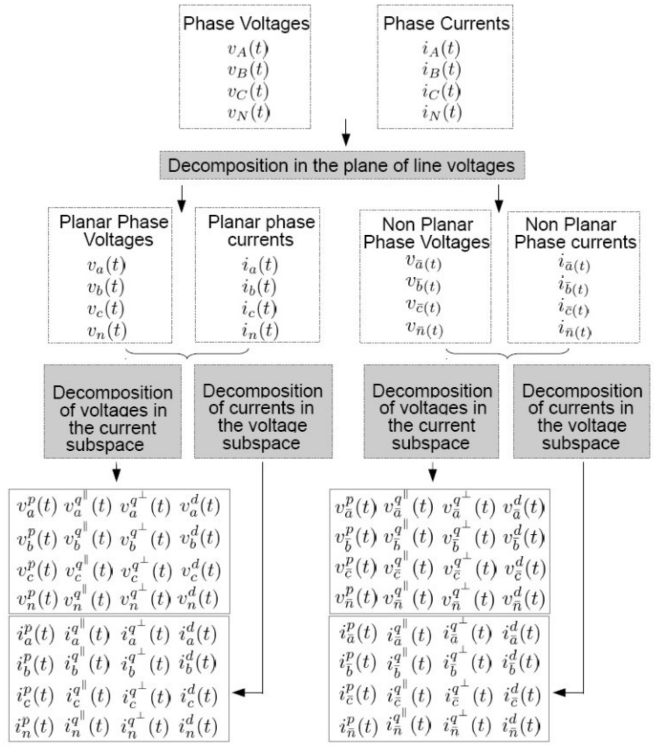

Fig. 3. Schematic diagram of the decomposition process by orthogonal components.

III. Simulation Results

The fuzzy system dedicated to distance estimation of occurrence of the fault, in addition to being tested with the data from the adjustment set, it was also tested with data coming from computer simulations not contained in the adjustment set. Thus, a total of 9,154 cases were submitted to fault location system developed in this work. The results obtained for the fault location are shown by Fig. 4 as relative error histogram.

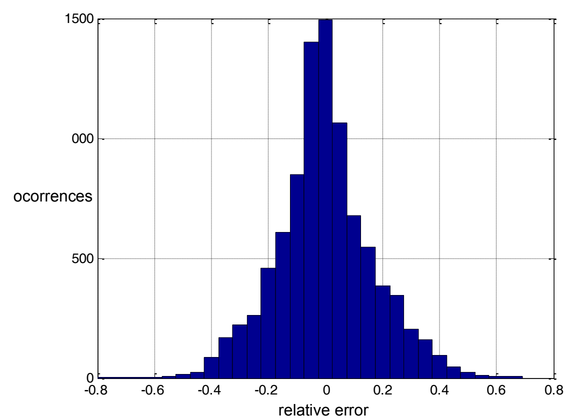

Fig. 4. Histogram of the relative error in relation to the fault distance estimation by the fuzzy system using test data.

IV. CONCLUSIONS

This paper presents a proposal for identification and fault location for distribution systems with Smart Grid. Noteworthy are the developments involving new signal processing methodologies required for extraction of electrical characteristics available on systems with large data acquisition.

The simulation results show that most of the patterns used to validate the system present mean relative errors centered at zero, indicating an excellent miss distance estimator

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