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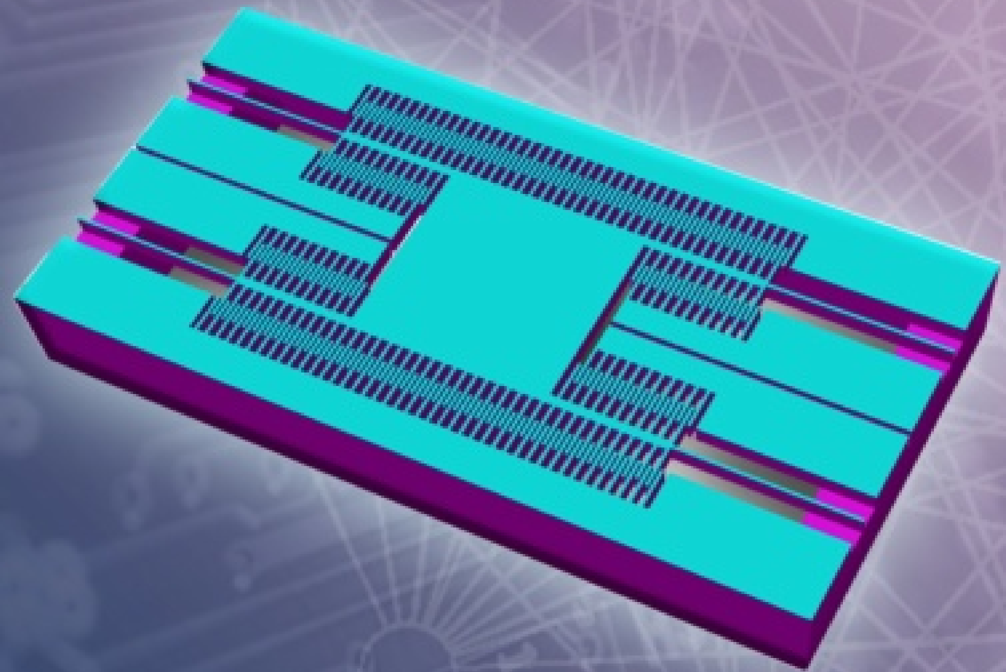

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An Intelligent ANN Based Control of a Quasi Six-Phase Voltage Source Inverter

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Abstract*:* In this paper, we propose a new high-phase (more than three-phase) motor drive system which are being successfully used in numerous areas. High-phase motor drive systems are nowadays considered for high power adjustable speed industrial applications since they offer numerous advantages. Several topologies are investigated in the literature as viable alternative to the existing three-phase drive system. The most popular among them are five-phase and six-phase. In six-phase system two topologies are possible depending upon their possible winding configuration. In one topology, the windings or phases are 60 degrees apart and called symmetrical six-phase system. The second topology has two sets of three-phases and is displaced by 30 degrees. This is called quasi- six-phase or dual three-phase. In this paper, control technique is described for a quasi six-phase voltage source inverter (VSI) for obtaining desired output. The output of the inverter is two set of three-phases with 30° phase displacement. The proposed control is in essence space vector pulse width modulation (PM) based on the artificial neural network (ANN) concept. ANN method of control is highly useful for high switching frequency operation. Several types of ANN topologies are considered and finally the most optimum solution is proposed to obtain similar performance obtainable from space vector PWM. Simulation and experimental results are provided to validate the proposed theory.

Keywords: Pulse width modulation (PWM), Quasi six-phase inverter, Artificial neural network (ANN), Multi-phase.

1. Introduction

The multi-phase variable speed electric drive was proposed in late 1960s. Since then the pace of development was steady but relatively slow and limited during the first three decades of its inception. The situation has, however, changed in the last decade, when an upsurge in the research effort in this area took place. The driving forces behind this accelerated development have been specific application areas: railway traction and electric vehicle/hybrid electric vehicle applications, "more-electric" aircraft and electric ship propulsion [1]. The reasons for employing multi-phase drives vary from application to application and range from reduction of the converter per phase rating to significantly improved fault tolerance. Since in variable-speed ac drives an electric machine is supplied using a power electronic converter, the number of phases is no longer restricted to three. Hence, the machine and the power electronic converter can be built with any number of phases appropriate to the specific application. The recent developments in the area of multi-phase machines and drives have been supported by advances in power semiconductor devices and DSPs. Detailed reviews on the development in the area of multi-phase drive research is published in recent past [2-6].

Many industrial applications require precise control algorithms of power electronic converters. Growing interest is found towards the Pulse width modulation techniques for power inverters. A variety of modulation techniques for quasi six-phase inverters have been developed in the recent past [7-22]. Among many modulation strategies, space vector pulse width modulation techniques (PWM) have seen more attention from the researcher. For the AC machine drive application, full dc bus voltage utilization is important in order to achieve maximum torque under all operating conditions. This is achieved in the space vector PWM. Nevertheless, the output of space vector PWM inverter contains lower order harmonics. It is indicated in the literature that it is not possible to completely eliminate these harmonics in a quasi six-phase inverter [6].

This paper thus proposes a voltage modulation method to provide sinusoidal output with improved dc bus utilization. The space vector PWM is implemented using ANN technique. The ANN modulator is trained to generate the PWM switching pattern. The ANN method is highly efficient for nonlinear mapping. The ANN method is more useful when high switching frequency operation is considered. The simulation and experimental results are provided for the ANN based PWM method.

