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Simulation Modelling on Artificial Neural Network Based Voltage Source Inverter Fed PMSM

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Abstract: In this proposed work a control of permanent magnet synchronous motor by using an artificial neural network and the motor is supplied by the voltage source inverter. The inverter gate pulses are controlled by using an artificial neural network. In the proposed system, the speed of the PMSM and the inverter output power are regulated. The system is based on the single artificial neuron which in turn minimizes complexity and computational burden requirements. The maximum power factor is obtained. The ANN based controller precisely and accurately follows command speed and also provides variable speed operation of the motor. This method of using artificial neural network reduces the output current ripples and motor torque ripples hence increases the efficiency. The performance of the proposed system and drive efficiency is verified by simulation results.

Key words: Artificial neural network (ANN), Permanent magnet synchronous motor (PMSM), Voltage source inverter, Speed control, Simulation Modelling.

I. INTRODUCTION

The permanent magnet synchronous motors are widely used in many industrial production systems and electric vehicle system due to their distinctive advantages such as compactness, high efficiency, high power density and wide constant power region. Conventionally PI (Proportional-Integral) and PID (Proportional-Integral-Derivative) speed controllers are used to attain the desired speed operation. But PI and PID controllers are very sensitive to parameter variations, thus there is a ripple in the output current [1], [2]. Researchers have used parameter-insensitive fuzzy logic controllers (FLC's) and sliding mode controllers (SMC's) to address above issues. However, FLC-based systems typically require extensive initial tuning and may impose significant computational burden. SMC's suffer the problem of chattering and methods of addressing this tend to increase the controller complexity. The Least mean square algorithm incorporated along with fuzzy inference, optimizes the weights used for combining the rules, which in turn makes the controller more efficient. The modified robust Extended Kalman Filter (EKF) rejects the outliers in real-time, thereby eliminating the need for manual intervention in tuning the parameters of the EKF [7], [11]. For a few years, ANN techniques have been applied with success in control of Active power filter and are very promising in the field. Indeed, the learning capacities of the ANNs allow an online adaptation to every changing parameter of the electrical network, e.g., nonlinear and time-varying loads. Most of these control constraints are quite still very challenging with classic control methods [9], [10]. Most recently, artificial neural network based permanent magnet synchronous motor drives have been reported. In order to make the neural network adaptation really practical and effective for real-time implementation, there are many aspects to consider. As a normal multilayer feed forward artificial neural network (FANN) deals with static problems inherently, the conventional static training algorithm known as error back propagation (BP) severely restricts its use for applications requiring real-time adaptation [8], [12]. In practical industry applications, in order to utilize digital controllers and achieve comparable performance under a lower sampling frequency, a discrete-time or quasi-SMO (QSMO) is commonly used. However, because of the saliency of an IPMSM, the magnitude of the extended electromotive force (EMF) will change with load (torque and/or speed) variations, which makes it challenging for the QSMO to estimate the extended EMF accurately [4]. However, when the torque reversal occurs, instability is observed. The position estimation error diverges quickly. This neural network controller for minimization of torque ripple in PMSM drives [6],[15]-[23].

Therefore to overcome the limitations of conventional system, this project proposes an ANN (Artificial Neural Networks) based controller for the permanent magnet synchronous motor in which it precisely and accurately follows command speed and also can provide variable speed operation. The ANN technique is used to control the speed of the PMSM. The system is simplified to a single artificial neuron (SAN) to minimize complexity and computational burden requirements. Speed error is conditionally used at each iteration to adaptively modify the SAN parameters to produce the precise command torque to minimize speed error. To ensure drive stability, further tuning is conditionally executed at each iteration by the comparison of the SAN's output command torque. And the power factor is maintained near unity. In existing

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system there are increased torque ripples and output current ripples. These limitations are overcome by the proposed technique. The actual speed of motor is measured by either optical encoders or hall effect sensors which will provide accurate information about rotor position.

