ARAŞTIRMA MAKALESİ

MODELING SWITCHING CONDITIONS-SPACE VECTOR MODULATION AND PASSING CAPACITORS OF AN IGBT-INVERTER WITH NEURAL NETWORKS IN CONTROL SYSTEMS ENVIRONMENT

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KONTROL SİSTEMLERİ ÇEVRESİNDE SİNİR AĞLARI İLE BİR IGBT INVERTERİN UZAY VEKTÖR MODULASYONU İÇEREN ANAHTARLAMA DURUMLARI VE GEÇİŞ KAPASİTELERİNİN MODELLENMESİ

ÖZET

IGBT birçok AC motor kontrol uygulamasında kullanılan ve cok iyi bilinen bir güç elemanıdır. Son 10 yılda piyasaya sürülen eşdeğer elemanlar içinde izole bir kapı girişi olan güç MOSFET'i gibi çalışır. Aynı zamanda düşük direnim gösteren bir güç bipolar transistörü gibi de işlev görür. Bunlar IGBT'yi diger güç elektroniği elemanlarindan ayıran en önemli özelliklerinden ikisidir. Bu makalede, literatürde açıklanan IGBT'nin analitik modeli için sinir aglari yöntemi, sürme devresinin anahtarlama harmoniklerini önlemek için kullanılmıştır. Burada, invereterin anahtarlama durumlari ile kapı- kollektör, kapı-emitter ve kollektör-emitter arasındaki geçiş kapasiteleri, 100 kHz'in altındaki frekans bandında yeni tip bir model tasarlanarak uygulanmıştır.

ABSTRACT

IGBT is a very well-known power device used in the most AC motor control applications. It is also a new power device according to the most of the other power electronic ones in the last 10 years with an insulated gate input like that of power MOSFET but with the low on-state resistance of a power bipolar transistor. In this paper, the analytical model of the IGBT explained in the literature to match the drive circuit requirements is used with the neural network model of switching conditions of the inverter at the same time and transient operation of IGBT is considered to model new type of the device to prevent switching harmonics sourced by inverter to the motor according to the low frequency band range (below 100 kHz) on the passing capacitors between gate and collector, gate and emitter, collector and emitter.

1. INTRODUCTION

In recent years, control systems have assumed an increasingly importance in the development and advancement of modern civilization and technology. Practically, every aspect of day-to-day activities is affected by some types of control systems. Control systems are found in abundance in all sectors of industry such as quality control of manufactured products, automatic assembly line, machine-tool control, space technology and weapon systems, computer control, transportation systems, power systems, robotics, and many others.

Considering these application areas, the power electronic devices rapidly spreads with the advance at electric power and high speed processors in daily technology. The conducting emissions with the switching condition which was not taken up by now becomes a large tangibly problem. The effect of the conducting emissions broaden electric power system and give rise to dependence on the parameters of the main devices or filters as a failure to the peripheral equipment [1-3].

IGBT is a very well-known power device used in the most AC motor control applications. It is also a new power device incomparision to the most of the other power electronic ones in the last 10 years. It has an insulated gate input like that of power MOSFET, while benefiting low on-state resistance of a power bipolar transistor. Also, it is known that the IGBT functions as a bipolar transistor, when its base current is supplied by the drain of a MOSFET which has its source short circuited to the collector of the bipolar transistor (Figure 1) [4-10]. In this paper, the analytical model of the IGBT explained in the literature to match the drive circuit requirements (modelling the passing capacitors of the gates) is used with the neural network model of switching conditions of the inverter (Figure 4) at the same time and transient operation of IGBT is considered to model new type of the device for switching conditions with space vector modulation of the inverter to the motor according to the low frequency band range (below 100 kHz) on the passing capacitors between gate and collector, gate and emitter, collector and emitter (Figure 5).

