A Study on High Current Rectifier Systems with Mitigated Time-Varying Magnetic Field Generation

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Abstract

This paper investigates occupational exposure to time-varying magnetic field generation in high power rectifier systems. Two different kinds of high power rectifier systems of 25kA are modeled and analyzed. The performance is compared and evaluated on the basis of exposure guidelines from ICNIRP. In order to focus on the qualitative effect of rectifier operation, the mechanical structure of current carrying conductors is simplified as infinite long bus-bar model and low frequency harmonic contents up to 65kHz are considered. Thyristor rectifier generates a significant amount of low frequency magnetic field harmonic contents both at ac and dc side of rectifier infringing the limit from ICNIRP. The multilevel rectifier-IGCT type has almost negligible field generation from ac input side and smaller harmonic contents in dc load side complying with ICNIRP guideline. This remarkable advantage of multilevel rectifier-IGCT type can lead to very simple site layout design for installation and cost-effective compliance to guideline of occupational exposure against magnetic field.

1. Introduction

For several years, diode and thyristor rectifiers have been the dominant technology platform in large current rectifiers. These well-proven diode and thyristor system still offer the reliable and cost-effective performance. These advantages become more evident in the rectifier system of higher current [1]. IGCT(Integrated Gate Commutated Thyristor) has been introduced as a much advanced GTO to the industry of high power and medium voltage application in late 90s [2], [3]. The maximum current rating of IGCT is much higher than IGBT and reliable turn-off at 6.5kA versus 2.8kVdc has been reported in the previous literature [4]. Owing to the remarkable switching capability at high current, IGCT has been anticipated as one of optimal turn-off switching devices for high power rectifiers. The possibility of applying IGCT into high power rectifiers with the optimal power converter topology has been investigated and presented in [5].

Recently, the human exposure to time-varying magnetic field in high power rectifiers has been a growing concern. A high power rectifier characterizes itself as the source of relatively high current in the order of tens and hundreds of kA among many other industrial power conversion systems. This high current generates a time-varying magnetic field of significant amplitude around the high current carrying conductor and the process load. Adverse biological effects of exposure to this strong magnetic field have been reported in previous literatures [6]-[8]. Health criteria have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to non-ionizing radiation. Guidelines for limiting exposure to time-varying magnetic field has been established and ready to be put into effect by several regulatory bodies [9], [10].

This paper investigates the time-varying magnetic field generation in high power rectifier systems. Several state-of-the-arts high power rectifier system are modeled and analyzed with respect to the generation of magnetic field. In order to focus on the qualitative effect of rectifier operation upon the time-varying magnetic field generation, the mechanical structure of current carrying conductors in complete rectifier system is simplified. The performance of several different topologies are compared and evaluated on the basis of previously reported guidelines for limiting exposure to time-varying magnetic field. The operational scheme of state-of-the-arts high power rectifier system to mitigate occupational exposure to time-varying magnetic fields is proposed. In addition, the optimal topology of high power rectifier system better complying with the exposure guidelines is presented.

2. Two types of high current rectifier systems

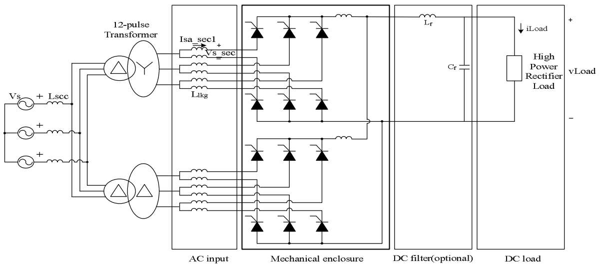

Fig. 1 Schematic of 12-pulse parallel connected thyristor phase-controlled rectifier system(Topology 1).

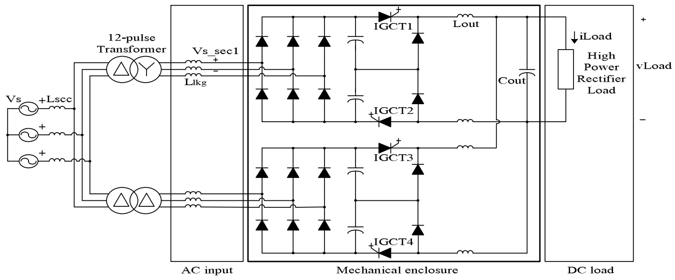

Fig. 2 Schematic of multilevel rectifier-IGCT type(Topology 2).

TABLE I

OVERALL SYSTEM INPUT/OUTPUT SPECIFICATIONS AND PARAMETERS

Specifications	Symbol	Values
Medium voltage ac input	Vs	22 kV
Input frequency	fin	50 Hz
DC output voltage	vLoad	625V
DC load current	iLoad	25kA
DC output power	Pout	15.6 MW

The most popular type of high power rectifier found in industry of present times is a thyristor rectifier described in Fig. 1. The proposed power converter topology employing IGCT is shown in Fig. 2. It is a combination of unregulated diode rectifier followed by 3-level step-down dc/dc converter. The particular limit for time-varying magnetic field is provided in Fig. 3. In this figure, the flux density has limited reference levels for exposure to frequency varying magnetic fields. These reference levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. The overall system specification for both topologies is summarized in Table I.