2. Modeling of Six-Phase Inverter - A Review

The power circuit of a quasi six-phase VSI is shown in Fig. 1. Each switch consists of a power switching device such as IGBT or MOSFET in parallel to a snubber circuit. Since six dependent currents can flow in a general case, therefore, this is a six dimensional system. Thus modeling and control problems of such system must be addressed from the point of six dimensional spaces. The inverter input dc voltage is treated as constant. The load is star-connected (dual three-phase) with isolated neutrals as shown in Fig. 1. The inverter output phase voltages are denoted in Fig. 1 with lower case symbols (*a, b, c, d, e, f*), while the pole voltages have symbols in capital letters (*A, B, C, D, E, F*). The relationship between the inverter phase-to-neutral voltages and inverter pole voltages is obtained as:

$$\begin{aligned}
v_a &= (5/6)v_A - (1/6)(v_B + v_C + v_D + v_E + v_F) \\
v_b &= (5/6)v_B - (1/6)(v_A + v_C + v_D + v_E + v_F) \\
v_c &= (5/6)v_C - (1/6)(v_A + v_B + v_D + v_E + v_F) \\
v_d &= (5/6)v_D - (1/6)(v_A + v_B + v_C + v_E + v_F) \\
v_e &= (5/6)v_E - (1/6)(v_A + v_B + v_C + v_D + v_F) \\
v_f &= (5/6)v_F - (1/6)(v_A + v_B + v_C + v_D + v_E),
\end{aligned} \tag{1}$$

where the inverter pole voltages take the values of $\pm 0.5V_{DC}$.

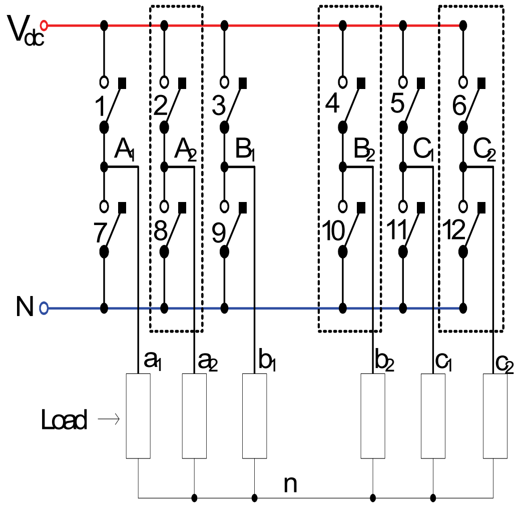

Fig. 1. Power circuit of asymmetrical six-phase voltage source inverter.

In general, an n phase two level VSI has a total 2^n number states. Therefore for a six-phase VSI, total number of switching states is 64, in which four are zero vectors and the remaining 60 are active vectors. By using decoupling transformation matrix given in (2) each voltage vector can be decomposed into three orthogonal two dimensional subspaces *d-q, x-y* and o_1-o_2. The o_1-o_2 are equal to zero because the neutrals n_1 and n_2 are assumed isolated. Thus this pair of vectors is omitted from further discussion. The modulation techniques thus confines to the two remaining orthogonal sub-spaces *d-q* and *x-y*.

$$[T] = \frac{2}{6}\begin{bmatrix} 1 & \cos(\theta) & \cos(4\theta) & \cos(5\theta) & \cos(8\theta) & \cos(9\theta) \\ 0 & \sin(\theta) & \sin(4\theta) & \sin(5\theta) & \sin(8\theta) & \sin(9\theta) \\ 1 & \cos(5\theta) & \cos(8\theta) & \cos(\theta) & \cos(4\theta) & \cos(9\theta) \\ 0 & \sin(5\theta) & \sin(8\theta) & \sin(\theta) & \sin(4\theta) & \sin(9\theta) \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix} \tag{2}$$

$$\underline{v}_{dq} = \frac{2}{6}(v_a + \underline{a}v_b + \underline{a}^4 v_c + \underline{a}^5 v_d + \underline{a}^8 v_e + +\underline{a}^9 v_f) \tag{3}$$

$$\underline{v}_{xy} = \frac{2}{6}(v_a + \underline{a}^5 v_b + \underline{a}^8 v_c + \underline{a}v_d + \underline{a}^4 v_e + \underline{a}^9 v_f), \tag{4}$$

where $\underline{a} = exp(\pi/6)$. Fig. 2 represents the space vector representation of all the vectors in *d-q* axis and Fig. 3 represents in *x-y* axis. All the zero vectors are at the origin so that a vector can be represented in six dimensional spaces as shown in Figs. 3 and 4, according to the largest vectors lie at the vertices of the polygon there are total twelve $\pi/6$ radian sectors.

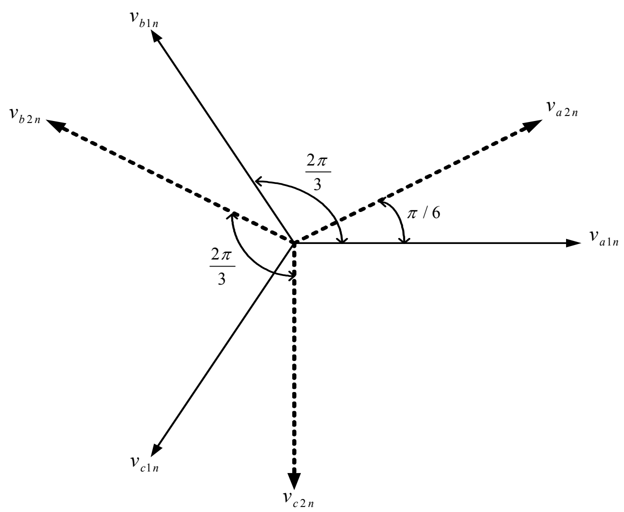

Fig. 2. Phasors of phase-to-neutral voltages for quasi six-phase system of switching.

