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Steady state simulation of a distributed power supplying system using a simple hybrid time-frequency model

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ABSTRACT

The paper presents a hybrid time-frequency model, which is a combination of two types of models are typically used in a modern computer simulation of power systems: time domain models and frequency domain models. To simulate the nonlinear part of the system a Simulink time domain model of each nonlinear element is used, while the simulation of the linear part of the system is performed using a frequency domain model of the system applied in PCFLO. A well-designed programming interface allows seamless data exchange between the two environments and provides control over the simulation process. It is shown how the hybrid model compares to the time and frequency domain models using a 20 bus power supplying system with nonlinear loads (6-pulse rectifies). The comparison allows to examine the convergence and efficiency of the developed hybrid model and determine the directions for its further improvement.

1. Introduction

Contemporary power systems can be characterized by its increasing complexity and a growing number of nonlinear loads. An increasing number of electronic devices equipped with high-efficiency power supplies, power electronic devices such as rectifiers and inverters, modern light source such as fluorescent lamps or LED lamps [1–3], on the one hand contribute to more efficient use of electricity, on the other hand, significantly complicate the design and analysis of the modern power systems The nonlinear devices can be a source of significant interference/distortion and may cause serious problems on the designing stage of the power system. In a worst case, it can lead to a situation where connected devices will interfere with each other, what may cause additional energy losses or even results in malfunction or damage of the devices [1–3]. An additional issue is the fulfillment of energy standards for maximum allowed levels of harmonic distortion which the power system can generate in the normal operating state. If there is no any king of analysis from this point of view, it may result in building a system which the customer will not be allowed to connect to the power grid. The presented problems necessitate the use of more advanced methods of computer modeling and analysis of the power systems. It allows to anticipate and eliminate potential problems at the designing stage. A software which enables reliable analysis and simulation of the power system allows not only to avoid potential errors, but also to optimize the elements of the system for the specific application. This approach generally leads to significant savings at the construction stage of the power system and during its further operation.

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In modern computer software dedicated to power systems analysis, two types of models are typically used: models described in the time domain and models described in the frequency domain [1,3–6]. Time domain models are usually based on the differential equations which are then solved using numerical algorithms [3,6]. Such a description enables a good representation of the objects dynamical behavior, but it does require a considerable computing power, so it is often used for analysis of the individual system components or systems with a small number of elements. An important advantage of the time domain modeling is the ability to faithfully reproduce its nonlinearity, which is the cause of higher harmonics distortion in currents and voltages [7]. A well-defined time domain model allows to faithfully reproduce the behavior of an element for a wide range of currents and voltages [3,8]. If the size of the analyzed system is significant, and the main purpose of the analysis is to determine the power flow and harmonic flow, the frequency domain model is often considered [3–5]. In case of the nonlinear circuit the model is based on spectral analysis and comes down to the description of the system in the form of a series of linear models representing the system state for each harmonic separately. In this case, the nonlinear elements are often modeled using the so-called current injection method, where higher harmonics generated by the element are modeled as current sources for each individual harmonic [6,9]. This approach can significantly reduce the required computational effort necessary to solve the equations describing the system (instead of differential equations the algebraic equations are solved). The main disadvantage of the frequency domain method is a significant simplification of the model and the ability to simulate operation of the system only in a steady state and at one particular operation point. This method works well when the distortion generated by the nonlinear elements is relatively small (voltage THD smaller than a few percent) and parameters of the system components are substantially constant.The best solution would be to combine the accuracy of time domain models with the performance of the frequency domain models. This leads directly to a hybrid time-frequency models. They are based on the use of the frequency domain model to analyze the linear part of the system, while the nonlinear elements are modeled in the time domain. This approach has many advantages, such as good mapping of the nonlinear elements behavior in a wide range of currents and voltages and better computing performance in comparison with the time domain models. Examples of hybrid modeling available in the literature [10–16] show, that this method of analysis has a considerable potential, but also raises a number of problems. The most significant are problems with numerical stability of the hybrid models, problems with fast evaluation of the steady state of the nonlinear elements and the considerable complexity of the hybrid model because of its dual time-frequency character. Another problem is that usually the developed hybrid model is optimized for a given group of electrical equipment [12]. This allows to speed up the process of calculation, however, the versatility of the developed solution is rather limited. Developing a reliable hybrid model that enables an efficient and accurate analysis of power system is therefore a challenge from both: a scientific and an engineering point of view, but the advantages of such a solution seem to be indisputable. A well-constructed hybrid model should enable the analysis of the system in virtually any steady state with performance unattainable for a time domain models. It should be versatile enough to be able to use practically any kind of time domain models of nonlinear elements defined by the user.

In the paper has been presented proposal of a hybrid time-frequency domain modeling in Section 2. In Section 3 the software implementation of the method is described. Section 4 contains description of an exemplary power system which can be used as a basis for the evaluation of the hybrid algorithm. In Section 5 the results of the evaluation are presented. The hybrid method is compared with the frequency domain and time domain models of an exemplary power system. Summary and final conclusions are included in Section 6.

2. The hybrid model

The basic concept of the hybrid algorithm is to use a frequency domain model for the whole simulated system with the exception of the selected nonlinear devices. For the nonlinear devices independent models in the time domain are used. In a particular operating point, input parameters i.e. voltages (or currents), for the simulation in time domain will be obtained from the frequency domain model. On the other hand, currents (or voltages) obtained from a simulation in the time domain allow the insertion of higher harmonics sources into the frequency domain model. Since it is assumed that the results achieved in the time domain and the frequency domain will depend on each other, it is necessary to simulate the system in an iterative way using a loop. A simplified diagram of the proposed algorithm is shown in Fig. 1.

In the first step, the initial state of the system is evaluated using the frequency domain model (Fig. 1). Then the algorithm enters the main loop. Inside the loop currents flowing through the nonlinear devices are calculated using the time domain models of the elements. In the next step, these currents are used to set the current injection models of the nonlinear loads in the frequency domain models. The result is the harmonic flow in the frequency domain model and the voltage spectrum in each bus of the considered power supplying system. At the end of the loop, the obtained voltage spectrum is compared with the voltage spectrum from the previous iteration. If the difference is below the assumed value, the algorithm stops. The results from the last iteration are the harmonic flow solution for the considered power system with the assumed accuracy. Theoretically by the presented approach satisfactory results in a reasonable time should be given, but everything depends on the time domain models of the nonlinear elements. First of all, in each iteration it is necessary to wait for the steady state of the nonlinear devices and the transient state of each nonlinear device might be completely different. Second problem is in the convergence of the algorithm. The convergence mainly depends on the nonlinear device models used in the time domain. In other words, sometimes it will end after a few iterations, and sometimes it even might be divergent. These problems must be addressed during the implementation of the hybrid algorithm.