A NOVEL NEURAL-NETWORK BASED CURRENT CONTROL SCHEME FOR A THREE-LEVEL CONVERTER

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1. Abstract

This paper present the design of a novel neural- network (NN) based pulse-width modulation (PWM) techniques for a three-level power converter of electric trains along with nonlinear mapping of essential switching patterns and fault tolerance, which are inherent characteristics of NNs.

Considering the importance of safety, power factor and harmonics of electric train power converters, two-level type and three-level type of power converters using NNs are precisely investigated and compared in computer simulation. A computer simulation shows that a new current control scheme provides an improved performance over a fixed-band hysteresis current control in many aspects.

2. Introduction

The advantage of PWM type GTO and IGBT converters over phase-controlled thyristor converters has been recently recognized by modern traction vehicles [1,2]. This has resulted in a rapid transition in traction applications. Even though a phase-controlled thyristor rectifier for traction system has been extensively employed because of their high capacity and acceptable performance, it does have disadvantages of a lower power factor and a larger high frequency content. In order to overcome these disadvantages, the optimized PWM control of GTO voltage source converter using NNs, which can produce a power factor close to unity and greatly reduced harmonics due to the nearly sinusoidal input line current, has been investigated. The task of power converters for electric trains is to convert power between power supply and the traction motors. They must be able to reverse the direction of the power flow for driving and braking. Regarding line-side and load-side power converters of megawatt class capacity, they are confined to electric rail traction only nowadays. However, due to the restrictions of high switching frequencies in high power GTOs, a multiple (two or three-level) PWM GTO voltage-source type converter should be adopted to increase the total capacity of the system [3,4]. Since each converter can apply proper d.c. voltage to its transformer secondary, the synthesis of each of multiple converters produces a unity displacement factor and also reduces the input line current ripple and harmonics, achieving a power factor close to unity with better dc voltage regulation. But, recently, high power IGBTs with fast switching capability for light railway traction vehicle have come available. It provides more scope in reducing unwanted harmonics in line and motor currents or in economizing on filter capacitors and smoothing reactors. Both circuits have been compared on the basis of power factor and harmonics in the literature [5]. First, the power factor should be kept below a specific limit to reduce the size of the capacity of the electric supplies, which include a reduced input-side transformer and a minimized power filter weight and volume. Second, it is always important to reduce the harmonics in voltages and currents caused by periodic switching so that harmonic pollution of the line system is kept to a minimum and also so that the motors produce only little torque pulsation. In recent years, new emerging soft-computing technologies such as NNs and fuzzy logic have been rapidly applied to power electronics area. One application of NNs and fuzzy logic is for PWM signal processing in power converters, where the main advantage of NNs, namely, parallel distributed processing, learning ability, robustness and generalization, can be used effectively [6]. In the meantime, fuzzy logic did not receive much attention, when it was first published by L.A. Zadeh in 1965. But fuzzy logic has been very active, especially in Japan, proving the effectiveness of controlling an ill-defined nonlinear system. Since fuzzy logic does not need a detailed mathematical model of the process, it can control the plant, for example, nuclear reactor, elevator, automatic train operation system and steam boiler system, very accurately. Lately, the application of fuzzy control to power converters has been widely studied, showing better dynamic performance and less steady state error [7].

Since current-controlled voltage source power converters offer substantial advantages in improving traction motor dynamics, the variety of current-controlled methods have been studied. Among the several current control methods, hysteresis current control is the simplest and most extensively used method. However, a current controller with fixed hysteresis bands has two disadvantages. First, the switching frequency varies during the fundamental period, resulting in irregular operation of the converter. Second, the ripple current is relatively large. As a result of the these disadvantages, the load current contains harmonics that cause additional traction motor heating. By the way, using a sinusoidal-band hysteresis current controller, the ripple can be varied and reduced with the current magnitude so that load current contains lower harmonic contents.

This paper deals with the relative performance of both traction converter circuits and provides the concept of applications of NNs to generate the on-off switching pattern of both two- and three-level type of three phase PWM motor side power converter. Also, the prominent feature of NNs for fault tolerance to some of miss connections in power converters will be investigated. Besides providing fault tolerance, based on the results of analysis an optimized PWM three-level type of power converter using NNs shows that it is a most appropriate topology, producing reduced harmonic currents and improved transient performance over the other method. ACSL (Advanced Continuous Simulation Language) was used to simulate the circuit's operation in the time domain.