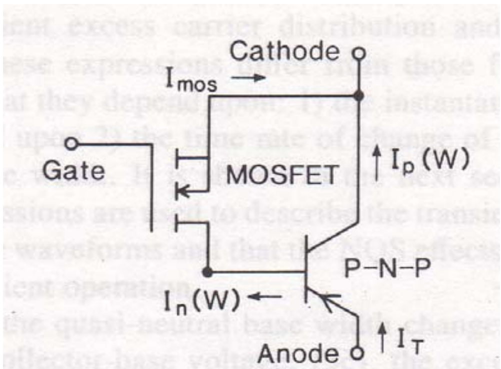


Figure 1. Equivalent circuit model of IGBT

2. SPACE VECTOR (SV) MODULATION TECHNIQUE

The structure of a typical three-phase inverter is shown in Figure 2. Here, the main devices of the inverter are the six IGBTs that shape the output, which are controlled by A, A', B, B' and C, C'.

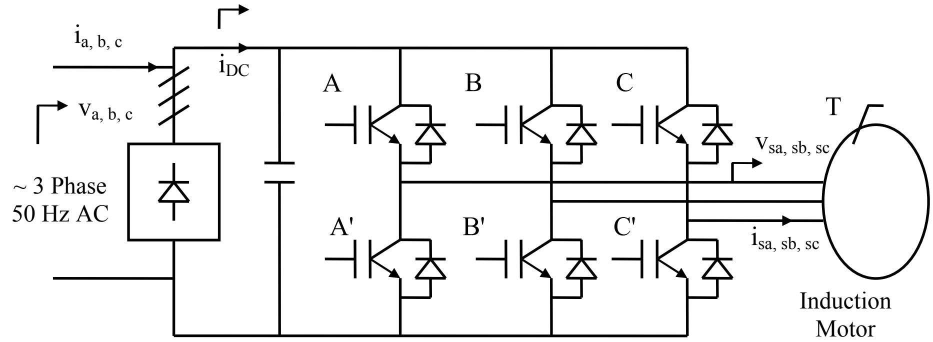


Figure 2. The structure of a typical three-phase inverter

The relationship between the switching variable vector $[a, b, c]^t$ and the line-to-line output voltage vector $[V_{ab}\ V_{bc}\ V_{ca}]^t$ and the phase (line-to-neutral) output voltage vector $[V_a\ V_b\ V_c]^t$ is given by equations 1 and 2 below.

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{DC} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3} V_{DC} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{2}$$

where V_{DC} is the DC supply voltage or bus voltage (similarly for DC current i_{DC}).

Assume d and q are fixed horizontal and vertical axes in the plane of the three motor phases. The vector representations corresponding to the eight combinations can be obtained by applying the transformation called d-q transformation to the phase currents. This transformation is equivalent to an orthogonal projection of $[a, b, c]^t$ onto the two dimensional plane perpendicular to the vector $[1, 1, 1]^t$ in a three-dimensional coordinate system, the results of which are six non-zero vectors and two zero vectors as shown in Figure 3. The nonzero vectors form the axes of a hexagonal. The angle between any adjacent two non-zero vectors is 60 degrees. The zero vectors are at the origin and apply zero voltage to a three phase load. The eight vectors are called the Basic Space Vectors.

