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Three-dimensional visualization and animation for power systems analysis

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ABSTRACT

This paper describes a novel approach for three-dimensional visualization and animation of power systems analyses. The paper demonstrates that three-dimensional visualization of power systems can be used for teaching and can help in easily understanding complex concepts. The solutions of power flow analysis, continuation power flow, optimal power flow and time domain simulations are used for illustrating the proposed technique. The paper presents a variety of examples, particularly oriented to education and practitioner training. Conclusions are duly drawn.

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1. Introduction

1.1. Motivation

The visualization of the results of power system simulations has been limited so far to bi-dimensional plots of state and algebraic variables versus time or some other relevant parameters (e.g., the loading factor in continuation power flow analysis). This way of visualizing system transients and parametric analyses requires a previous knowledge of the network topology in order to fully understand the system behavior. In other words, conventional two-dimensional plots requires a relatively high level of abstraction in order to get the full picture of the system. This level can be reached with practice and experience by practitioners that run simulations on a daily basis, but can be hardly obtained by students of undergraduate courses. Even for graduate students, the process of familiarising with system transients typically requires a relevant time of their Ph.D. courses.

In several other fields of engineering applications (e.g., civil engineering, mechanics, chemistry, etc.), three-dimensional (3D) plots and animations have been introduced years ago. We believe that time is ready to upgrade power system visualization and propose full 3D, full coloured, animated plots. In this paper, we present and describe in detail how 3D plots and animations are able to show state and algebraic variables as well as the topology of the power system.

1.2. Literature review

The importance of an intuitive and fully informative visualization of power system results has been recognized and formalized in early nineties. In [2], the authors specifies three guidelines for setting up a good graphical representation of a physical phenomena: (i) natural encoding of information; (ii) task specific graphics; and (iii) no gratuitous graphics. In [3,4], two-dimensional contour plots are proposed for the visualization of voltage bus levels with inclusion of the topological information of the network. The contour plot complies with the three guidelines mentioned above. In this paper the idea of using contour plots proposed in [3] is extended to three dimensions. Furthermore, 3D animation is used to show electromechanical transients and continuation power flow analysis.

In [5–10], the contour plot technique is further developed for visualizing a variety of data, such as power flows in transmission lines, locational marginal prices, available transfer capability, contingency analysis, etc. All these references focus on static data visualization and are basically two-dimensional plots. A simple animation is provided for visualizing the effect of load power variations. The flows are represented by moving arrows in the topological scheme, and transmission line and transformer saturation is indicated by means of pie charts. Three-dimensional representation is limited to coloured "thermometers" on top of the network scheme. The tool described in [5–10] is proprietary software and cannot be customized or freely distributed.

3D visualization has not been exploited so far for power system analysis, although in [11], the advantages of the 3D visualization are discussed and recognized. In [12], rotor speeds of a multi-machine system are displayed in a kind of 3D plot, however the topologi-

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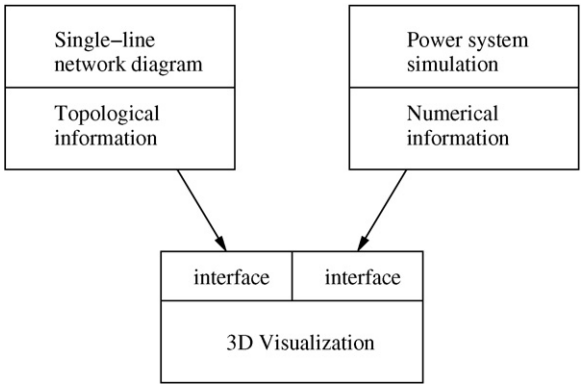

Fig. 1. Basic functioning of the 3D visualization tool.

cal information is missing. Reference [13] proposes a variety of 3D visualizations and animations of traveling waves in transmission lines. In [13], the third dimension is used to display the topology and the animation to represent time evolution. This paper extends the approach given in [13] to electromechanical transients as well as to other stability and economical analyses of power systems. The applications of the proposed visualization approach are especially suited for, but not limited to, teaching power systems. The main focus of education is not proposing new technical ideas, but rather to propose novel approaches for easing the learning process of well-assessed concepts.

1.3. Contributions

In summary, the contributions of this paper are:

(1) A novel approach for 3D visualization and animation of a variety of power system analyses, including power flow, continuation power flow, optimal power flow and time domain simulations.
(2) A technique that can help power engineering students, practitioners and also non-technical people in understanding the behavior and the operation of electrical energy systems.