II. CONVENTIONAL INVERTER CONTROL METHOD FOR HIGH POWER FACTOR

In existing system a power factor correction method using an inverter driven PMSM was presented. The system consists of a single phase diode rectifier, a small film capacitor and a three-phase voltage source inverter. The film capacitor is used to absorb the dc-link current ripple due to the pulse width modulation (PWM) switching of the inverter. It consists of a few energy storage elements and the single-phase power ripple is smoothed by the moment of inertia of the load motor. The inverter controller used in the system has following two functions; it regulates the speed of the speed of the IPM motor and it controls the source-side-current waveform to obtain high power factor of the single-phase diode rectifier. The power factor improvement is realized by the switching devices at the inverter. The diode rectifier has nonlinear characteristic. Hence, it is difficult for the inverter to regulate the input current continually. It is also necessary for the inverter controller to regulate the motor current with twice the source frequency. Here in order to obtain a unity power factor operation at the source side, a control method that regulates the inverter output power was used. This control method is that the inverter regulates d-q axis current synchronous with input voltage.

The inverter output power controller regulates the speed of the motor and it controls the source side current waveform to obtain high power factor. The speed controller used here is PI controller. For speed control, the error between the speed reference w_m^* and calculated speed w_m is the input to the PI controller, w_m is calculated by differentiating the rotor position obtained from the encoder. The output of speed PI controller corresponds to the peak value of the input power required by the system. The currents i_d and i_q obtained by coordinate conversion from the detected currents i_u and i_w respectively, are subtracted from the reference currents i_d^* and i_q^*, each current is regulated by the PI controller. The voltage references are generated by the decoupled control outputs of the PI controllers. The inverter is operated by the modulation of these voltage references and the PMSM is driven. [1]

Disadvantages of existing system are as follows, The output current has several ripples synchronized with the source voltage, Torque ripples are present in the motor output, and Motor efficiency is less.

III. PROPOSED ANN BASED CONTROL OF PMSM DRIVE

In the proposed system the artificial neural network technique is used to control the speed of the PMSM which is supplied by the voltage source inverter. To overcome existing system limitations, this project proposes an ANN based controller for the permanent magnet synchronous motor in which it precisely and accurately follows command speed and also can provide variable speed operation. The system is simplified to a single artificial neuron. Inputs to the SAN are command speed w_m^*, speed error, and change of speed error. Neuron output ranges from -1 to 1 via transfer function. The power factor is maintained near unity. The ANN based PMSM drive is seen to reach and maintain command speeds quickly and accurately during the step increase and step decrease of command speed. The AC supply is given to the diode rectifier which converts AC to DC and reduces the ripples. The output of rectifier is given to the voltage source inverter and the output is given to the permanent magnet synchronous motor. The actual speed of the motor is calculated by using optical encoder or hall effect sensor and that is given to the artificial neural network based controller which precisely and accurately follows command speed and also provides variable speed operation. The output of the controller is given to the firing circuit from which the gate signals are given to gate terminals of the switching devices in voltage source inverter.

Fig. 1. Shows the block diagram of the proposed ANN based PMSM drive. The 230V single phase AC supply is used in this system. A diode bridge is an arrangement of four diodes in a bridge circuit configuration that provides the same polarity of output for either polarity of input. The essential feature of a diode bridge is that the polarity of the output is the same regardless of the polarity at the input. Inverter is referred as a circuit that operates from a stiff dc source and generates ac output. If the input dc is a voltage source, the inverter is called a voltage source inverter (VSI). A basic three-phase inverter consists of three single-phase

A. Block Diagram Of Proposed Control Of PMSM Drive

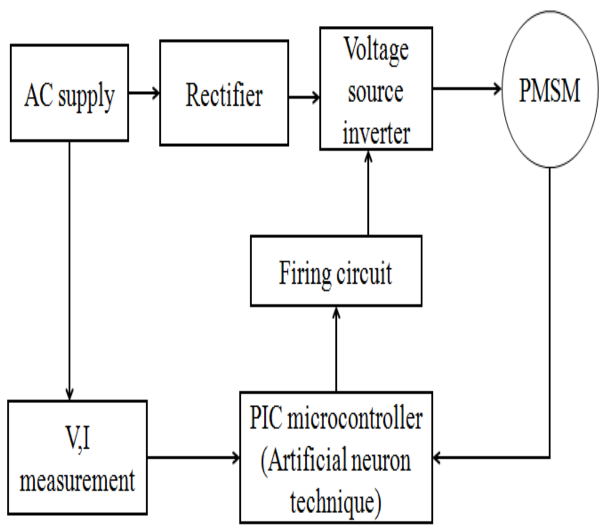

Fig. 1. Block diagram of proposed system

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inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated. The individual control signal for the switches needs to be provided across the gate and source terminals of the particular switch. The gate control signals are low voltage signals referred to the source terminal of the switch. The switches used here is MOSFET. Here the gate signals are controlled by using the ANN technique with respect to the motor. The actual speed of the rotor is determined by using hall effect sensor which gives the accurate information about the rotor position of the motor. A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications. In its simplest form, the sensor operates as an analog transducer, directly returning a voltage.

