AC Traction Front End Converters THD Analysis

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Abstract— Rectifier locomotives, which used AC power transmission and DC motors, were common, though DC commutators had problems both in starting and at low velocities. Today's advanced electric locomotives use brushless three-phase AC induction motors. These polyphase machines are powered from GTO or IGBT-based inverters. The cost of electronic devices in a modern locomotive can be up to 50% of the cost of the vehicle. Also they introduce harmonics due to use of diode rectifier for converting AC to DC, which further get injected inside the line of locos. To reduce these harmonics in a context of limited switching frequency, as it is the case in railway traction applications, due to the relatively high transferred power and the necessity to limit power losses, two are the main solutions used for increasing input catenary current harmonic quality (and power): parallel association of several converters or using multilevel NPC topologies. Here two AC traction front-end converter topologies are compared theoretically based on 3 different aspects: hardware requirements, modulation technique necessities and current harmonic quality. This research has been mainly focused in the third aspect, catenary current quality, which is considered as the most important. Consequently current quality has been analyzed in detail and validated in simulation and experimentally by means of various physical converter prototypes. The complete model is simulated in MATLAB/SIMULINK and the results are analyzed to see that the system works as required.

Keywords: THD Analysis, NPC Topologies, MATLAB/ SIMULINK

I. Introduction

A railway electrification system supplies electric power to railway trains and trams without an on-board prime mover or local fuel supply. Electric railways use electric locomotives to haul passengers or freight in separate cars or electric multiple units, passenger cars with their own motors. Electricity is typically generated in large and relatively efficient generating stations, transmitted to the railway network and distributed to the trains. Some electric railways have their own dedicated generating stations and transmission lines but most purchase power from an electric utility. The railway usually provides its own distribution lines, switches and transformers.

Power is supplied to moving trains with a (nearly) continuous conductor running along the track that usually takes one of two forms: overhead line, suspended from poles or towers along the track or from structure or tunnel ceilings; third rail mounted at track level and contacted by a sliding "pickup shoe". Both overhead wire and third-rail systems usually use the running rails as the return conductor but some systems use a separate fourth rail for this purpose.

The first known electric locomotive was built in 1837 by chemist Robert Davidson of Aberdeen, and it was powered by galvanic cells (batteries). Davidson later built a larger locomotive named Galvani, exhibited at the Royal Scottish Society of Arts Exhibition in 1841. The seven-ton vehicle hauled a load of six tons at four miles per hour (6 kilometers per hour) for a distance of one and a half miles (2 kilometers). It was tested on the Edinburgh and Glasgow Railway in September of the following year, but the limited power from batteries prevented its general use. It was destroyed by railway workers, who saw it as a threat to their job security.

First Electric Locomotive built

The first electric passenger train was presented by Werner von Siemens at Berlin in 1879. The locomotive was driven by a 2.2 kW, series-wound motor, and the train, consisting of the locomotive and three cars, reached a speed of 13 km/h. During four months, the train carried 90,000 passengers on a 300-metre-long (984 feet) circular track. The electricity (150 V DC) was supplied through a third insulated rail between the tracks.

The first successful operational and regular use of the 50 Hz system dates back to 1931, tests having run since 1922. It was developed by KálmánKandó in Hungary, who used 16 kV AC at 50 Hz, asynchronous traction, and an adjustable number of (motor) poles. The first fully electrified line was Budapest–Győr–Hegyeshalom. Although Kandó's solution showed a way for the future, railway operators outside of Hungary showed a lack of interest in the design. The first railway to use this system was completed in 1951 by SNCF between Aix-les-Bains and La Roche-sur-Foron in southern France, initially at 20 kV but converted to 25 kV in 1953. The 25 kV system was then adopted as standard in France, but since substantial amounts of mileage south of Paris had already been electrified at 1,500 V DC, SNCF also continued some major new DC electrification projects, until dual-voltage locomotives were developed in the 1960s.

II. Literature review

Etxeberria-Otadui, A. Lopez-de-Heredia et.al [1]in this paper a H-NPC topology is analyzed as the front-end converter at an AC traction application. These converters permit to achieve higher voltage levels and better current quality spectra than conventional single-phase H -bridge converters.

A.Lopez-de-Heredia, H. Gaztanagaet.al in their paper [2] they have reviewed about context of limited switching frequency, as it is the case in railway traction applications, due to the relatively high transferred power and the necessity to limit power losses, two are the main solutions used for increasing input catenary current harmonic quality (and power): parallel association of several converters or using multilevel NPC topologies.

Liqun He, IEEE, JianXiong et.al [3] discusses about the recent development of railway traction drives, four quadrant converters are widely adopted at grid side as front-end converters. Since switching frequency of such megawatt (MW) rated converters is limited to several hundred hertz, the bandwidth of current controller is usually restricted. In addition to feedback control of instantaneous current, indirect current control (ICC) is also an alternative in high-power, low switching frequency applications.

Bishnu Prasad Muni, EswarRao et.al [4] has reviewed about the DSP implementation of single-phase Pulse Width Modulation (PWM) type Front End Converter (FEC) for traction applications. The FEC has been simulated using MATLAB/SIMULINK as well as digitally implemented in Digital Signal Processor (DSP).The FEC aims to maintain a desired dc voltage at the output with sinusoidal input current at unity power factor.

Prashant Jain, Krishna Priya et.al [5]presents DSP implementation of single-phase Pulse Width Modulation (PWM) type Front End Converter (FEC) for traction applications. The FEC has been simulated using MATLAB/SIMULINK as well as digitally implemented in Texas Instruments based Digital Signal Processor (DSP) TMS320F2812.The FEC aims to maintain a desired dc voltage at the output with sinusoidal input current at unity power factor.