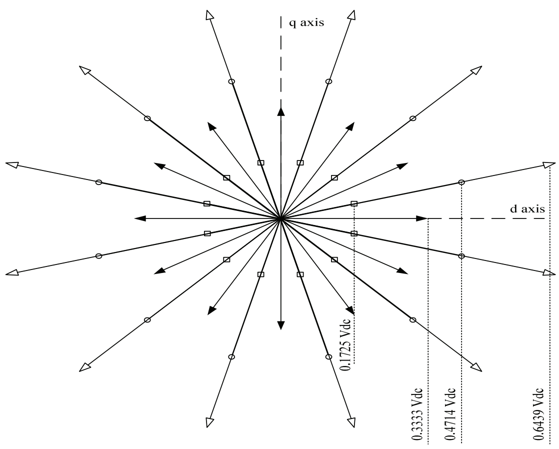

Fig. 3. Space vector representation of all vectors in *d-q* axis.

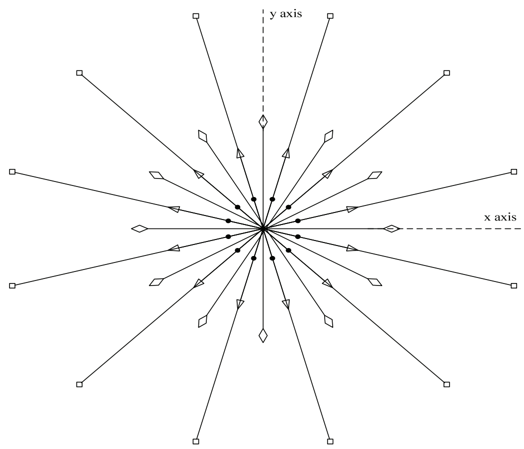

Fig. 4. Space vector rep of all vectors in *x-y* axis.

3. Conventional Space Vector PWM Schemes

It is shown in [10] that for an *n* phase inverter, the minimum (*n*-1) numbers of vectors are required to synthesize the input reference and the output obtained is sinusoidal in nature. Therefore, following the same principle for six-phase, inverter minimum number of vectors required for sinusoidal output is 5.

There are numerous methods of choosing vectors so that they have maximum amplitude on *d-q* axis and minimum amplitude on *x-y* axis [10-11]. In the most simple form of space voltage PWM, only those switching states vectors , which lie at the vertices of the polygon as shown in Fig. 3 are employed to synthesize the reference vector (V^*). Two active vectors of largest length and zero vectors are used during one sampling interval [3]. This is similar to the one used in a three-phase VSI. However, this scheme when employed in a six-phase VSI leads to unwanted low-order harmonics due to the presence of the space vectors in *x-y* plane.

Another method is the vector space decomposition scheme proposed by Y. Zhao [9], in this method four adjacent voltage vectors are always selected which spans the outer most polygon on the *d-q* plane according to the position of the reference voltage vector V^*, the fifth vector is chosen from the zero vector located at the origin of the *d-q* plane as shown in Fig. 3. Space vector PWM strategy is accomplished by the following equation:

$$\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \end{bmatrix} = \begin{bmatrix} V_d^{\,1} & V_d^{\,2} & V_d^{\,3} & V_d^{\,4} & V_d^{\,5} \\ V_q^{\,1} & V_q^{\,2} & V_q^{\,3} & V_q^{\,4} & V_q^{\,5} \\ V_x^{\,1} & V_x^{\,2} & V_x^{\,3} & V_x^{\,4} & V_x^{\,5} \\ V_y^{\,1} & V_y^{\,2} & V_y^{\,3} & V_y^{\,4} & V_y^{\,5} \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_d^{\,*}T_s \\ V_q^{\,*}T_s \\ 0 \\ 0 \\ T_s \end{bmatrix}, \tag{5}$$

where V_x^k is the projection of the k^{th} voltage vector on the x axis and T_k is the dwell time of that vector during time interval T_s. The quantities V_d^* and V_q^* are the *d-q* plane reference voltages. During each sampling period T_s, a set of five voltage vectors must be chosen to guarantee that each T_k has positive and unique solution. Although the current harmonics are suppressed but the computation time required to implementing this method is considerably large.

Three largest vectors and one smaller vector, used in vector classification algorithm [11], are generalized conventional SVPWM. The vectors used in SPWM and the SVPWM method based on unified modulation method proposed by L. Ching [13], where three largest vectors and two smaller vectors are chosen automatically. The implementation of this scheme is easier but the drawback of this method is higher switching losses.

Another method proposed by K. Marouani [14], PWM strategy based on 24 sectors. This technique combines the maximum magnitude *d-q* plane voltage vectors and the ones with half magnitudes. These voltage vectors divide the *d-q* plane into twenty four $\pi/12$ radian sectors. In each sampling period, the reference voltage vector is achieved by selecting a set of three voltage vectors among those have maximum magnitude and fourth vector among the ones with half magnitude. This method once again suffers from the drawback of larger computational time. The method does not give satisfactory results when the switching frequency is very high of the order of 50 kHz. In such applications ANN is a better alternative.

4. Artificial Neural Network Based Space Vector PWM Scheme

Artificial Neural Network (ANN) is accomplished to resolve paradigms better than linear computing. ANN is an effective tool for mapping non-linear systems. The PWM operation of a power converter is a good example of non-linear mapping and hence ANN is highly useful in this application. Expansion of technology like artificial neural network has given various effortless explanations to the industries. To design a neural network programmer does not require in-depth knowledge about complicated neural network programming and also no exact modelling of the system under study is required. The work flow of ANN can be achieved in this approach, first of all gather the systems information and then create model of network and configure the required network. Assign the weights and biases to train the network and finally authenticate the network to use in the experimentation. Several neural network software is available in the market and MATLAB/Simulink environment is used in the present study.