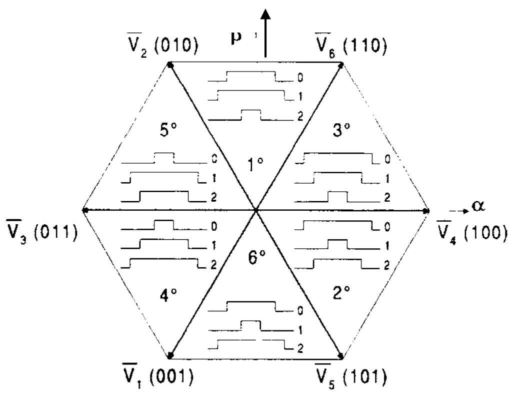


Figure 3. The model of space vector modulation

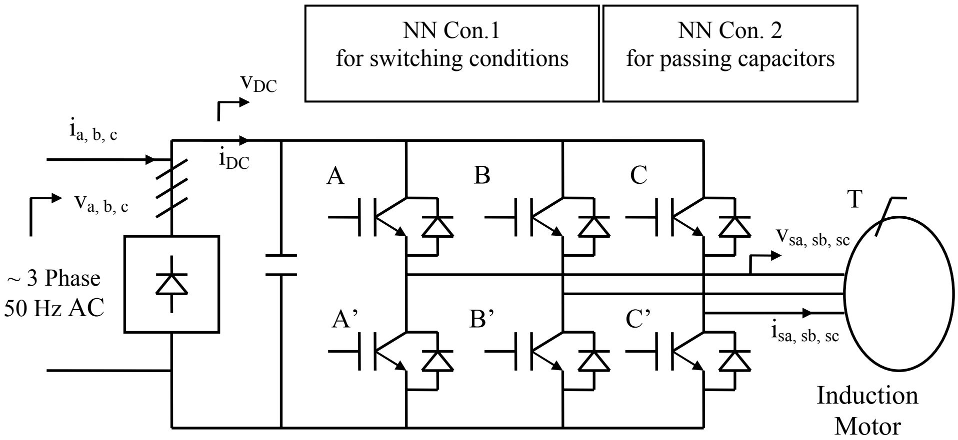


Figure 4. The structure of a typical three-phase inverter with block diagrams neural network model

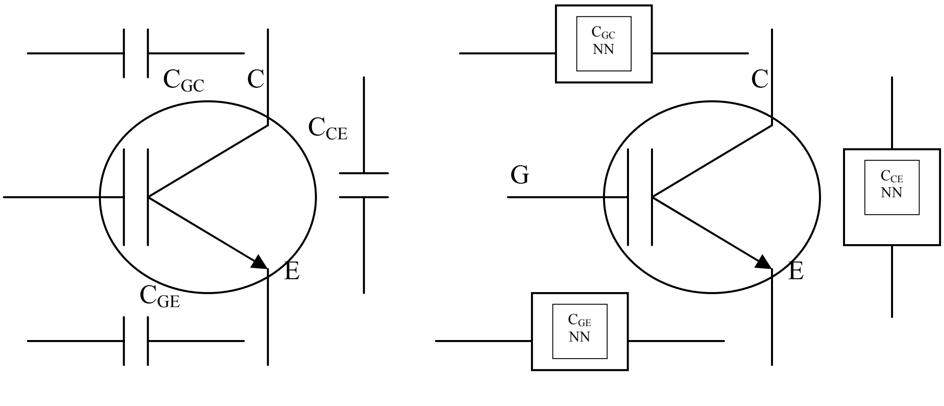


Figure 5. Modeling of IGBT with neural networks according to frequencies on the capacitors of the gates; (a) IGBT general structure, (b) model of the structure

3. THE APPLICATION PART OF THE SYSTEM

Figure 6 shows neural network based current controller in conjunction with PWM related to space vector modulation condition in Figure 3. The network receives the phase current error signals through the scaling gain K and generates the PWM logic signals for driving the inverter devices. The sigmoidal function is clamped to 0 or 1 when the threshold value is reached. The output signals have eight possible states (as to be seen in table 1 and related to equations 1 and 2) corresponding to eight states of the inverter which is called space vector modulation in chapter 2. If the current in a phase reaches the threshold value +0.01 the respective output should be 1 which will turn on the upper device of the leg. If, on the other hand, the error reaches –0.01, the output should be 0 and the lower device will be switched on. The network is trained with eight input-output patterns (table 1 and 2). Figure 7 shows the whole control system including the production scheme of space vector PWM signals with ANN [13].

The processor used in this work is, 40Mhz TMS320C50 DSP with 10k x 16 words of on-chip RAM which works parallel with TLC320C40 analogue interface circuitry (AIC) with 14 bit resolution. An operation sampling condition is taken to train the network. After training the set, thus according to this sampling, PWM pulses are produced by the designed ANN controller in its test phase from the related computer. Table 2 shows the result of one leg switching condition of one phase of the inverter in the test phase of ANN. It is depicted the architecture of ANN for switching conditions in Figure 8 and the one for passing capacitors in Figure 9. For this NN controller (switching conditions) of this part of the system, Classic Back-propagation Algorithm is used for 300000 iteration numbers with a very small system error as %0.0011.

