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Simulation on Voltage Unbalance Reduction in Railway Electrification System by Different Special Transformers

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Abstract

In recent years, electric railway system becomes an efficient mass transportation in large urban areas. A railway electrification system supplies electric power to railway trains through the transformers. Therefore, the transformer is a key component to help reduce problems of the unbalance of voltage and current in the power grid. As electric trains have their power delivered on a single-phase system, the single-phase transformer causes the unbalance of voltage and current in the power system network, with which the railway electrification system is connected. In order to alleviate these problems, special transformers, i.e. Scott transformer and Le-Blanc transformer, have been proposed to be used in the railway electrification system. This paper focuses on developing the special transformer models for using in DIgSILENT PowerFactory software. The developed models have been verified with a simple train system in order to study the effectiveness of reduction of voltage unbalance factors from the three types of transformers. In addition, the developed special transformer models can be applied in a large-scale power system network for power quality problem analysis.

1. Introduction

Electric railway system is widely regarded as an effective mass transportation alternative to reduce energy consumption and emissions in urban areas. As electric trains have their power delivered on a single-phase system

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and the grid power, on the other hand, is delivered on three phase, one single-phase transformer could be connected to the train system, however, that would cause unbalance in the power supply. Use of electric railway system in large cities around the world is on the rise. With growing concerns about the power quality impacts of electric railway system connected to the power grid [1], engineers have tried to use the special transformer as a way to power single phase electric railways from three-phase utility supplies. Practically, the use of the special transformer results in improvement of balanced currents on the three-phase side. Among special transformers, Scott and Le-Blanc transformers are widely used in the railway electrification system. However, studies on the effect of electric railway system on wide-area power systems using commercial power system analysis software such as DIgSILENT PowerFactory has not been widely spreading. This paper focuses on developing the special transformer models for using in DIgSILENT PowerFactory software. The Scott and Le-Blanc transformer models [2]-[4] are developed and verified on a simple train system in order to study the effectiveness in voltage unbalance reduction on a power system. Then, correlation analysis is performed to identify the key parameter which affects the performance on voltage unbalance reduction. It is found in the study results that the voltage unbalance factor (VUF) directly relates to the maximum of power difference between the phases. Moreover, the developed special transformer models are useful and can be applied for further studies on the effect of larger railway electrification system network in a large-scale power system for power quality problem analysis.

2. Scott Transformer Model

Fig. 1(a) shows the model of the Scott transformer in DIgSILENT PowerFactory. The Scott transformer can be modeled by combination of two single-phase transformers, T1 and T2 as illustrated in Fig. 1(b). The transformer T1 has a 50% tapped winding on its primary side, and a single winding on its secondary side. The teaser transformer T2 has a 86% tapped winding on its primary side and a single winding on its secondary side. Fig. 1(c) shows the voltage-phasor diagram of Scott transformer.

3. Le-Blanc Transformer Model

Fig. 2(a) shows the model of the Le-Blanc transformer in DIgSILENT PowerFactor. The Le-Blanc transformer can be modeled by combination of five single-phase transformers with appropriate turn ratios, A1, A2, B1, B2, C1, C2 as illustrated in Fig. 2(b). Fig. 2(c) shows the voltage-phasor diagram of Le-Blanc transformer.
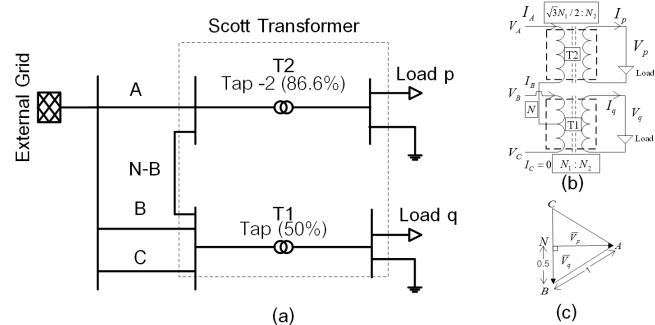

Fig. 1. (a) Scott transformer model in DIgSILENT PowerFactory, (b) Scott connection scheme, (c) Voltage-phasor diagram of Scott transformer

4. Study Power System Feeding the Electric Railway System

To demonstrate the voltage unbalance phenomenon, the transformers at each substation shown in Fig. 3(a) can