B. Permanent Magnet Synchronous Motor

The development of high-quality permanent magnet materials into commercial production has encouraged several manufacturers to launch various permanent magnet synchronous machine into the market for the various applications.

In principle, vector control is required for controlling the PMSM. The characteristics of a permanent magnet machine are highly dependent on the rotor structure. The rotor can be implemented in various ways. When employing the modern permanent magnet materials, the rotor can be constructed even completely without iron. In that case, the rotor frame is constructed for instance of aluminium, onto which the shaped permanent magnets are glued so that the sinusoidal flux density distribution is achieved in the air gap of the machine. An ironless rotor structure wastes permanent magnet material, since the magnetic circuit closes through air in the rotor side. Therefore, a thin steel rim, to which the magnets are attached, is employed. The rim can be either a laminated structure, in which case the eddy current losses of the rotor remain very low, or a thin steel tube; however, in this case, there is a danger that the rotor warms up excessively due to the effect of the time harmonics of the stator.

The configuration is applied for instance to servo motors, of which a minimum inertia is required. The direct and quadrature inductance of the machine are in this case approximately equal, and the machine is thus a non-salient pole construction.

The adjustment of the machine inductances at a desired level can, if necessary, be implemented by iron parts; it is possible to mount pole shoes on the magnets, and thus to achieve the sinusoidal air gap flux density. When employing pole shoes, the magnets are well protected against both electric and magnetic stresses. In the assembly phase in particular, the pole shoes are very useful, as they protect the magnets from mechanical damages. Classification based on rotor construction as follows: *Interior-Magnet*-The interior-magnet rotor has radially magnetized and alternately poled magnets. Because the magnet pole area is smaller than the pole area at the rotor surface, the air gap flux density on open circuit is less than the flux density in the magnet. The magnet is very well protected against centrifugal forces. Such a design is recommended for high frequency high speed motors. *Surface-Magnet Rotor*-The surface magnet motor can have magnets magnetized radially or sometimes circumferentially. An external high conductivity non ferromagnetic cylinder is sometimes used. It protects the PMs against the demagnetizing action of armature reaction and centrifugal forces, provides an asynchronous starting torque, and acts as a damper.

Voltage equation is,

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_b & L_{cb} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

Voltage equation in dq reference frame,

$$v_d = Ri_d + p\lambda_d - \omega_r \lambda_q \quad (2)$$

$$\lambda_q = L_q \quad (3)$$

$$v_q = Ri_q + p\lambda_q - \omega_r \lambda_d \quad (4)$$

$$\lambda_d = L_d i_d \quad (5)$$

Torque equation is,

$$T_e = \frac{3P[\lambda_{af} i_q + (L_d - L_q) i_d i_q]}{2} \quad (6)$$

The equation (1) describes the simplified voltage equation of the permanent magnet synchronous motor. It is derived from the basic voltage equation of the motor. The voltage equation can also be written in the dq reference frame as mentioned by the equation (2) and (4). This equations are useful in the calculation of efficiency of the motor. And the equations (3) and (5) defines the expression of the flux linkages. General characteristics of PMSM are, Compact, High efficiency (no excitation current), Smooth torque, Low acoustic noise, Fast dynamic response (both torque and speed). [13]

C. Proposed Circuit

As shown in fig. 2. a single phase AC supply is given to the diode rectifier which converts alternating current to direct current and reduces ripples. Then output of the rectifier is given to the three phase voltage source inverter, the motor is connected to the inverter. The artificial neural network based controller is used to control the gate signals of the switching devices. The controller output is given to the driving circuit from that the output signals are given to

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the gate terminals of the switching devices. A rectifier is a