3. Two-Level and Three-Level Type Power Converters

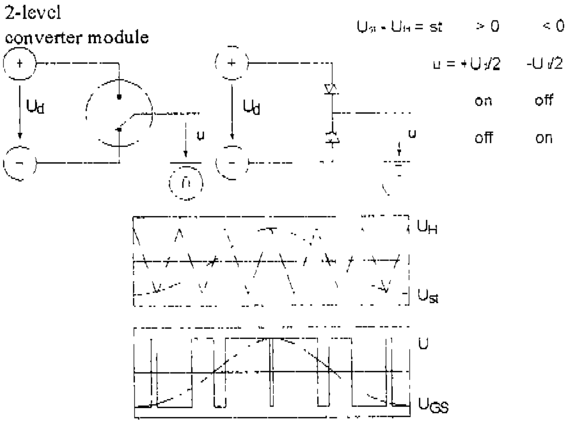

Fig. 1. 2-Level Converter Module

Figure 1 shows circuit, symbol and PWM of two basic two- and three- level power converter modules adopting a sinusoidal-band current control method in modern traction vehicles. An usual way to generate the sinusoidal PWM pulse pattern (st) to modulate the two-level converter module of the upper part of Fig. 1 is to use a sinusoidal signal u_{st} and one triangular signal u_H. At each intersection point of the both signals the two-level converter is changing the polarity of its two-level output voltage u. The sinusoidal signal determines the fundamental component u_{GS} and the triangular carrier signal determines the switching frequency F per the switching device.

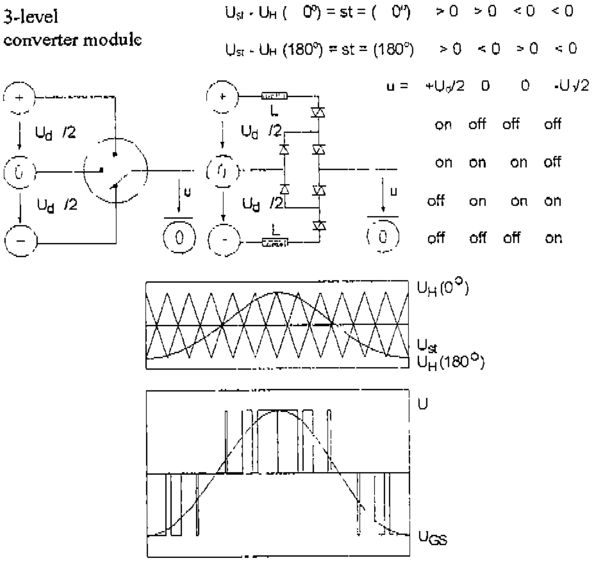

Fig. 2. 3-Level Converter Module

Three-level converter modules are made up of four switching devices and two additional diodes and can be operated at zero-voltage compared with the two-level converter with two switching devices. For its sinusoidal PWM, two pulse patterns st (0°) and st (180°) are required. They can be generated by two triangular carrier signals u_H (0°) and u_H (180°). At the intersection points of each of them with the sinusoidal signal u_{ST} two of the four switching devices are turned on or off as shown in Fig 2, bottom. Here again, the sinusoidal signal determines the fundamental component u_{GS} in the converter output voltage whereas the frequency F of the triangular carrier signal determines the switching frequency F per the switching device The 180° phase shift between both triangular carrier signals enforces a staggered switching of the four devices. This method of staggered switching (at the line-side converter and at the motor-side converter) has significant advantages: a drastic reduction of the low order harmonics in the resultant converter output voltage u.

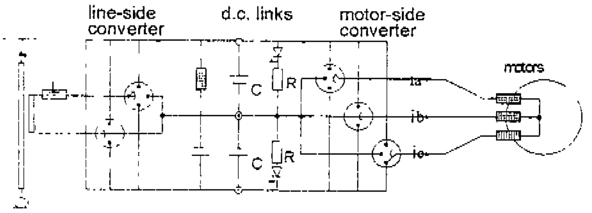

Fig. 3. The Circuit Diagram of a Single-Phase A.C. Fed Three-Level Converter with Induction Motor

Figure 3 shows the circuit diagram of a single-phase a.c. fed three-level type of power converter with a three-phase induction motor. By controlling each capacitor voltage even, the converter can apply three voltage levels to the transformer secondary winding: $V_{DC}/2$, 0, $-V_{DC}/2$. A multiple of three-level type converter operates very similar to the two-level type one, being again capable of synthesizing a sine wave at the transformer secondary. This circuit has advantages over the two level type power converter, which are as follows:

- a less bulky transformer
- a higher voltage rating of converter
- reduced switching losses
- lower transformer harmonic currents at the same switching frequency

