Abstract—This paper mainly deals with converters which are used in high power applications like traction systems. Some of observed AC-DC converters are used in traction applications today as well as other medium and high power AC-DC converters are observed that can be used in traction in future. Rectifier systems are addressed in DC smoothing problem. The article deals with a number of DC smoothing methods, but each of these methods leave the next effect on other system parameters. Main parameter that can be affected by smoothing method is converter consumed current form. The article considerations are given of the smoothing methods and prevention techniques of bad characteristics.

I. INTRODUCTION

DC voltage has gained wide application, depending on the device where DC voltage is used. DC voltage can have a capacity of less than one watt to several MW. This paper discusses the higher power AC-DC systems rectified voltage smoothing techniques that are used for early railway traction nowadays. Also other methods are observed and considerations given of their application in the railway traction. Many AC electrified railway locomotives are supplied by single-phase 25kV network. Early designs of locomotive are driven by DC motors, requiring AC-DC converter that meets certain requirements. These older types of locomotives are expected to be in service for many years. In result DC smoothing is very topical issue for high power converters. Conventionally rectifiers are consisting of diodes or thyristors to provide controlled or uncontrolled power also power flow is unidirectional or bidirectional. Mainly in the above mentioned drive systems are diode and thyristor based, as well as the diode-thyristor mixed. These rectifiers have disadvantages of poor power quality in terms of varying rippled dc output at load, large size of AC and DC filters, bad THD and poor power factor affecting AC mains. Active shunt filters have to be used in combination of this rectifier system to compensate harmonics injection into AC mains. Recently, a little more than ten years ago the high-power rectifier schemes were introduced in advanced semiconductors, these circuits that use high speed contactless switches sometimes are called a chopper (Fig. 1.) [3]. These new generation of converters are known mainly as Power Factor Correction Converters (PFCs), Switched Mode Rectifiers (SMRs) and Pulse Width Modulation (PWM) Converters, they can be called the Improved Power Quality Converters (IPQCs). IPQCs are been developed to mitigate DC voltage ripple also they overcome drawbacks of conventional rectifier so that passive filters, VAr compensators and active power filters used for harmonics and reactive power compensation are not have to be used.

A. Conventional Rectifier

As it is well known basic configuration of conventional rectifier is shown on (Fig. 2. a). Configuration uses LC filter in DC side, there are two common reasons to include DC-side LC filter: to obtain smooth DC output voltage (large capacity) and to obtain acceptable AC line current waveform (large inductance). Harmonic distortion is shown in (Fig. 2.) in two modes of rectifier operation. Continuous current mode (CCM), see (Fig. 2. b) curve of an sinusoid voltage (u_S), that being loaded with large L, that draw continuous current from rectifier. As the filter inductance is approaching infinity the line current approaches a square wave in this situation distortion factor become approx 30%. Discontinuous current mode (DCM), as filter inductance approaching zero, current approaches impulse function (peak detection), see (Fig. 2. c). As the inductance is reduced, the THD rapidly increases, so
in this situation especially for rectifier that uses small filter inductivity will introduce large THD approx 145%. If this system is used as a traction converter, the LC filter of DC voltage is one of main elements and its drawback is a big weight and dimensions. This is due to the fact that the mains voltage is low frequency (50 Hz) and for smooth coil L currents it requires coil L with a very large inductance [7]. In result coil dimensions and weight is strongly increasing. Discussing conventional system even with very large filter inductance, it does not give an acceptable THD, so the conventional rectifier should be used in combination with the rectifier input active shunt filter or harmonics trap filter. As a result, the rectifier weight and costs are rising substantially. To conventional rectifiers here are added phase controlled rectifiers where instead of diodes the thyristors are used to control the power flow. But phase control commutation impacts the phase displacement between the first harmonics of current and the first harmonics of the supply voltage. This displacement leads to power factor degradation and reactive power consumption.