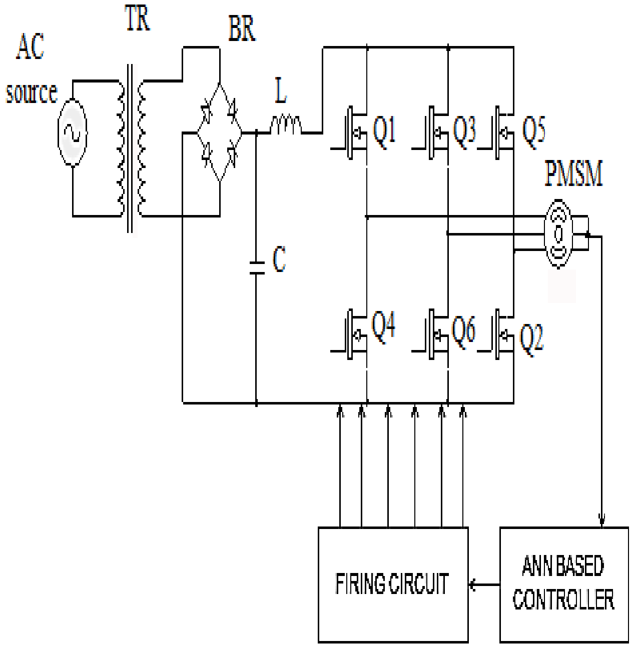

Fig. 2. Circuit diagram of proposed ANN based control of PMSM drive.

converts alternating current, which periodically reverses direction, to direct current, which flows in only one direction. The process is known as rectification.

Then through capacitor and inductor, rectifier is connected to the voltage source inverter and this ensures the maximum power factor in the inverter side. An inverter is an electrical device that converts direct current to alternating current; the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. The output of the inverter is given to the permanent magnet synchronous motor. The voltage source inverter consists of six switches which is MOSFET in this system. A power MOSFET is a type of metal oxide semiconductor field-effect transistor (MOSFET) designed to handle significant power levels. Compared to the other power semiconductor devices, for example insulated-gate bipolar transistor (IGBT), Thyristor, its main advantages are high commutation speed and good efficiency at low voltages. The power MOSFET is the most widely used low-voltage (that is, less than 200 V) switch. It can be found in most power supplies, DC to DC converters, and low voltage motor controllers. From fig. 3. 'E_{dc}' is the input dc supply and a large dc link capacitor (C_{dc}) is put across the supply terminals. Capacitors and switches are connected to dc bus using short leads to minimize the stray inductance between the capacitor and the inverter switches. Needless to say that physical layout of positive and negative bus lines is also important to limit stray inductances. Q_1, Q_2, Q_3 etc. are fast and controllable switches. D_1, D_2, D_3 etc. electrical device that are fast recovery diodes connected in anti-parallel with the switches.

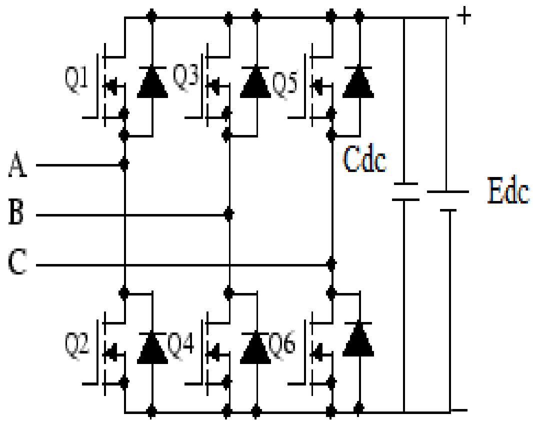

Fig. 3. Three phase voltage source inverter.

'A', 'B' and 'C' are output terminals of the inverter that get connected to the ac load. Inverter, as in fig 3.3 need to be provided with isolated gate drive signals. The individual control signal for the switches needs to be provided across the gate and source terminals of the particular switch. The A, B, C terminals are connected to the motor. Here the control signals are given by the ANN based controller. The actual speed of the motor and reference speed is given to the controller then the controller produces the output by comparing both. The controller is based on the ANN technique to reach and maintain command speeds quickly and accurately during the step increase and step decrease of command speed. The system uses a single artificial neuron and speed error is conditionally used at each iteration to adaptively modify the SAN parameters to produce the precise command torque to minimize speed error. By using the output of ANN the gate pulses are produced by using the firing circuit. And firing circuit output is connected to the gate terminals of MOSFET's in the inverter circuit.

