Gasiyarov V.R., Radionov A.A., Maklakov A. EMC Analysis of 18-pulse Circuit based on of 3L-NPC AFE Rectifiers with SHEPWM

Maklakov A.S*

"South Ural State University, Chelyabinsk, Russia"

Abstract

The article is devoted to electromagnetic compatibility (EMC) analysis of 18-pulse connection circuit based on three level active front-end (3L-AFE) rectifiers with a pulse width modulation selective harmonic elimination (PWMSHE) method. Despite the high number of scientific works in this field, address the problems mentioned in the previous section are unique and it requires the in-depth knowledge of operating principles of 3L converters, multipulse connection schemes and modern PWM methods. The research results show total harmonic distortion (THD) dependencies and harmonic spectrums of grid current and voltage.

© 2016 The Authors. Published by European Science publishing Ltd.
Selection and peer-review under responsibility of the Organizing Committee of European Science publishing Ltd.

Keywords: "electromagnetic compatibility 18-pulse circuit; AC-DC converter; pulse width modulation; selective harmonic elimination; THD"

1. Introduction

Modern connection methods of powerful industrial consumers of electrical energy to the grid are generally made by three-level (3L) frequency converters with one-directional or bi-directional rectifiers [1-5]. In most cases, high energy performance of bi-directional rectifiers provide electromagnetic compatibility (EMC) and energy efficiency of IEC or IEEE standards for different electrical drives in motor and generative modes [6]. However, deviations from IEC or IEEE standards can arise in operational process of industrial installations that occur as a result of a suboptimal use or choice of a pulse width modulation (PWM) algorithm or/and a frequency switching of semiconductor modules [7-9]. A non-compliance of the EMC standards lead to the following problems:

- Overheating of transformers, reactors and power lines entailing a decrease in their service life and an occurrence emergency situations;
- False responses of high-accuracy protection systems and analog-to-digital instrumentation failures;
- False responses of near or distant power electrical equipment that result from high harmonics in voltage and current power line;
- The penalties from energy companies.

* Corresponding author.

© 2016 The Authors. Published by European Science publishing Ltd.
Selection and peer-review under responsibility of the Organizing Committee of European Science publishing Ltd.
Analysis There is no doubt that any of the foregoing problems can be cause of layup, increasing capital costs and defective products. This observation implies that research and solutions of these problems related to the EMC of powerful electrical consumers are a pending task.

2. "Purpose of Article"

Despite the high number of scientific works in this field, address the problems mentioned in the previous section are unique and it requires the in-depth knowledge of operating principles of 3L converters, multipulse connection schemes and modern PWM methods. Thus, a power circuit of a working reversible electric drive system of a rolling mill has been chosen as a research object and analysis. A main purpose of this article is research of 18-pulse connection scheme, which is based on three 3L natural point clamped (NPC) converters with a selective harmonic elimination (SHE) method for rectifiers.

3. "Research Object"

A plate mill of 5000 hot rolling has been commissioned on OJSC "Magnitogorsk Iron and Steel Works" (MMK) (Fig. 1) in 2009.

Fig. 1. 5000 four-high roll mill plate

This mill power and quality characteristics of the products is the first and one of the few in Russia. Electric drive consist of two synchronous motors (SMs) connecting with work rolls. The SMs are supplied by three 3L neutral point clamped (3L-NPC) BiB converters. The BiB converter consists of 3L-NPC inverter and active front-end (AFE) rectifier. The maximal power of each converter is 8.6 MVA. 18-pulse connection circuit is used for this drive and created by three power transformers connecting in parallel with voltages phase shifts 20°, 0°, and -20°.
Selective harmonic elimination (SHE) or selective harmonic mitigation (SHM) modulation method are often applied to control 3L-NPC AFE rectifiers [10]. In this paper will review only SHE method and present results illustrating the benefits to be gained at the switching minimization for the 18-pulse connection circuit. SHE algorithm allows one to select requisite number of higher harmonics in output voltages of the 3L-NPC AFE rectifier [11]:

\[
\begin{align*}
n &= N - 1, \\
\end{align*}
\]

where \(N\) is number of the switching angles for a quarter-period, \(n\) is number of the selective harmonics [12].

If the 18-pulse connection circuit is used, only multiple harmonics 18 have a negative effect, consequently, harmonic numbers 18\(n\) ± 1 should be eliminated. Three switching angles for the quarter-period of the output phase voltages have been selected to minimize the switching. As result, it eliminates the 17\(th\), 19\(th\) harmonics and 17\(th\), 19\(th\), 35\(th\), 37\(th\) harmonics. The system of equations has been derived to calculate the switching angles for the 18-pulse connection circuit:

\[
\begin{align*}
\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) - m &= 0 \\
\cos(17\alpha_1) - \cos(17\alpha_2) + \cos(17\alpha_3) &= 0, \\
\cos(19\alpha_1) - \cos(19\alpha_2) + \cos(19\alpha_3) &= 0
\end{align*}
\]

\[
\begin{align*}
\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) - \cos(\alpha_4) + \cos(\alpha_5) - m &= 0 \\
\cos(17\alpha_1) - \cos(17\alpha_2) + \cos(17\alpha_3) - \cos(17\alpha_4) + \cos(17\alpha_5) &= 0 \\
\cos(19\alpha_1) - \cos(19\alpha_2) + \cos(19\alpha_3) - \cos(19\alpha_4) + \cos(19\alpha_5) &= 0 \\
\cos(35\alpha_1) - \cos(35\alpha_2) + \cos(35\alpha_3) - \cos(35\alpha_4) + \cos(35\alpha_5) &= 0 \\
\cos(37\alpha_1) - \cos(37\alpha_2) + \cos(37\alpha_3) - \cos(37\alpha_4) + \cos(37\alpha_5) &= 0
\end{align*}
\]
where $m = \frac{\pi}{2} \frac{U_{AFE}}{U_{DC}}$ is modulation index ($0 \leq m \leq 1$), $U_{AFE}$ is an amplitude of the 3L-NPC AFE rectifier output phase voltage, $U_{DC}$ is the rated DC voltage, $\alpha_{1-5}$ are the switching angles.

Solution of the systems (2, 3) has been obtained by using well-known Newton–Raphson method. Among the obtained results, only several variants have been chosen with the following requirements: $0 < \alpha_1 < \alpha_2 < \alpha_3 < \pi/2$. Fig. 3 shows the calculation results of the switching angles and Fig. 4 represents the harmonic spectrum.

![Diagram](image1)

Fig. 3. The switching angles for the 18-pulse connection circuit with elimination of the 17th, 19th harmonics (a) and the 17th, 19th, 35th, 37th harmonics (b).

![Diagram](image2)

Fig. 4. Grid current at elimination of the 17th, 19th harmonics (a) and the 17th, 19th, 35th, 37th harmonics (b).
4. Conclusion

The electromagnetic compatibility analysis of 18-pulse connection circuit based on three level active front-end rectifiers with a pulse width modulation selective harmonic elimination method has been considered. The research results show satisfactory total harmonic distortion (THD) grid current (2.20% and 1.72%) and harmonic spectrums of grid current and voltage. The research results can be used to assess the EMC powerful three level NPC active rectifiers or inverters.

References