Switching conditions for transient state of IGBTs are also very important in case of THD (Total Harmonic Distortion) of the Common Mode (CM) voltage and phase-to-phase voltage of the system studied. Analytical model and dynamic model of an IGBT including the passing capacitors are effective on such condition (transient state). They are also effective on both V_A anode voltage and V_g gate voltage for higher voltage stability. Neural Network approximation gives a kind of improvement in some extend to this issue. Thus, it is needed to think about frequency change conditions on a practical application in low frequency band of interest.

Table 3 and 4 show some values of the training set for passing capacitors according to the frequency change and test phase results respectively. For ANN model (passing capacitor conditions) of this part of the system, also Classic Back-propagation Algorithm is used with an input variable; frequency values in the unit of kHz as output variables; passing capacitors, C_{GC}, C_{GE} and C_{CE} in the units of nF for 450000 iteration numbers with a very small system error %0.0257. Comparison diagrams of calculated values of passing capacitors with neural network ones is depicted in Figure 10-12.

Table 1. The values of ON/OFF states used in training the NN Controller 1

i_a	i_b	i_c	1	2	3	4	5	6
0	0	0	0	0	0	0	0	0
0.01	-0.01	-0.01	1	0	0	0	1	1
0.01	0.01	-0.01	1	1	0	0	0	1
0.01	0.01	0.01	1	1	1	0	0	0
-0.01	0.01	0.01	0	1	1	1	0	0
-0.01	-0.01	0.01	0	0	1	1	1	0
-0.01	-0.01	-0.01	0	0	0	1	1	1
1(0)	1(0)	1(0)	0	0	0	0	0	0

Table 2. The values taken from NN Con. 1 test phase for one of eight switching conditions

i_a	i_b	i_c
0.01	-0.01	-0.01

1	2	3	4	5	6
0.99865	0.00138	0.00009	0.00145	0.99883	1.0

Table 3. Some values of frequency and passing capacitors used in training the NN Controller 2

F (kHz)	C_{GC}, (nF)	C_{GE} (nF)	C_{CE} (nF)
0.01	14.4	13.2	7.2
0.5	7.638	7.026	3.819
1	0.73	0.72	0.36
2.5	0.719	0.709	0.354
10	0.667	0.657	0.328
30	0.527	0.519	0.259
47.5	0.397	0.399	0.199
72.5	0.222	0.226	0.113
89	0.107	0.112	0.056
97.5	0.0475	0.0541	0.0305

Table 4. Test phase results for the NN Controller 2

F (kHz)	C_{GC} (nF)	C_{GE} (nF)	C_{CE} (nF)	C_{GC}, NN Res. (nF)	C_{GE} NN Res. (nF)	C_{CE} NN Res. (nF)
0.03	14.124	12.948	7.062	14.054	12.891	7.041
0.225	11.433	10.491	5.716	11.427	10.474	5.709
5	0.702	0.692	0.346	0.677	0.669	0.337
50	0.384	0.385	0.183	0.356	0.365	0.169
90	0.105	0.109	0.051	0.101	0.090	0.045