The presented modulation scheme is based on artificial neural network system. Instead of implementing SVM by DSP, it is possible to implement it by a feed-forward neural network because the SVM algorithm can be looked upon as a nonlinear input/output mapping. [25-31] This means that the reference voltage vector V^* magnitude, and α^* angle can be impressed at the input of the network and the corresponding pulse width pattern of the quasi six- phases can be generated at the output. There are two approach of implementing SVM using ANN called 'Direct method' and 'Indirect method'. In the so called 'Direct method', the feedforward backpropagation ANN directly replace the conventional SVM algorithm. Since feedforward ANN network can map only one input pattern onto only one input pattern, the sampling time is divided into *n* subintervals. Thus each subinterval includes only one output switching pattern for every input pattern. Thus it requires huge data set for proper training of the network. Thus this approach is limited in use. The later method uses two separate feed-forward back-propagation ANN, one for the magnitude of the reference voltage and other for the reference voltage position. The magnitude network yield voltage magnitude scaling function which is linear in the linear modulation region and is non-linear function of V_{DC} in the over-modulation region. The reference position network yield turn on pulse width function at unit voltage magnitude. This pulse width functions are then multiplied by a suitable bias signal and the product is compared with the up/down counter to generate appropriate switching signals for the inverter. The complete implementation block diagram is illustrated in Fig. 5.

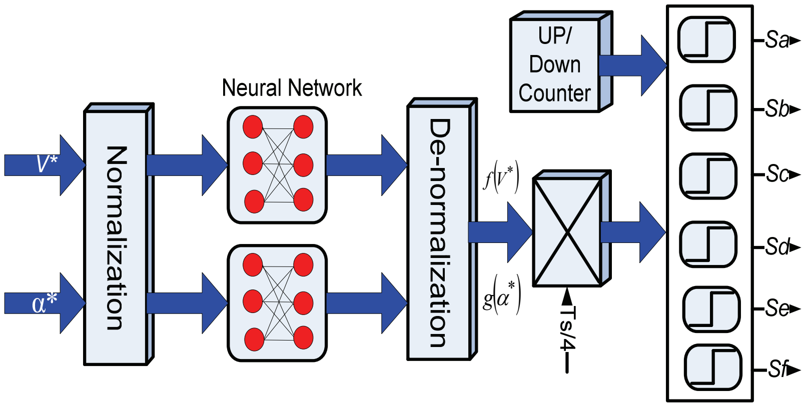

Fig. 5. Functional Block diagram of ANN based SVM for a quasi six-phase VSI.

Then the MATLAB neural network tool is used for the training and simulation purpose which is later formed the ANN block for the above scheme. There are three layers in the neural network; one is input layer with six neurons, one hidden layer with ten neurons and one output layer with six neurons. The neural network topology for the scheme for quasi-six phase voltage source inverter is shown in Fig. 6 a and 6 b.

6. Simulation Results

Simulation results are provided in Fig. 7. The output phase 'a' current in an R-L load is depicted in Fig. 7 (a) and Fig. 7 (b) shows the harmonic spectrum for phase 'a'. The results obtained using the PWM shows that output contains the 50 Hz component with the magnitude of 0.3639 p.u. rms (0.51477 p.u. peak). The hidden layer contains 10 neurons. Network is Feed-forward back propagation type and the training function "TRAINLM" is used for the simulation purpose. The adaptation learning function is LEARNGDM and Mean squared error (MSE) performance function is used. Transfer function is TANSIG (tansigmoidal) type.

The results obtained using the PWM show that output contains the 50 Hz component with the magnitude of 0.3577 p.u. rms (0.5059 p.u. peak). The THD is 2.95 % of the fundamental and the WTHD is 2.78 % of the fundamental.

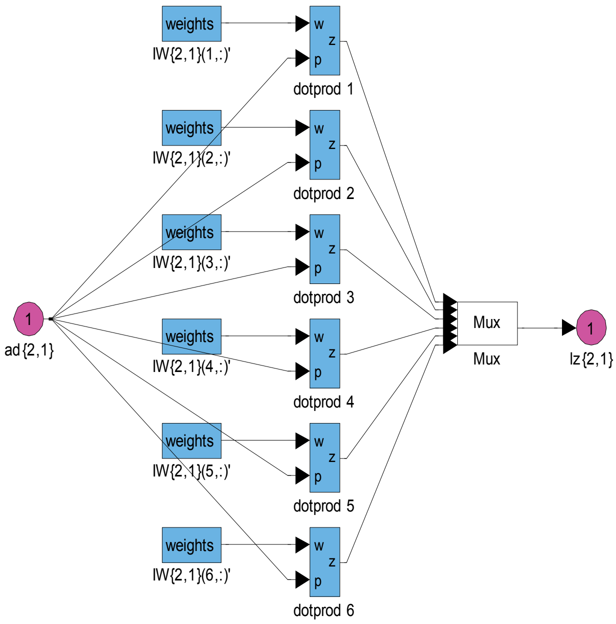

Fig. 6 (a). Output layer with six neurons.

