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Harmonic analysis on various traction transformers in co-phase traction system

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Abstract Traction loads are subjected to significant load changes and frequent voltage change of about 5%, which is usually unacceptable to the public electricity supply. This paper presents a comparative study of traction transformers such as Scott, YNvd, Leblanc and Impedance Matching Transformer for reducing the total harmonic distortion and thereby improving the power quality in a co-phase traction system. A dual converter with a compensator is employed together with special traction balanced transformers to reduce the harmonics, voltage unbalance, negative sequence current and reactive power problems. This scheme is implemented by using Matlab/Simulink R2009a software. The simulation results show that the performance of the Impedance Matching Transformer is better compared to other special traction transformers.

1. Introduction

In the present scenario, electric traction system is the most economical and efficient channel for both personnel and material transmission. The first railway use of three-phase supply and induction motors was on the Lugarno tramway in 1896, on which Brown installed a system using 40 Hz supply [1]. The research and development in electric traction system is progressing dramatically over the past 100 years. The study commenced in 1930s, when McGee and Harder discussed the characteristics of the traction supply system with available ac systems (two wire system, three wire system without and with transmission system) [2]. Price also produced a paper emphasizing the need of a commercial frequency power supply for railway electrification in 1957 [3].

The ac traction system consumes 25 kV, 50 Hz ac supply from 220/132/110/66 kV Extra High Voltage 3-phase grid system through a traction substation, in which step-down transformers are employed. The transformer feeds the electric locomotive through contact line system. The contact line system consists of the contact wire, suspension wire and return wire. Fig. 1 shows the basic components of the ac traction supply system. To facilitate easy load sharing, each transformer feeds to a distance of 30 km to one side. Electric locomotives are connected single phase loads in our power system. They create power quality problems due to their dynamic speed

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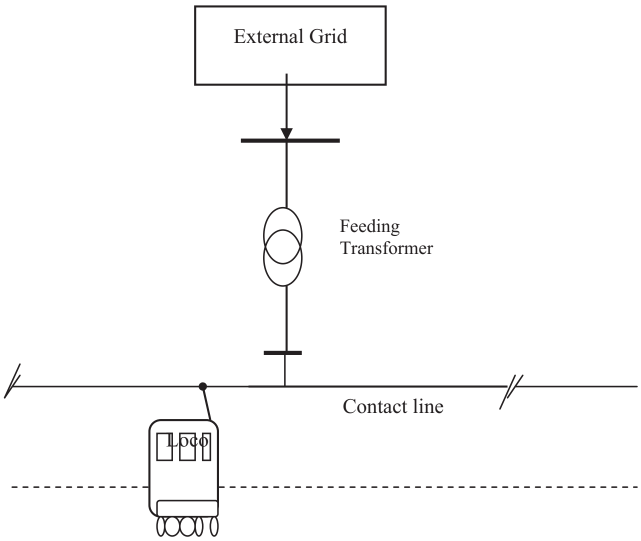

Figure 1 The schematic of electric traction supply system.

and load conditions. The new high capacity swift-flying trains require good quality power. So the transformers are designed so as to increase the power quality of system.

Power quality problem refers to a set of disturbances or conditions that produce undesirable results for equipment, system or a facility [4]. The major power quality problems in traction are voltage distortion, harmonics, negative sequence currents, power unbalance, reactive power problems, power factor problems, impulse current, flicker, etc. These problems initiate vibrations and torque reduction in machines, overheating, extraline losses in transformers and lines, interference problems with neighboring communication lines and also malfunctioning of relays. So power quality studies are given key importance in traction system.

The degree of the problem depends on the feeding electric railway traction loads, including train movement, tractive profile of electric locomotives, and power-supply scheme [5]. The current harmonics and power quality aspects are very complicated because of the frequent and strong transient regimes. Several papers discuss about the major solutions for the power quality problems in traction systems. Consequently, some standards and recommendations have been established in order to avoid the potential problems caused.

The most used standard for harmonic pollution limits is IEEE 519-1992. Harmonic suppression can be done either by rectifying the source or by implementing harmonic filtering circuits. Due to the expense in source modeling, harmonic filters are used to limit the harmonic currents flowing into the upstream network and to decrease the resonance effect causing current amplification along the 25 kV supply line. Among passive, active and hybrid filters, passive filters are most economic, but they cannot give dynamic compensation.

The negative sequence current suppression can be done with either using transformer with specific connection to balance load current or feeding from high voltage. The voltage unbalance problems caused by the unbalanced current can be resolved by using the following solutions: distribution of different power supply position, distribution of different phases to balance the load, by feeding high voltage power supply or by implementing balanced devices/equipments.

In 1984, Duncan Glover et al. have done train voltage analysis for modeling of supply system and discussed the use of booster transformers and autotransformers in traction system [6]. In 1985, Kneschke summarized the theory regarding unbalance problems [7]. He initiated the discussions on the use of special winding three phase to two phase transformers such as Scott connected, modified Woodbridge-connected, and Le Blanc connected transformers in traction systems to reduce unbalance which include the typical arrangement for rotary balancing equipment, such as synchronous condensers or induction motors, to remove the negative sequence currents from the three-phase system.

In 1993, Fumi et al. proposed a Static Power Conditioner (SPC) using self-commutated inverters in order to solve the problems of AC electrified railway [8]. This paper concluded that the SPC connected at phase A and phase B of a modified Woodbridge connected transformer installed at Substations can control active power, reactive power and harmonic currents. Simplified models of electric railway power-supply substations for three-phase power flow studies have been developed and are introduced by Chen in 1994 [9].

In 1999, Olofsson and Thunberg proposed an Energy Management System (EMS) function for optimal starting and stopping of converter units. The focus was on calculating train positions and power demands [10]. They also proposed the idea of introducing SCADA in traction systems. At the same time Bhargava concluded the electrical configuration of a traction system depends on the rail system, train load, clearance requirement, technology availability, etc. [11]. Hence the power requirements for different traction systems are different and should be such that it is cost effective economical. It provides reliable and efficient operating system without adverting other power company consumers. The paper summarized the different systems of rails, their power requirements and the main power quality problems in U.S., Sweden and Germany.

Active Filters and Harmonic Compensators were introduced for active, reactive power and harmonic compensation, flicker, voltage distortions, etc. [12–15]. Also a signal processing system for extraction of harmonics and reactive current of single-phase systems, static voltage fluctuation compensator, Multi-mode Active Power Quality Conditioner for Series Voltage Compensation and STATCOM were implemented to improve line conditions. Table 1 shows the comparison of various filters and static VAR compensators [16].

In order to avoid the disadvantage of two phase power supply system, co-phase traction system was implemented.

Table 1 Comparison of filters and static VAR comp.

Compensators	Compensations against		
	Harmonics	Passive power	Negative sequence current
Passive Power Filter	Y	Y	Y
Active Power Filter	Y	Y	N
Synchronous condenser	N	Y	N
Static VAR generator	N	Y	Y
Static VAR compensator	N	Y	Y