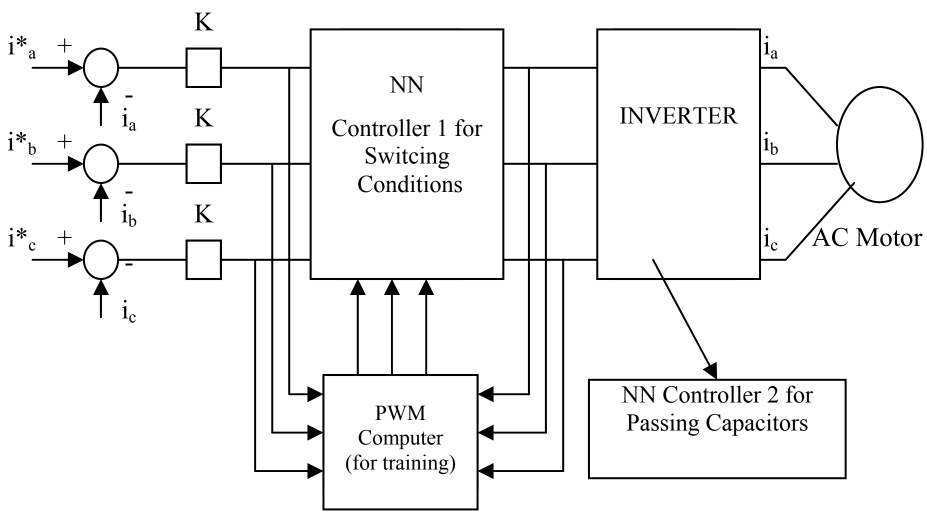


Figure 6. NN based production of a current controlled PWM

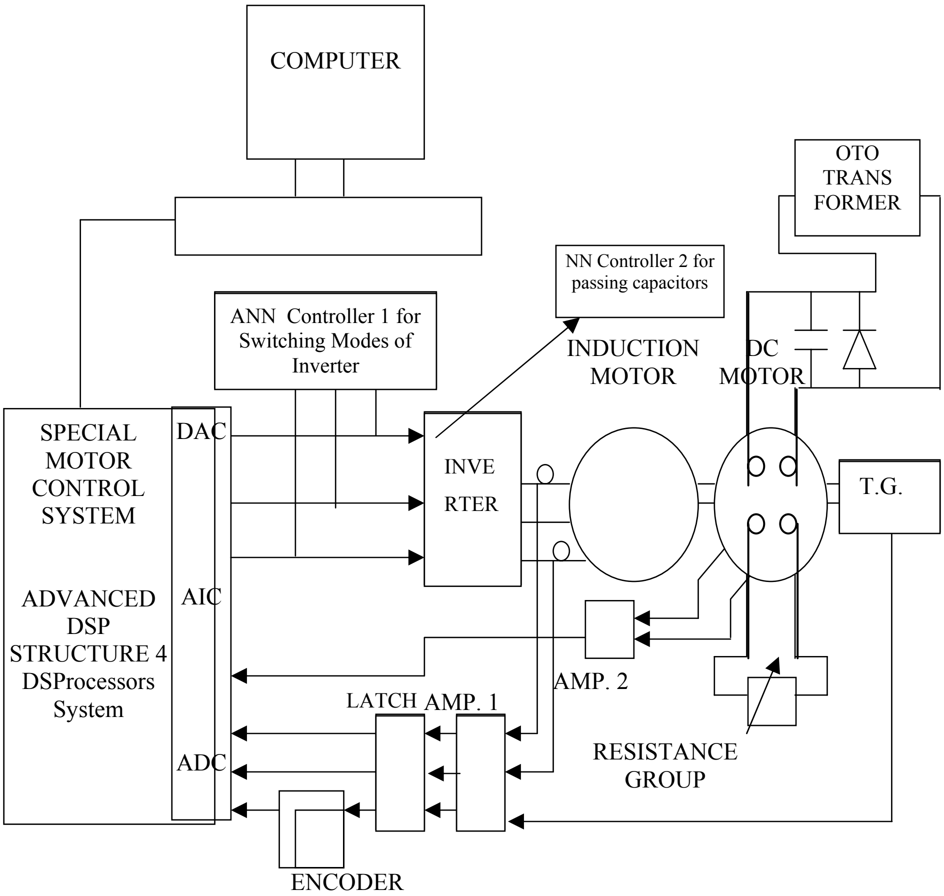


Figure 7. The block diagram of DSP- based control system including ANN controller