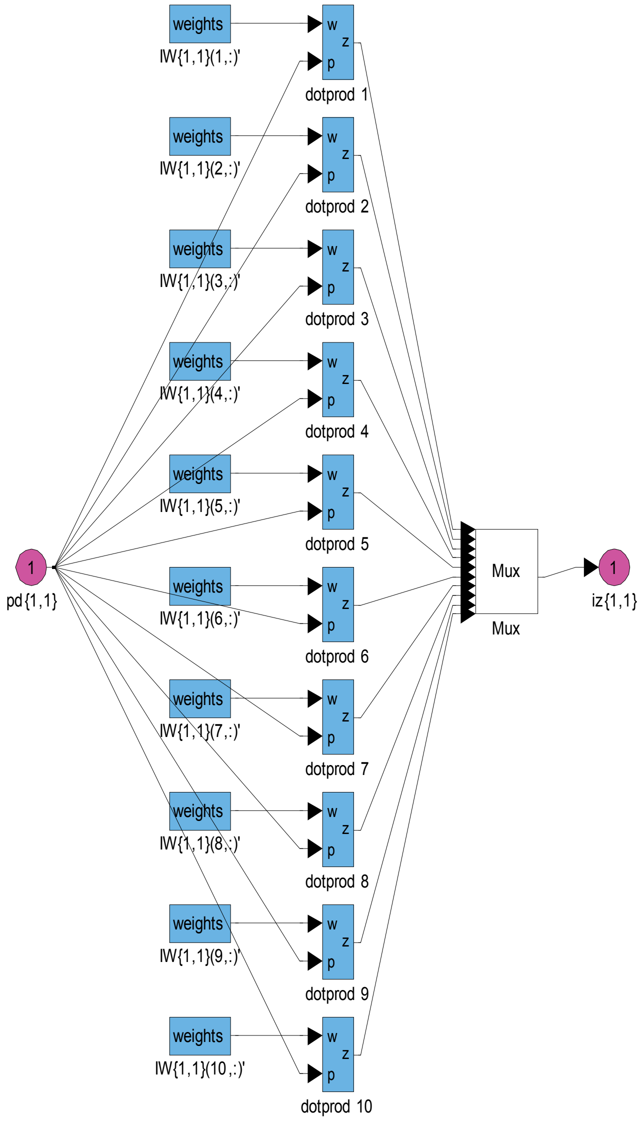

Fig. 6 (b). Hidden layer with ten neurons a quasi-six phase VSI.

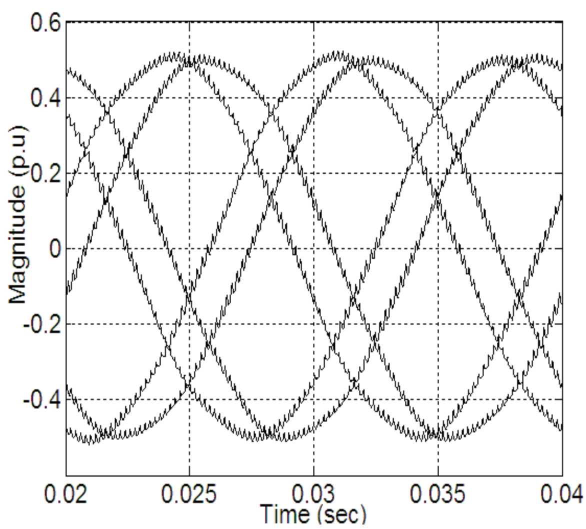

Fig. 7 (a). Filtered output voltage.

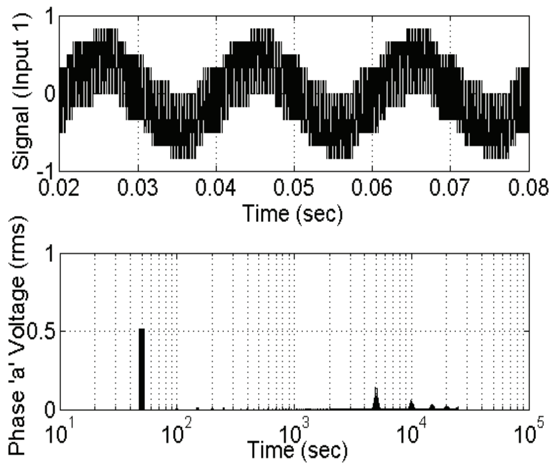

Fig. 7 (b). Harmonic spectrum for phase 'a' 10 neurons in hidden layer.

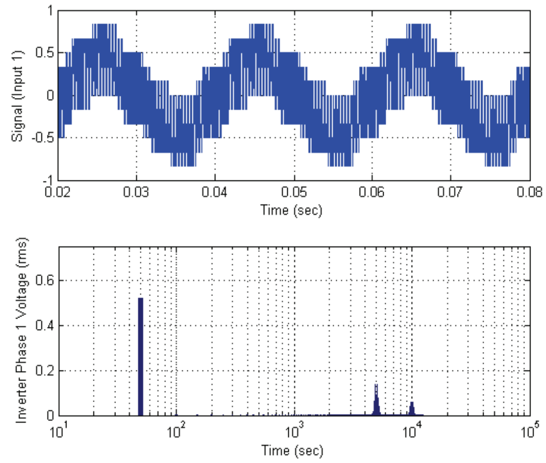

Fig. 8. Harmonic spectrum for phase ‘a’ with 15 neurons in hidden layer.

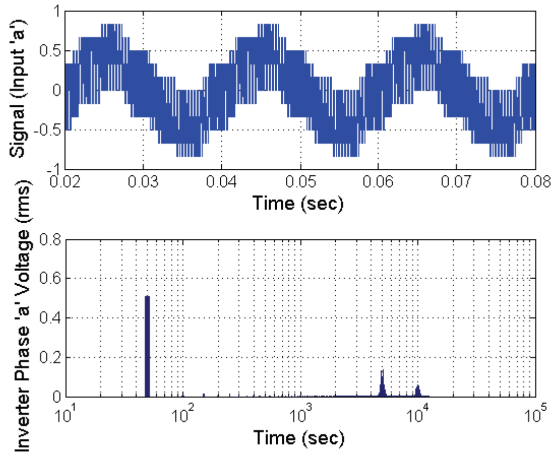

Fig. 9. Harmonic spectrum for phase ‘a’ with 20 neurons in hidden layer.