4. Neural Network Power Converter Control

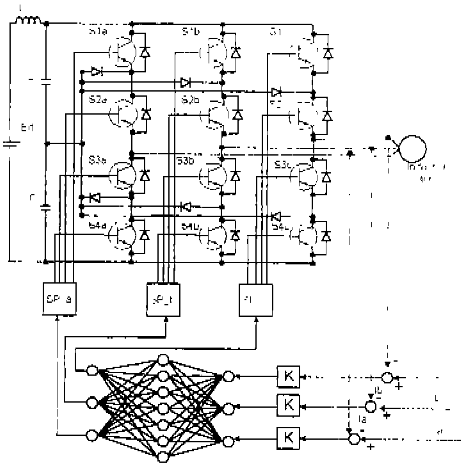

Fig 4 Current Control Using Neural Comparator

The voltage source power converter using a neural comparator is illustrated in Fig. 4. The input signals to the converter are three phase current errors between the reference currents and the actual output currents. The output signals are binary signals. Therefore, the neural controller should have the property of a nonlinear function to map the analog input into binary switching patterns of the PWM converter Neural network architectures of Fig. 5 have been proved as a universal function approximator, i.e. with sufficient training on appropriate input/output data.

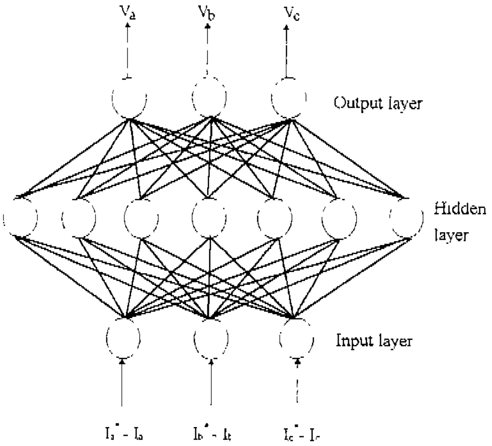

Fig. 5. Feedforward Neural Network

Figure 6 shows eight stimulus patterns of teaching signals for the two-level converter [8]. But total 27 patterns of those shown in Table 1 must be used for the three-level converter

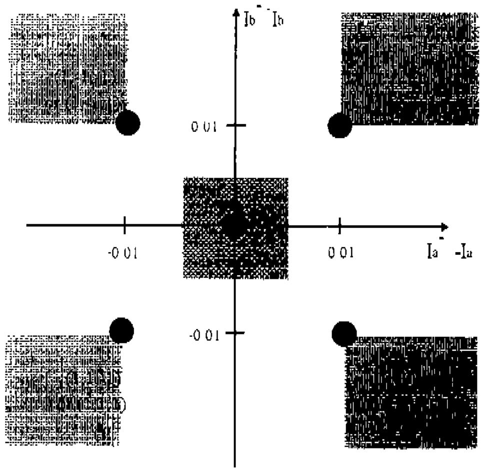

Fig. 6. Eight Stimulus Patterns for 2-Level Converter

Table 1 27 Stimulus Patterns for 3-Level Converter

	INPUT SIGNAL			DESIRED PATTERN		
1	0.01	0.01	0.01	-1.0	-1.0	-1.0
2	-0.01	0.01	0.01	1.0	-1.0	-1.0
3	0.01	-0.01	0.01	-1.0	1.0	-1.0
4	0.01	0.01	-0.01	-1.0	-1.0	1.0
5	0.01	-0.01	-0.01	-1.0	1.0	1.0
6	-0.01	0.01	-0.01	1.0	-1.0	1.0
7	-0.01	-0.01	0.01	1.0	1.0	-1.0
8	-0.01	-0.01	-0.01	1.0	1.0	1.0
9	0.01	0.01	0	-1.0	-1.0	0
10	-0.01	0.01	0	1.0	-1.0	0
11	0.01	-0.01	0	-1.0	1.0	0
12	-0.01	-0.01	0	1.0	1.0	0
13	0.01	0	0.01	-1.0	0	-1.0
14	-0.01	0	0.01	1.0	0	-1.0
15	0.01	0	-0.01	-1.0	0	1.0
16	-0.01	0	-0.01	1.0	0	1.0
17	0	0.01	0.01	0	-1.0	-1.0
18	0	-0.01	0.01	0	1.0	-1.0
19	0	0.01	-0.01	0	-1.0	1.0
20	0	-0.01	-0.01	0	1.0	1.0
21	0.01	0	0	-1.0	0	0
22	-0.01	0	0	1.0	0	0
23	0	0.01	0	0	-1.0	0
24	0	-0.01	0	0	1.0	0
25	0	0	0.01	0	0	-1.0
26	0	0	-0.01	0	0	1.0
27	0	0	0	0	0	0

5. Simulation Results

To perform a comparative evaluation of fixed-band hysteresis current control and neural network control, a simulation model is developed. The system parameter of Fig 4 are as following;

- a.c. single-phase voltage V = 100 volt
- d.c bus voltage V = 300 volts
- Input inductance L = 0.005 henry
- Input resistance R = 1 ohm
- Approximate switching frequency = 1 Khz

Simulation results for the output currents of the converter by fixed-band neural network control and hysteresis current control for each of two-level and three-level converters are shown in Fig. 7 and 8.