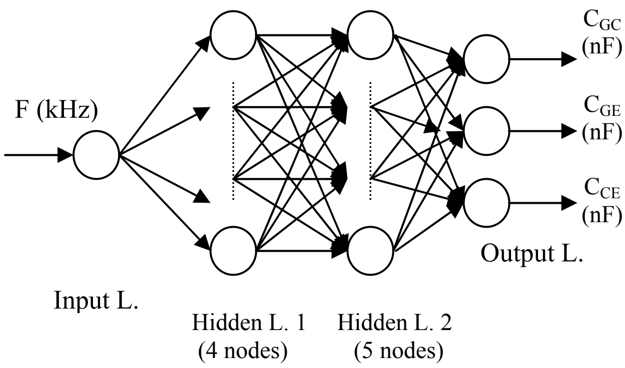


Figure 9. The general architecture of NN controller for passing capacitors

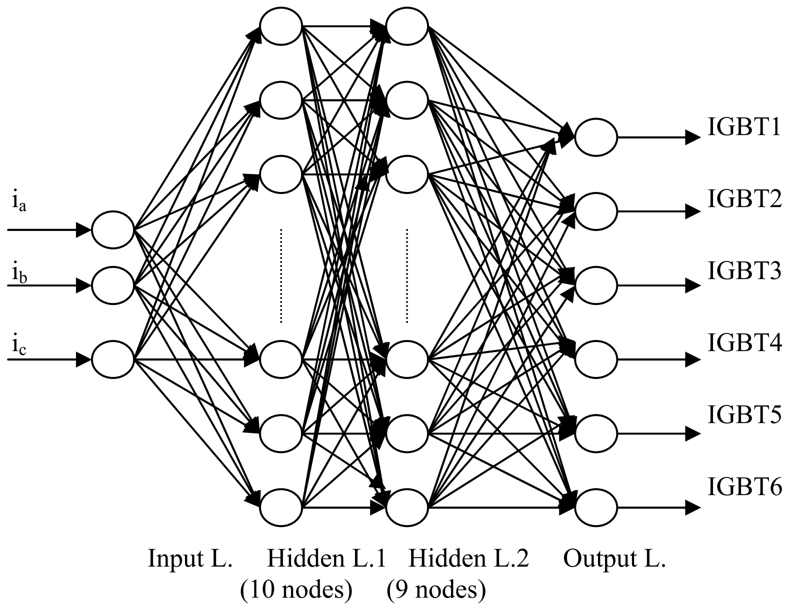


Figure 8. The architecture of NN Controller 1 for the inverter SV-PWM pulses modulation-8 witching conditions

