

Distribution System Modelling: A Holistic Approach for Harmonic Studies

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Abstract : The procedures for performing harmonic studies for medium-voltage distribution feeders have become relatively mature topics since the early 1980s. The efforts of various electric power engineers and researchers were mainly focused on handling large harmonic non-linear loads connected scarcely at several buses of medium-voltage feeders. In order to assess the impact of these loads on the voltage quality of the distribution system, specific modeling and simulation strategies were proposed. These methodologies could deliver a reasonable estimation accuracy given the requirements of least computational efforts and reduced complexity. To uphold these requirements, certain analysis assumptions have been made, which became de facto standards for establishing guidelines for harmonic analysis. Among others, typical assumptions include balanced conditions of the study and the negligible impact of impedance frequency characteristics of various power system components. In latter, skin and proximity effects are usually omitted, and resistance and reactance values are modeled based on the theoretical equations. Further, the simplifications of the modelling routine have led to the commonly accepted practice of neglecting phase angle diversity effects. This is mainly associated with developed load models, which only in a handful of cases are representing the complete harmonic behavior of a certain device as well as accounting on the harmonic interaction between grid harmonic voltages and harmonic currents. While these modelling practices were proven to be reasonably effective for medium-voltage levels, similar approaches have been adopted for low-voltage distribution systems. Given modern conditions and massive increase in usage of residential electronic devices, recent and ongoing boom of electric vehicles, and large-scale installing of distributed solar power, the harmonics in current low-voltage grids are characterized by high degree of variability and demonstrate sufficient diversity leading to a certain level of cancellation effects. It is obvious, that new modelling algorithms overcoming previously made assumptions have to be accepted. In this work, a simulation approach aimed to deal with some of the typical assumptions is proposed. A practical low-voltage feeder is modeled in PowerFactory. In order to demonstrate the importance of diversity effect and harmonic interaction, previously developed measurement-based models of photovoltaic inverter and battery charger are used as loads. The Python-based script aiming to supply varying voltage background distortion profile and the associated current harmonic response of loads is used as the core of unbalanced simulation. Furthermore, the impact of uncertainty of feeder frequency-impedance characteristics on total harmonic distortion levels is shown along with scenarios involving linear resistive loads, which further alter the impedance of the system. The comparative analysis demonstrates sufficient differences with cases when all the assumptions are in place, and results indicate that new modelling and simulation procedures need to be adopted for low-voltage distribution systems with high penetration of non-linear loads and renewable generation.

Keywords : electric power system, harmonic distortion, power quality, public low-voltage network, harmonic modelling

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