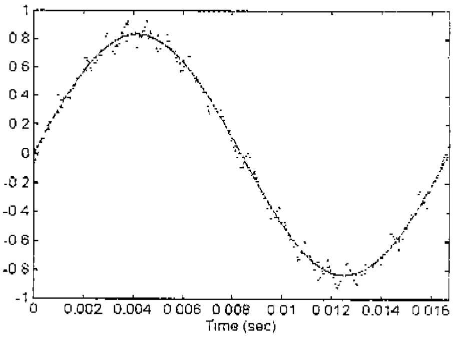

Fig. 7. Output Currents of 2-level (:), 3-level(.-) and Reference (-) Using NN Control

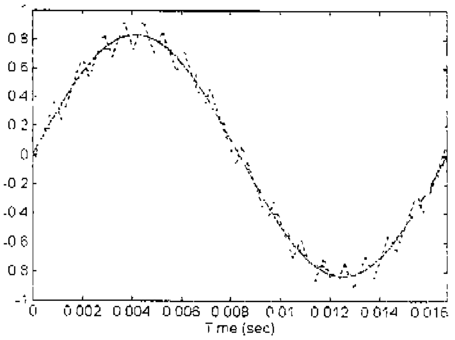

Fig. 8. Output Currents of 2-level (:), 3-level(.-) and Reference (-) Using Hysteresis Control

From the simulation of neural network control, the RMS current error in phase A is 3.4629 for the two-level converter and 1.1794 for the three-level converter, while the ratio of the number of actual device switchings to the number of possible switchings is being maintained about 10% both in order to compare with 1Khz switching frequency of fixed-band hysteresis current control, and the variance of current error is 3.0444 for the two-level converter and 0.4115 for the three-level converter. In the fixed-band hysteresis current control, the RMS current error in phase A is 3.4615 and 1.4043, and the variance of current error is 11.9940 and 0.6031, for the two- and three- level, respectively. The neural network control method has both lower absolute mean and variance of current error than those of the fixed-band hysteresis control method in each of two-and three-level cases. Finally, Fig. 9 and 10 illustrates the comparisons of the normalized total harmonic components of both methods in the two- and three-level converters.

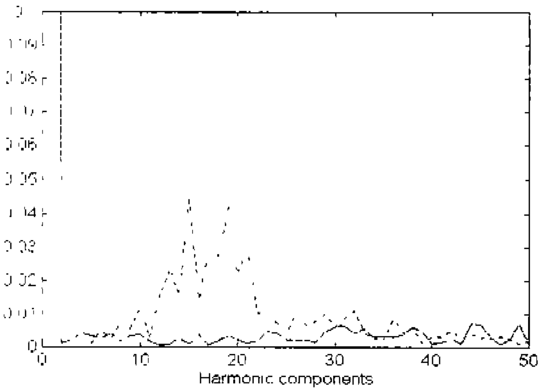

Fig. 9. 2-level (:), 3-level(-) Using NN Control

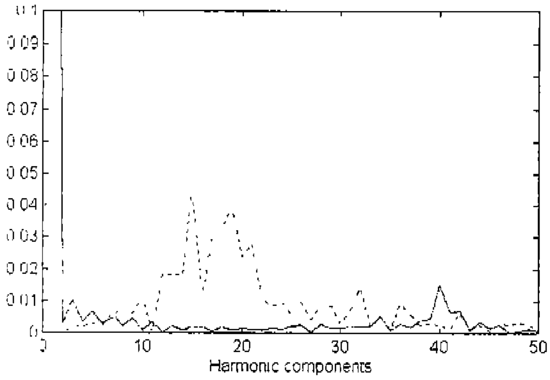

Fig. 10. 2-level (:), 3-level(-) Using Hysteresis Control

6. Conclusions

A method of applying NNs for two- and three-level power converter system for traction vehicle is presented. The fault tolerance of NNs has not been illustrated due to the limited space, but it works well even if one of three current sensors failed. Furthermore, the application of neural networks to three-level converters has never been tried before. Therefore, even though the promising results have been shown in simulation, many efforts should be needed in this power electronics field. One of them is the three-level power converter control using a hysteresis-band current control method. Since the hysteresis current control of the three-level voltage source converter has not been clearly known, a training NNs for learning the dynamic behavior of the hysteresis current control should be further investigated. Second, an NN control must be trained and also compared with a sinusoidal-band current control approach in both two- and three-level convert cases.

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