The Total Harmonics Distortion factor computation uses and normalizing this expression with respect to the quantity (V_1) i.e. fundamental, the Weighted Total Harmonic Distortion (WTHD) become

$$\text{THD} = \sqrt{\sum_{n=3,5,7..}^{\infty} \left(\frac{v_n}{v_1}\right)^2} \tag{6}$$

$$\text{WTHD} = \frac{\sqrt{\sum_{n=3,5,7..}^{\infty} \left(\frac{V_n}{n}\right)^2}}{V_1} \tag{7}$$

Another method used for the simulation where network is Cascade forward backpropagation type and the training function “TRAINDA” is used for the simulation purpose. The adaptation learning function is LEARNGDM and Mean squared error (MSE) performance function is used. Transfer function is LOGSIG (logsigmoidal) type. The simulation results shown in Fig. 10 depict the harmonic spectrum for the phase ‘a’ voltage. The output contains the 50 Hz component with the magnitude of 0.3632 p.u. rms (0.5137 p.u. peak). The THD is 10.45 % of the fundamental and the WTHD is 10.31 % of the fundamental.

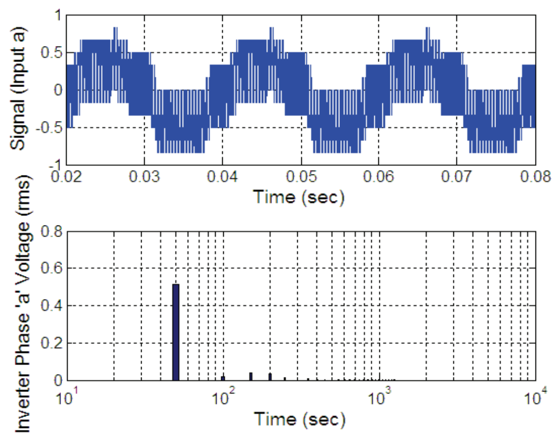

Fig. 10. Harmonic spectrum for phase ‘a’ .

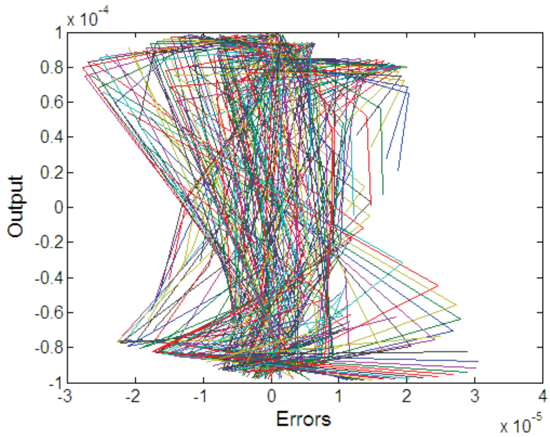

Fig. 11. Plot between the error and outputs with 20 neurons in hidden layer.

7. Experimental Investigation

Experimental investigation is performed to implement the proposed scheme for a quasi-six phase VSI. The DC link is paralleled to make it common for all the modules. The DSP TMS320F2812 has provision of generating four independent PWM outputs per event manager thus a maximum of eight-phase inverter can be controlled using one DSP. Out of six PWM, three are generated using full compare units and the other one is generated by the GP timer compares units. The full compare unit has programmable dead-band for PWM output pairs but the other one PWM channel does not have the provision of dead band. Thus a dead band generating circuit is fabricated which act upon those PWM signals which do not have inbuilt dead band. A distribution panel is developed which distributes the twelve PWM signals generated from DSP to three power modules. Fig. 15 and Fig. 16 show the experimental results of a DSP based quasi-six phase VSI. Fig 14 (a) shows the filtered PWM signals and Fig. 14 (b) shows the harmonic spectrum of the phase 'a' voltage. Fig 15 (a) shows the output of the PWM inverter and Fig. 15 (b) shows the switching waveforms of the PWM signals.

Fig. 12. The quasi-six phase voltage source inverter set-up.

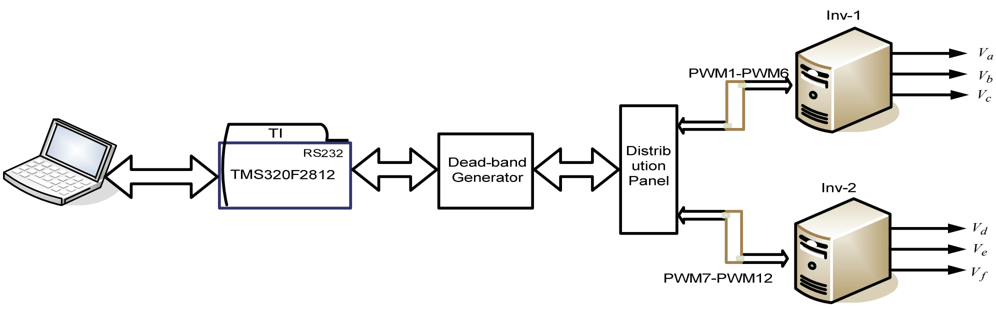

Fig. 13. Block schematic of a DSP based quasi-six phase VSI.

8. Conclusion

In this paper a voltage modulation technique is presented based on artificial neural network system. Different types of processing functions are tried for the ANN implementation and also different numbers of Hidden layers are used. The results are compared in terms of the total harmonic distortion and weighted total harmonic distortion in the output phase voltages. The best results are obtained with feed forward back propagation, training function, 'TRAINLM', adaption learning function 'LEARNGDM', performance function 'MSE' and the transfer function 'TANSIGMOIDAL' with 10 hidden layers. The worst results are obtained for Cascade forward backpropagation, training function 'TRAINGDA', adaption learning function 'LEARNGDM', performance function MSE and transfer function 'LOGSIGMOIDAL' with 20 hidden layers. Hence it can be said that there is an optimum value of number of hidden layers that gives the minimum harmonic distortion in the output voltage.

