Fragility analysis framework for transmission tower systems subjected to straight line winds

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ABSTRACT:

Electrical transmission tower systems are an integral part of the electric power network (EPN). These systems are a complex and dynamic system which are vulnerable to natural hazards. Failures associated with these systems can lead to massive blackouts which can severely disrupt the everyday life of the societies that depend on them. In this study, we present a framework for assessing the vulnerability of these systems under wind events through development of fragility functions. Initially, a finite element model for a line of transmission towers, insulators, and conductors is developed in ANSYS and validated with the available test-to-failure data. The models consider the effect of material and geometric nonlinearity. A pushover analysis for the tower of interest is conducted to understand the structural response, select modes of failure, and associated structural parameters. This model is then used to develop a realistic but computationally cost-effective solution to represent the boundary condition of the tower as represented by the adjacent conductors and towers. With the established simplified model, a nonlinear buckling analysis is performed for the tower of interest for straight line winds. This analysis helps with establishing the limit states for the transmission tower. For considering the uncertainty in wind loading, two different wind models are considered which consider the horizontal and vertical coherence associated with straight line winds. These wind models include the wave superposition method and the frequency wavenumber spectrum method. For considering uncertainty in the material properties, two variables which influence the structural response of the tower are selected. These variables include the yield stress and Young's Modulus for the material composing the transmission tower. Finally, dynamic analysis is carried out for the simplified transmission tower system where the failure criteria is defined by a combination of three conditions which include: failure of the tower, failure of the conductors and the tower and conductors failing together. For applying realistic dynamic wind loads on the system using the two wind models, drag coefficients for the transmission tower and conductors are determined in wind tunnel tests for different orientations for the tower and conductors. The probability of failure for the simplified model is combined for different uncertain models to get a final probability of failure value for the simplified system. This procedure provides a detailed understanding of the behavior of transmission tower system under wind loads. It can also help us in better designing these tower cable systems which can make them more reliable in nature and less susceptible to failure due to wind loads.

Keywords: fragility framework, nonlinear buckling analysis, dynamic wind analysis