B. Smoothing Transformer Technique

Principle is based on coupled inductor application into a conventional rectifier DC side [1], called a ‘Zero’ Ripple Technique. The technique replaces a series smoothing choke with a “smoothing transformer” (a pair of coupled inductors) and a blocking capacitor, see (Fig. 3.). Because these components form a linear two-port filter, the technique can be applied to any dc circuit, and reduces the ripple current wherever a choke is currently used. Thus it may be applied to the dc input of a converter, its dc output, or an internal dc link (in applications such as motor drives or HVDC transmission). Filter of this configuration has two ports they are labeled as “noisy” connected to ripple source, other “quiet”. The transformer windings are labeled as “dc” and “ac” windings to indicate their purpose in the circuit. The DC winding carries heavy DC current like a smoothing inductor, while AC winding carries only small AC ripple current. If this method is used in combination with conventional rectifier, the system consumes almost square wave current in result active shunt filter application is required, overall system costs may increase to achieve the same result.
C. Pulse Width Modulated Rectifier

In order to avoid these negative properties caused by conventional and phase controlled, there should be applied controlled converters which management is quite complex. Such converters are realized with controllable semiconductor IGBT transistors or GTO thyristors. The rectifier is controlled by pulse width modulation. A rectifier controlled in this way consumes current of required shape, which is mostly sinusoidal. It works with a given phase displacement between the consumed current and the supply voltage. The power factor can also be controlled and there are minimal effects on the supply network. PWM rectifiers can be divided into two groups according to power circuit connection - the current and the voltage type. For proper function of current a type rectifier, the maximum value of the supply voltage must be higher than the value of the rectified voltage. The main advantage is that the rectified voltage is regulated from zero. They are suitable for work with DC loads (DC motors, current inverters). For proper function voltage type rectifiers require higher voltage on the DC side than the maximum value of the supply voltage. The rectified voltage on the output is smoother than the output voltage of the current type rectifier. They also require a more powerful microprocessor for their control [6].

![PWM rectifier input current shaping and switching](image)

Some researches [6], have shown that these converters can be achieved outputting sufficiently small dc ripple and its THD ranges from 4% to 8% [15]. even smaller. But these systems lack in comparison with a conventional rectifier is a complex control algorithm and operational safety.

PWM rectifier rectifiers can be created in a number of topology [13] and [10]. The single-phase boost converter with unidirectional power flow is realized by cascading single-phase diode bridge rectifier with boost chopper topology. Other topologies with unidirectional power flow, semi-boost converter topology are known as diode and IGBT symmetrical rectifier bridge semi-boost converter and asymmetrical semi-boost converter. One of common topologies of PWM rectifier can be seen on (Fig. 4.a) as well as its input current, voltage and output voltage curves (Fig. 4.b) and PWM rectifier input current shaping and switching (Fig. 5).

D. Multilevel AC-DC Converters

One of this converter configurations is shown on (Fig. 5.), it can have different configurations [12], [15] and [16]. bidirectional diode clamped three-level converter (Fig. 6.), bidirectional three-level converter using two bidirectional switches, bidirectional flying capacitor clamped three-level converter, bidirectional cascaded five-level converter and other configurations. Multi-level converters offer a number of advantages compared with single-level PWM of low voltage stresses on switches, reduced switching losses due to reduced switching frequency, provides the same performance with reduced input current harmonic content at high power factor and provides very low ripple DC output at a variable load. These converters can have bidirectional power flow and are used for even high-power applications as traction, etc. These can be developed for a higher number of levels for high-voltage and high-power applications. Mains supply current THD can be reduced below 1%. The stepped voltage waveform generated by multilevel converters avoids high-order harmonics, reduces switch losses and stress on switching devices, and these are most suitable for high-power and high-voltage applications.

II. Conclusions

This paper mainly deals with converters, which are applicable to high power traction. AC-DC converter output voltage smoothing can be solved in different ways, smoothing techniques themselves are not complex, but each smoothing method may cause side effects as the influence to the AC power network. Conventional, phase controlled and smoothing transformer techniques are able to provide sufficient output voltage stability installing of the appropriate size of the DC filter inductance or smoothing transformer. These converters consume almost square-wave current
therefore these systems should be equipped with an input shunt filter to provide input current shaping. As a result, the converter weight, price and size are considerably large, which are major drawbacks of these converters. The use of PWM control in rectifiers eliminates the problems caused by using conventional rectifiers. A rectifier controlled in this way consumes current of required shape, which is mostly sinusoidal. Also, the DC side inductance can be significantly reduced compared to conventional methods. Using the three-level boost topology of high power and high-voltage single-phase applications, significant advantages are achieved compared with single-level PWM converter. Required DC inductance for three-level boost converter is significantly reduced and semiconductor rated voltage is only half the output voltage. As a result, the converter power density and efficiency are greatly enhanced and high power and voltage application costs are reduced.

REFERENCES