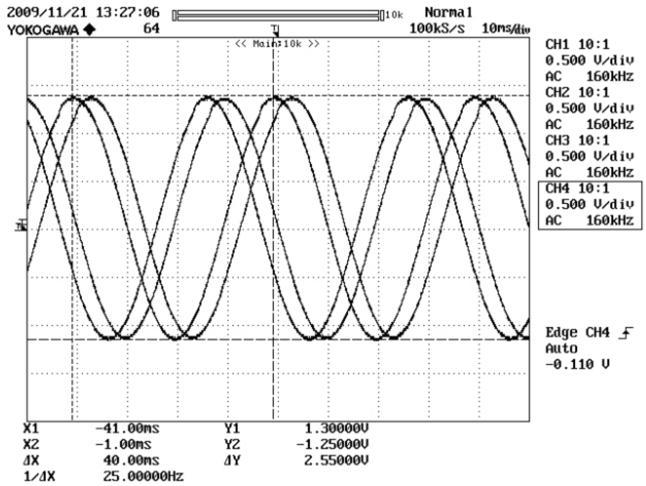

Fig. 14 (a). Filtered PWM signals.

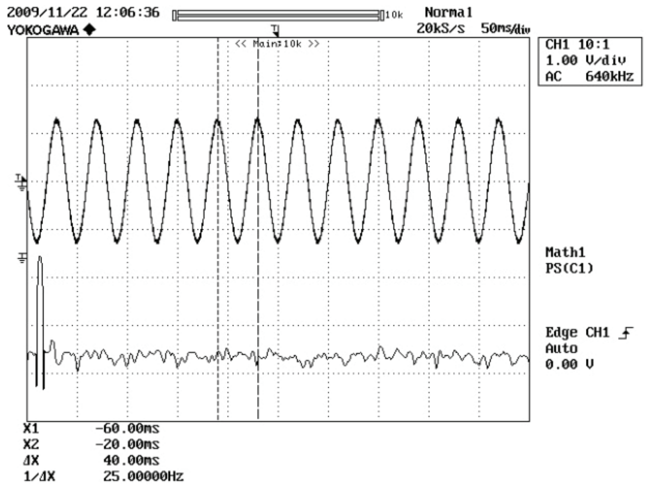

Fig. 14 (b). Harmonic spectrum of phase 'a' voltage.

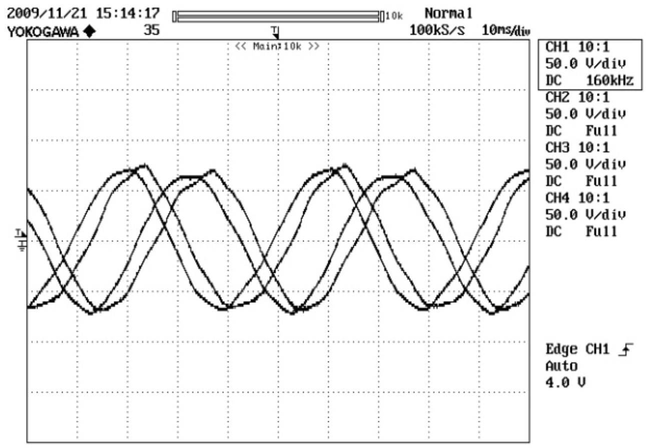

Fig. 15 (a). Output of the PWM inverter.

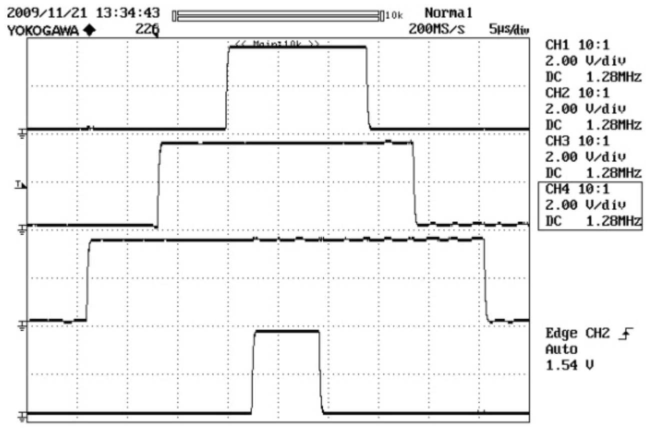

Fig. 15 (b). Switching waveforms for the PWM signals.

References

[1]. E. Levi, Guest editorial, *IEEE Trans. Ind. Electronics*, Vol. 55, No. 5, May 2008, pp. 1891-1892.

[2]. G. K. Singh, Multi-phase induction machine drive research-a survey, *Electric Power System Research,* 61, 2002, pp. 139-147.

[3]. M. Jones and E. Levi, A literature survey of the state-of-the-art in multi-phase in ac drives, *UPEC,* Stafford, UK, 2002, pp. 505-510.

[4]. E. Levi, R. Bojoi, F. Profumo, H. A. Toliyat and S. Williamson, Multi-phase induction motor drives-A technology status review, *IET Elect. Power Appl.* 1, No. 4, July 2007, pp. 489-516.

[5]. R. Bojoi, F. Farina, F. Profumo and Tenconi, Dual three induction machine drives control-A survey, *IEEE Tran. On Ind. Appl.*, 126, No. 4, 2006, pp. 420-429.

[6]. E. Levi, Multi-phase Machines for Variable speed applications, *IEEE Trans. Ind. Elect.*, 55, No. 5, May 2008, pp. 1893-1909.

[7]. J. S. Kim, S. K. Sul, A novel voltage modulation technique of the space vector PWM, *IPEC,* Yokohama, 1995, pp. 742-746.

[8]. K. Gopakumar, V. T. Ranganathan and S. R. Bhat, Split-phase induction machine operation from PWM voltage source inverter, *IEEE Trans. Ind. Appl.*, Vol. 29, No. 5, 1993, pp. 927-923.

