Summary

Current and next generation power distribution networks (PDNs) are complex systems characterized by a large size, the interconnection of heterogeneous objects (e.g., distributed renewable sources or storages such as electric vehicles charging hubs, etc), and a stochastic behavior due to both unknown customer demand and other external conditions affecting power generation. All the above system features require the availability of innovative and general modeling solutions for the accurate prediction of the network state. This research focuses on theoretical investigation of model generation algorithms for complex systems and networks and their application to the problem at hand.

First in this dissertation, an alternate modeling technique for the power-flow analysis of PDNs is presented. The PDN is suitably interpreted as a decoupled circuit in the phasor domain, which is split into a linear and a non-linear sub-circuits, of which the large linear part represents the source and the interconnecting blocks including transmission lines, while the small non-linear part accounts for load characteristics and distributed generators (DGs). The circuital interpretation is directly solved in the frequency domain via a standard tool for circuit analysis in combination with a simple iterative scheme. At each iteration, the large linear part can be solved via either the modified nodal analysis (MNA) or any simulation program with integrated circuit emphasis (SPICE). The link of the proposed numerical scheme with the so-called waveform relaxation technique is also thoroughly discussed. The proposed approach has been proven to offer a general solution allowing to handle multiple DGs and other heterogeneous sources without requiring custom modifications for any arbitrary network. Additionally, it features fast convergence and very good accuracy.

While the first part deals with steady-state analysis of PDNs, the effect of stochastic behavior of distributed renewables and the changes in the physical medium (e.g., equivalent resistance, reactance, capacitance, etc.), due to external factors, on the network voltage profile is analyzed, in the second part of the Thesis, by performing the uncertainty quantification (UQ) of power networks. Several techniques are presented ranging from standard Monte Carlo (MC) simulation to the regression based accurate and fast-to-evaluate surrogate models such as the polynomial chaos expansion (PCE) and machine learning (ML) based least square support vector machines (LS-SVM). A two-step scheme is proposed, that involves the compression of the training response set with principal component analysis (PCA) and the generation of surrogate models from a limited number of samples.

The above proposed techniques are assessed for their accuracy and effectiveness by considering multiple test networks in chapters 2 and 3. These are further analyzed to handle larger realistic networks by considering a three-phase benchmark network, the IEEE 8500-node test feeder, used by Institute of Electrical and Electronics Engineers (IEEE) power research community. Specifically, a power-flow solution is performed for the mentioned test network using the proposed circuital interpretation with the fixed-point iteration and two state-of-the-art methods, the *Z-bus* method and the benchmark open source distribution system simulator (openDSS) software. After that, the proposed compressed surrogate model of network nodal voltages is built with LS-SVM in conjuction with PCA, whose predictions are compared in terms of accuracy and simulation time with those of the sparse PCE and MC simulation, where the former is a polynomial regression technique while the latter is a simple traditional scheme.

The results collected in this research work demonstrate the benefits and strengths of the proposed modeling and simulation solutions for PDNs compared to currently available state-of-the-art techniques [1, 2, 3].