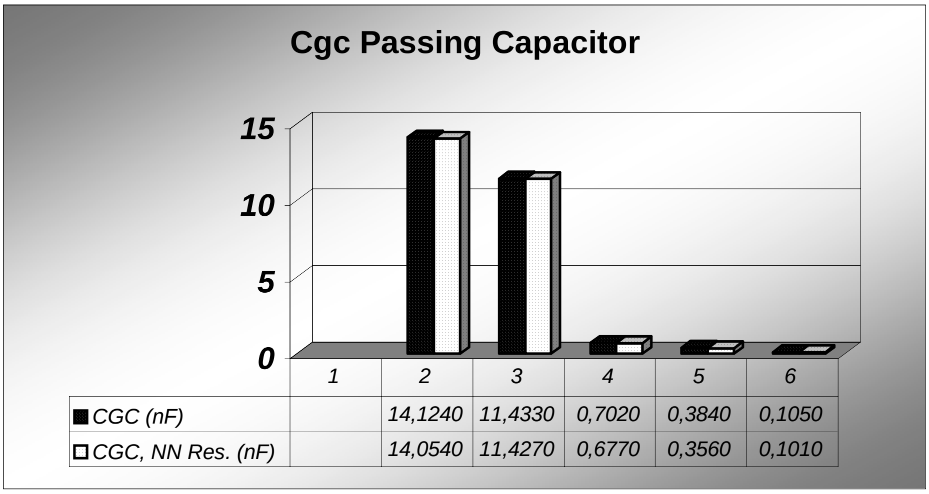
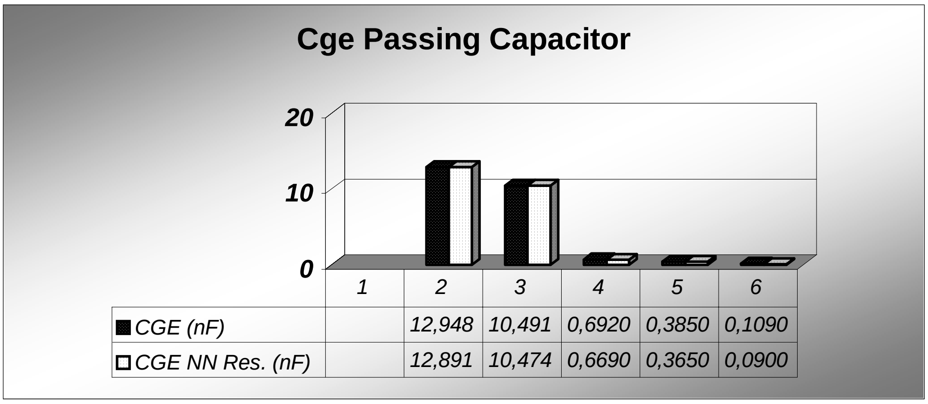
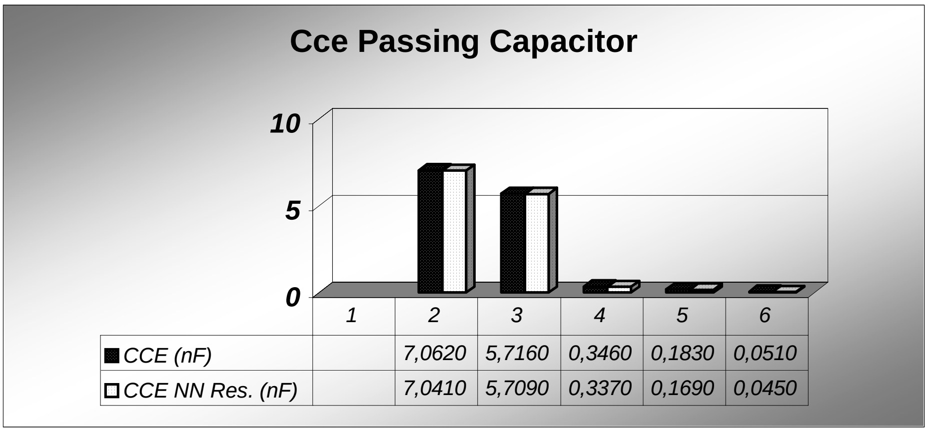


Figure 10. The comparison diagram for the passing capacitor of C_{GC} (nF) with the results of NN controller simulations



	1	2	3	4	5	6
■ CGE (nF)		12,948	10,491	0,6920	0,3850	0,1090
□ CGE NN Res. (nF)		12,891	10,474	0,6690	0,3650	0,0900

Figure 11. The comparison diagram for the passing capacitor of C_{GE} (nF) with the results of NN controller simulations



	1	2	3	4	5	6
■ CCE (nF)		7,0620	5,7160	0,3460	0,1830	0,0510
□ CCE NN Res. (nF)		7,0410	5,7090	0,3370	0,1690	0,0450

Figure 12. The comparison diagram for the passing capacitor of C_{CE} (nF) with the results of NN controller simulations

4. CONCLUSIONS

The application is a effective kind of NN controller one to obtain low harmonic and noise condition. The advantages of using NN controller parts here as a drive part of a motor controlled system areas following;
1- The faster results in test phase of NN controllers, the faster approximation to the related values of the variables,
2- There is a decrease of the initial cost functions of IGBT power electronic devices in case of passing capacitors with the advantage of training NN ones.

After NN controller is trained according to the system or circuit data once, it is assumed that there is no need for the capacitors of the gates in the model according to the simulation results. That is to say that NN controller gives a good understanding to approximate to the faults caused by the passing capacitors of IGBT devices using its dynamic structure from the literature studied. It is used a Dyna-Book Satellite 2060 computer to train NN controller. The language of

NN is C++. In the paper, for Classic Back-propagation Algorithm Structure as the input value to NN, Frequency (f) as the unit of kHz, as the output values to it as output variables; passing capacitors, C_{GC}, C_{GE} and C_{CE} in the units of nF for 450000 iteration numbers with a %0.0257 very small system error. Thus, It is considerably important success of this approximation to the some important parts of the system, that is, adapting to.

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