[9]. Y. Zhao and T. A. Lipo, Space vector PWM control of dual three-phase induction machine using vector space decomposition, *IEEE Trans. Ind. Appl.* 31, No. 5, 1995, pp. 1100-1109.

[10].J. W. Kelly, E. G. Strangas, and J. M. Miller, Multiphase Space Vector Pulse Width Modulation, *IEEE Trans. Energy Conv*., Vol. 18, No. 2, June 2003, pp. 259 - 264.
[11].A. R. Bakshai, G. Joos and H. Jin, Space vector PWM control of a split-phase induction machine using the vector classification technique, *IEEE-APEC*, 1998, pp. 802-808.
[12].D. W. Chung, J. S. Kim and S. K. Sul, Unified voltage modulation technique for real-time three-phase power conversion, *IEEE Trans. Ind. Appl.,* Vol. 34, No. 2, 1998, pp. 374-380.
[13].L. Ching and F. Yang, Unified Voltage modulation method for dual-three-phase induction machine, in *Proc. of the 3rd International Conference on Machine Learning and Cybernetics, Shanghai*, 26-29 August 2004, pp. 672-747.
[14].K. Marouni, L. Baghli, D. Hadiouche, A. Kheloui and A. Rezzoug, A new strategy based on a 24-sector vector space decomposition for a six-phase VSI-fed dual stator induction motor, *IEEE Trans. Ind. Electronics*, Vol. 55, No. 5, May 2008, pp. 1910-1920.
[15].D. W. Chung, J. S. Kim and S. K. Kul, Unified voltage modulation technique for real-time three-phase power conversion, *IEEE Trans. Ind. Application,* 34, No. 2, March-April 1998, pp. 374-380.
[16].Radu Bojoi, Mario Lazzari, Francesco Profumo, and Alberto Tenconi, Digital Field-Oriented Control for Dual Three-Phase Induction Motor Drives, *IEEE Trans. Ind. Applications*, Vol. 39, No. 3, 2003, pp. 752-760.
[17].R. Bojoi, F. Farina, M. Lazzari, F. Profumo, A. Tenconi, Analysis of the Asymmetrical Operation of Dual Three-phase Induction Machines, *Conf. Rec. IEEE IEMDC*, 2003, pp. 429-435.
[18].R. Bojoi, F. Farina, G. Griva, F. Profumo, A. Tenconi, Direct Torque Control for Dual-Three Phase Induction Motor Drives, *IEEE Trans. Ind. Appl.,* Vol. 41, No. 6, Nov./Dec. 2005, pp. 1627- 1636.
[19].R. Bojoi, F. Farina, G. Griva, F. Profumo, A. Tenconi, E. Levi, Stationary Frame Digital Current Regulation for Dual-Three Phase Induction Motor Drives, in *Proceedings of the 35th Annual IEEE Power Electronics Specialisers Conf.* Aachen, Germany, 2004, pp. 2121- 2127.
[20].K. Gopakumar, V. T. Ranganathan, and S. R. Bhat, Split-Phase Induction Machine Operation from PWM Voltage Source Inveter, *IEEE Trans. Ind. Application.,* Vol. 29, No. 5, 1993, pp. 927-932.
[21].D. Hadiouche, L. Baghli and A. Rezzoug, Space Vector PWM Techniques for Dual-3 Phase AC Machine: Analysis, Performance Evaluation and DSP Implementation, *Conf. Rec. IEEE IAS,* 2003, pp. 48-65.
[22].R. Bojoi, E. Levi, F. Farina, A. Tenconi and F. Profumo, Dual three-phase induction motor drive with digital current control in the stationary reference frame, *IEEE Proc. Electrical. Power Appl.,* Vol. 153, No. 1, January 2006, pp. 129 -139.
[23].J. O. P. Pinto, B. K. Bose, L. E. Borges da Silva and M. P. Kazmierkowski, A Neural Network based space vector PWM controller for voltage fed inverter induction motor drive, *IEEE Trans, Ind. Appl.*, Vol. 36, No. 6, 2000, pp. 1628-1636.
[24].R. J. Kerkman, B. J. Seibel, D. M. Brod, T. M. Rowan, and D. Leggate, A simplified inverter model for on-line control and simulation, *IEEE Trans. Ind. Application*., Vol. 27, No. 3, 1991, pp. 567–573.
[25].Simon Haykin, Neural Networks, *ND Prentice Hall*, 2004.
[26].Muthuramalingam and S. Himavathi, Performance Evaluation of a Neural Network based General Purpose Space Vector Modulator, *IJECSE,* Vol. 1, No. 1, April 2007, pp. 19-26.
[27].K. Zhou and D. Wang, Relationship between space vector modulation and three phase carrier base PWM – A comprehensive analysis, *IEEE Trans, Ind. Electric*, Vol. 49, No. 1, Feb. 2002, pp. 186-196.
[28].Bakhshai, J. Espinoza, G. Joos, and H. Jin, A combined artificial neural network and DSP approach to the implementation of space vector modulation techniques, in Proceedings of the *IEEE-IAS Annual Conference,* , 1996, pp. 934-940.
[29].H. W. Van Der Brock, H. C. Skundelny and G. V. Stanke, Analysis and realization of a pulse width modulator based on voltage space vectors', *IEEE Trans Ind. Appl*., 24, Jan/Feb 1998, pp. 140-150.
[30].O. Ogasawara, H. Akagi, and Nabel, A novel PWM scheme of voltage source inverters based on space vector theory, *in Proc. of the EPE European Conference on Power Electronics and Applications*, 1989, pp. 1197-1202.
[31].S. R. Bowes and Y. S. Lai, The relationship between spaces vector modulation and regular-sampled PWM, *IEE Trans. Power Electron*, Vol. 14, Sept. 1997, pp. 670-679.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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