1.4. Paper organization

This paper is organized as follows. Section 2 describes the proposed 3D visualization and the author's teaching experience using 3D maps. Section 3 presents several illustrative examples of 3D visualization and animation of power system simulations through a variety of test case networks. The differences and the advantages of the proposed visualizations with respect conventional plots are discussed in detail. For the sake of clarity, Section 3 also briefly introduces the power flow, the optimal power flow, the continuation power flow, and the time domain integration. Section 4 draws relevant conclusions. Finally, Appendix A briefly introduce the software tool used for the simulations.

2. Proposed visualization technique

The basic functioning of the proposed tool is depicted in Fig. 1. The 3D visualization needs two sources, one for topological data and another one for model/numerical data. These two sources are independent and are not necessarily part of the same software package. Some further implementation details are provided in Appendix A.

3D plot have been obtained by computing the convex hull that envelopes the values obtained from the simulations into a theedimensional surfaces with high resolution. For example, let us consider the bus voltage levels of the power network. The number of available voltage values is equal to the number of buses, which is typically not sufficiently high to adequately fill the surface up. To overcome this issue, we created a grid with a high number of

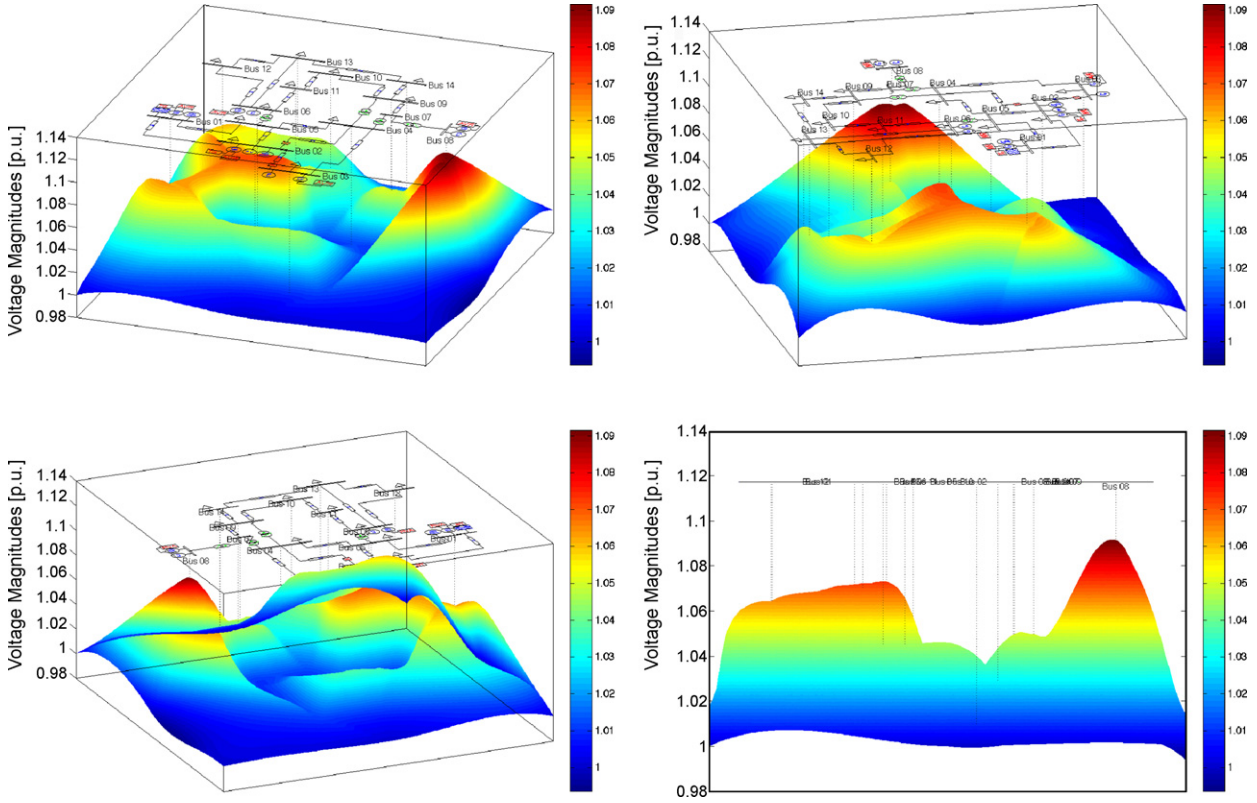

Fig. 2. A variety of points of view of the 3D voltage magnitude contour plot.

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