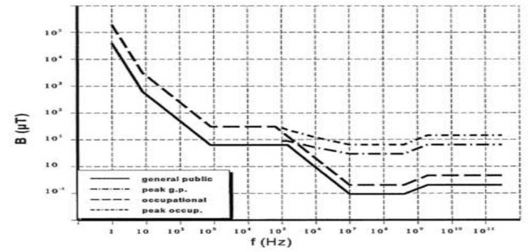

Fig. 3 ICNIRP Guideline of reference levels for exposure to time varying magnetic fields.

3. Analysis of occupational exposure to time-varying magnetic fields in two types of rectifier system

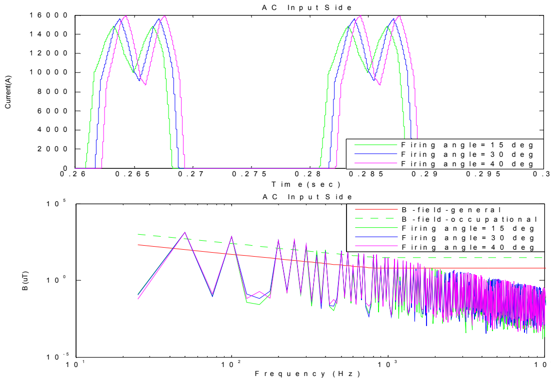

Fig. 4 Waveforms of ac input current(Isa_sec1) and frequency spectrum of magnetic flux density in Topology 1.

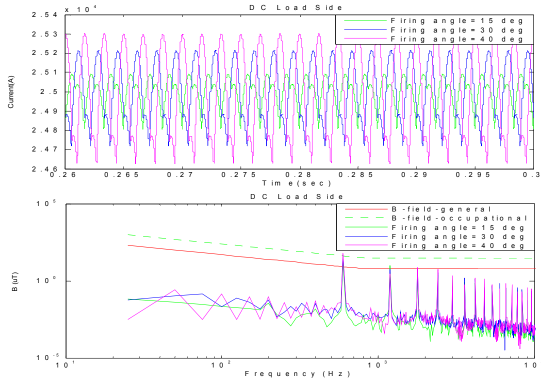

Fig. 5 Waveforms of dc load current(iLoad) and frequency spectrum of magnetic flux density in Topology 1.

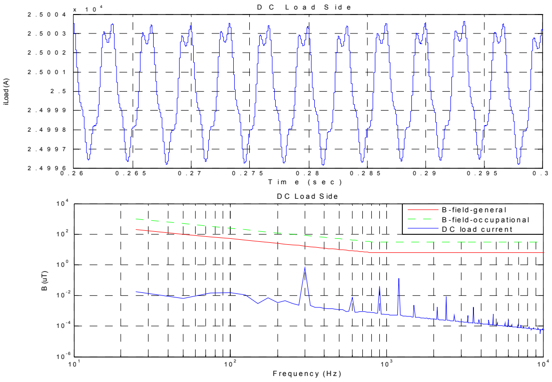

Fig. 6 Waveforms of dc load current(iLoad) and frequency spectrum of magnetic flux density in Topology 2.

Figure 4 and 5 show waveforms of ac input current(Isa_sec1), dc load current(iLoad) and the frequency spectrum of magnetic flux density in topology 1, respectively. All simulation results are obtained under different firing angle conditions due to the fact that firing angle plays an important role as control parameter and also determines the operating point and harmonic contents in a thyristor rectifier. Simulation results for multilevel rectifier-IGCT type are provided in Fig. 6. These results tell the fact that the harmonic contents produced by multilevel rectifier are a lot smaller than thyristor rectifier and well comply with the guideline of ICNIRP. Beside of the limited reference levels, the weighted sum of harmonics for the magnetic field (i.e. EMI Factor) plays a significant role and weighted sum of harmonics should be less than 1 as in (1). Equation (1) and Fig. 3 are used to calculate EMI Factor.

$$\sum_{j=1Hz}^{150kHz}\frac{B_j}{B_{L,j}}+\sum_{j=150KHz}^{10MHz}\frac{B_j}{b}\le 1 \qquad (1)$$

where b = 30.7μT for occupational exposure and 6.25μT for general public exposure, $B_{L,j}$= Flux density reference level, B_j = Flux density strength at frequency j

4. Conclusion

This paper investigates time-varying magnetic field generation in high power rectifier systems. The performance of two different topologies are compared and evaluated on the basis of previously reported guidelines for limiting exposure to time-varying magnetic field. Thyristor rectifier generates a significant amount of low frequency magnetic field harmonic contents both at ac and dc side of rectifier infringing the limit from ICNIRP. However, the multilevel rectifier-IGCT type has almost negligible field generation from ac input side and smaller harmonic contents in dc load side complying with ICNIRP guideline. This remarkable advantage of multilevel rectifier-IGCT type can lead to very simple site layout design for installation and cost-effective compliance to guideline of occupational exposure to magnetic field such as ICNIRP.

TABLE II

COMPARISON OF EMI FACTORS FOR TOPOLOGY 1 AND TOPOLOGY 2 UNDER VARIOUS FIRING ANGLE CONDITIONS

	Firing angle	Transformer turn ratio	Secondary Voltage	EMI Factor (AC input side)	EMI Factor (DC load side)	DC load current
Unit	degree		kV			kA
Thyristor rectifier	40	34.0	0.61	40.00	2.65	25
	30	39.0	0.54	38.60	2.04	25
	15	43.4	0.49	33.37	1.28	25
Multilevel rectifier-IGCT	0.25 (IGCT duty)	11.2	1.90	Negligible	0.07	25

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