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Detailed modelling, implementation and simulation of an "all-in-one" stability test system including power system protective devices

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ABSTRACT

This paper presents modelling and simulation results for multiple instability scenarios of the "all-in-one" test system. The test system is an alteration of the Bonneville Power Administration test system constructed to capture transient (angle), frequency and voltage instability phenomena, resulting in system collapse, within one system. The paper describes general overview of the test system and its associated individual devices modelling. These modelling are both customized and adapted from the built-in model developed by PowerFactory simulation software. The paper also provides a description of different instabilities that can be reproduced by this self-contained system. One of the case study is demonstrated in detail with the necessary initialization settings for reproducing instability scenario.

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1. Introduction

The different synchronous systems in the European Network of Transmission System Operators for Electricity (ENTSO-E) have experienced a chain of severe power system failures evidencing that these power systems are currently being operated under more stringent conditions. This fact motivates a search for methods capable of preventing severe failures or at least mechanisms to decrease the risk of blackouts. Large blackouts are the result of a complex sequence of component failures [1], equipment misoperations [2], unintended operator actions [3] and human error [4]. These complex sequence of events are commonly referred to as cascading failure or rolling blackouts. Cascading failures are rare because the most likely contingencies are considered beforehand in power system planning design and operational routines. It can be argued that with a high degree of the "controllability" in the power system, cascading failures can be mitigated or even completely avoided. This kind of controllability is raising with the increased number of installations of FACTS devices and VSC-HVDC systems. On the other hand, protective devices commonly act as the last resource to guarantee personnel and equipment safety, however under certain circumstances they might misoperate, initiating a rolling blackout.

The authors hypothesize in [5] that if the operation of protective devices is coupled to the potential relief capacity of power system controllable devices, then cascading failures can be avoided. To this aim, controls mechanisms coupling protection systems and power system controls can be developed to fulfil this aim. The first steps to develop such algorithms are to elaborate a test system which is able to reproduce all possible instability scenarios, and that at the same time, contains calibrated protective devices that act according to conventional protective relaying principles. Such test system can be used as a basis to develop the control mechanisms that consider both the conventional operation of protective relays and the

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operation and physical constraints of power system controllable devices. To fulfil these requirements, the test system must be developed with care, paying attention to important modelling details of each power system component, it's controls, and associated protective devices.

The objective of this paper is to perform detailed modelling and implementation of a test system that is capable of generating different instability scenarios. The test system is an alteration of the Bonneville Power Administration (BPA) test system which was originally implemented in a special toolbox developed in the MATLAB/Simulink®platform [6], in this article a completely new realization in PowerFactory has been implemented. Each individual device model is described in detail and mapped to different implementation approaches available within a commercial and proprietary simulation software.[1] A detailed example of a instability scenario is given with its initialization settings to show the need of accurate implementation of the different device models in the system. The detailed modelling of each device is necessary for developing algorithms capable of coordinating the operation of protective devices with power system controls in order to enhance the stability of power systems.

In view of the description above, the contributions of this paper can be summarized as follows:

- To perform detailed modelling and implementation of a test system capable of generating different instability scenarios, and including protective relays, within a commercial and proprietary software, i.e. the "all-in-one" system.
- To explain how built-in models which are implemented within the software's library can be modified to satisfy the user's modelling requirements.
- To illustrate different model implementation approaches that can be used within a commercial and proprietary software tool to implement specific customized user defined models which are necessary for the representation of important system dynamic behaviour.
- To demonstrate, through simulations, how the adapted and customized models are capable of accurately capturing power system dynamic behaviour.
- To exhibit the different relay coordination considerations that must be taken into account when specifying the protective device settings for the test system in this paper.
- To implement protective relay models within the test system that are capable of operating according to conventional power system protection design requirements.
- To show, through simulations, that the relay models implemented in the test system operate according to the design specifications considered within this study.

The remainder of this paper is organized as follows. Section 2 describes the power system models and their implementation in the DIgSILENT PowerFactory software. Section 3 describes instability scenarios that can be simulated by the "all-in-one" system. In Section 4, considerations for the design of protective relays and steps for their modelling and implementation in the "all-in-one" system are discussed. In Section 5 conclusions are duly drawn.

2. System modelling

The commercial and proprietary DIgSILENT PowerFactory simulation software offers a Graphical User Interface (GUI) to implement power system models for stability analysis purposes. The software is complemented with a library that contains built-in IEEE models, and it also allows users to create their own models if needed. The models can be implemented by either building block diagrams or programming in the DIgSILENT Simulation Language (DSL) block definitions; allowing for the representation of transfer functions, or differential equations for the more complex transient models. This section presents a test power system and the detailed models of each individual device implemented in PowerFactory by using block diagrams and DSL programming.

2.1. Test system

A one-line diagram of the "all-in-one" test system is shown in Fig. 1. The system consists of a local area connected to a strong grid (Thevenin Equivalent) by two 380 kV transmission lines. A motor load (rated 750 MVA, 15 kV) is connected at Bus 4 and supplied via a 380/15 ratio transformer. A load with constant power characteristics and load tap changer (LTC) dynamics at the distribution side are explicitly modelled at Bus 5. A local generator (rated 450 MVA, 20 kV) is connected at Bus 2 to supply the loads through a 20/380 ratio transformer.

From the power system viewpoint, excitation systems should be capable of responding rapidly to a disturbance so that proper voltage support is provided through excitation control. Thus, excitation systems should be designed to have a fast acting response to enhance transient stability. This fast response requirement has been taken into consideration by manufactures which have developed excitation control systems, such as the GE EX2100 [8], Westinghouse's static excitation system [9], and others, that can be modelled through the IEEE Type ST excitation models recommended by the IEEE Standard

[1] For definitions of software categories such as "commercial" and "proprietary" please refer to [7].

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