Hong-Je Ryoo Jong Soo Kim et.al [6]deals with the parallel operation of several numbers of PWM converters for a high power traction application. Several considerations are made to reduce the transformer interaction which can cause a current control problem in severe case.

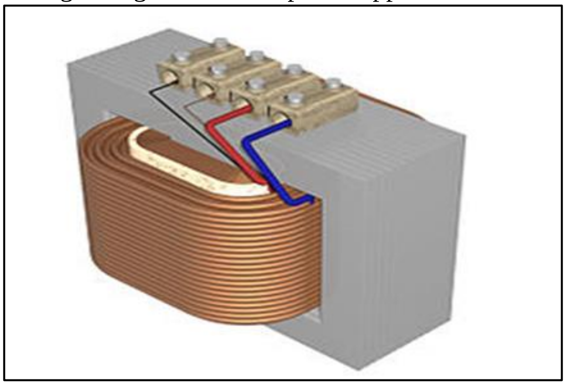
V.S R.V ChinnaRao and B. Ganga Raju[7] in their paper presents different technologies and topologies of medium-voltage (MV) drives available on the market. The carriers above and below zero reference line are in same phase. If all the carriers are selected with the same phase, the method is known as Phase Disposition (PD) method. In this paper, four multilevel Pulse width-modulation methods; phase disposition (PD), switching-loss minimization (SLM), and selective harmonic elimination (SHE) up to the 17th and 29th harmonics, respectively, are considered.

III. COMPONENTS OF FRONT END CONVERTERS FOR ELECTRIC TRACTION SYSTEMS

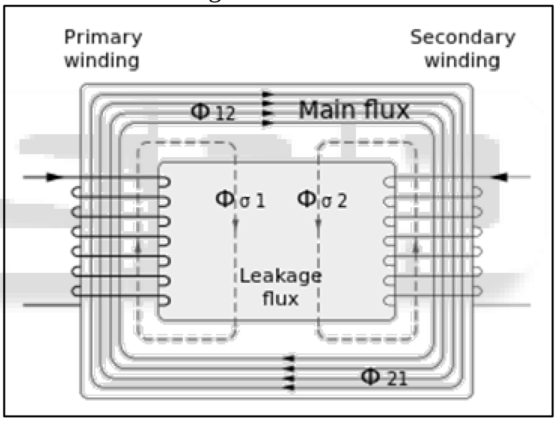
The AC (alternating current) Drive, also known as Variable Frequency Drive, has been the standard in industry for many years. While it has been used in locomotives for over two decades, it has only been recently that the price of the drives has allowed them to be used in most of the new diesel-electric locomotives. The AC drive works by converting the traction alternator output to DC (direct current) and reconverting it to a variable frequency AC which powers AC traction motors.

A. Transformer

A transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. A varying current in one coil of the transformer produces a varying magnetic field, which in turn induces a varying electromotive force (emf) or "voltage" in a second coil. Power can be transferred between the two coils, without a metallic connection between the two circuits. Faraday's law of induction discovered in 1831 described this effect. Transformers are used to increase or decrease the alternating voltages in electric power applications.



Basic diagram of a Transformer



Two winding Transformer

IV. PROPOSED TOPOLOGY AND CONTROL STRATEGIES

In the preceding chapters, all the components of the AC traction front end conveter have been discussed in detail and the most efficient components have been suggested. Thus, based on the previous theory a topology has been proposed and discussed along with all the modes of operation, design consideration and control strategies used.

A. Topology

The block diagram of the proposed topology is as shown in Fig. 4.1. The main task of a traction front-end converter consists in rectifying the catenary AC voltage, in order to obtain an appropriate DC voltage to feed traction motors through the inverters. A single phase transformer, which also plays the role of catenary connection filter, is used to adapt catenary voltage levels to the front-end converter input voltage.

The key design requirements for AC traction front-end converters are: limited harmonic generation to fulfill catenary requirements and sufficient dynamics to follow traction system load variations. Here studies is mainly focused on the first requirement due to the fact that tolerable catenary harmonic levels are relatively restricted, especially in low frequency in order to avoid disturbing the railway signalization system. Due to the relatively high transferred power and the necessity to limit power losses, switching frequency must be relatively low (generally lower than 1 kHz), and consequently improved topologies are required in order to increase input current harmonic quality (and power).

B. Model of FEC

In a context of limited switching frequency, as it is the case in railway traction applications, due to the relatively high transferred power and the necessity to limit power losses, two are the main solutions used for increasing input catenary current harmonic quality (and power): parallel association of several converters or using multilevel NPC topologies. Here these two AC traction front-end converter topologies are compared theoretically based on 3 different aspects: hardware requirements, modulation technique necessities and current harmonic quality. The study has been mainly focused in the third aspect, catenary current quality, which is considered as the most important. Consequently current quality has been analyzed in detail and validated in simulation.

V. Simulation Results and Analysis

In the previous chapter the proposed model is presented and modelling of each component is given. Various ways for reducing harmonics levels were discussed along with their topologies used. Here, simulation results of the proposed model, under all conditions have been presented and analysed. The results obtained using the proposed system is compared along with results of converter that employs only uncontrolled rectifier. Various graphs are obtained and shown here for analysis.

A. Comparison of Results between Transformers Current of Rectifier & Two Front End Converters

The comparison has been carried out considering identical output primary current and DC bus voltage for both conversion topologies.

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