IV. ARTIFICIAL NEURAL NETWORK TECHNIQUE

In this system the artificial neural network based controller is used from which the gate pulses are given to the switches of voltage source inverter. Artificial neural network (ANN) is a machine learning approach that models human brain and

consists of a number of artificial neurons. Neurons in ANNs tend to have fewer connections than biological neurons. Each neuron in ANN receives a number of inputs. An activation function is applied to these inputs which results in activation level of neuron (output value of the neuron). The artificial neuron is electronically modeled biological neuron. It has many inputs and one output. There are 2 modes -training mode & using mode. Training mode - neuron is trained to fire (or not), for particular input patterns. Using mode - when a taught input pattern is

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detected at input, its associated output becomes current output. In this proposed work training mode is used.

A. Layers Of Artificial Neural Network

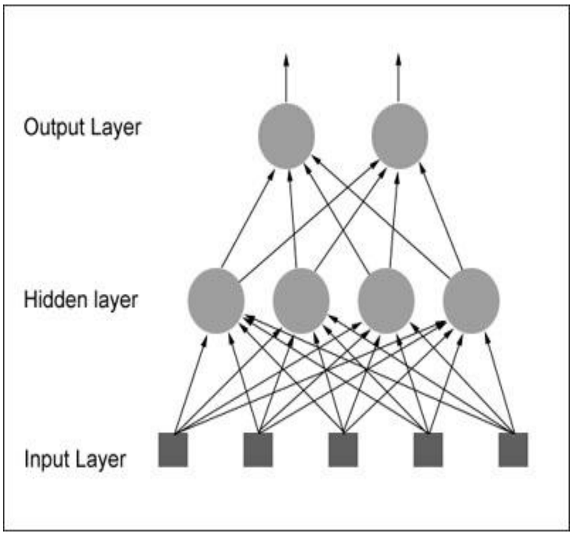

Fig. 4. Layers of artificial neural network

The back propagation algorithm is used in layered feed-forward ANNs. This means that the artificial neurons are organized in layers, and send their signals "forward", and then the errors are propagated backwards. The network receives inputs by neurons in the *input layer*, and the output of the network is given by the neurons on an *output layer*. There may be one or more intermediate *hidden layers*.

Input Layer - activity of input units represents raw information that is fed into the network.

Hidden Layer - activity of each hidden unit is determined by activities of input units and weights on connections between input and hidden units.

Output Layer - behavior of the output units depends on the activity of the hidden units and the weights between the hidden and output units.

The ANN technique has following advantages: Knowledge acquisition under noise and uncertainty, Flexible knowledge representation, Efficient knowledge processing, Fault Tolerance, and they have learning capability. An artificial neuron is a computational model inspired in the natural neurons. ANNs combine artificial neurons in order to process information. The higher a weight of an artificial neuron is, the stronger the input which is multiplied by it will be. [6]

Depending on the weights, the computation of the neuron will be different from Eq. (7). By adjusting the weights of an artificial neuron we can obtain the output we want for specific inputs. But when we have an ANN of hundreds or thousands of neurons, it would be quite complicated to find by hand all the necessary weights. But we can find algorithms which can adjust the weights of the ANN in order to obtain the desired output from the network. This process of adjusting the weights is called *learning* or *training*.

B. Single Artificial Neuron

In this proposed system single artificial neuron is used which provides precise and accurate speed control of motor.

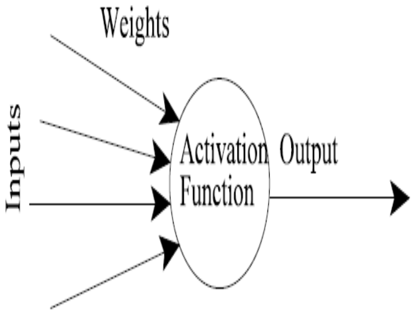

Fig. 6. An artificial neuron

The artificial neuron is the basic information processing unit of a ANN. It consists of:

1. A set of links, describing the neuron inputs, with weights $W_1, W_2, \ldots, W_m$.

2. An adder function (linear combiner) for computing the weighted sum of the inputs:

$$u = \sum_{j=0}^{m} W_j X_j \qquad (7)$$

3. Activation function φ for limiting the amplitude of the neuron output. Here 'b' denotes bias.

$$y = \varphi(u + b) \qquad (8)$$

The bias ***b*** has the effect of applying a transformation to the weighted sum *u*,

$$v = u + b \qquad (9)$$

The bias is an external parameter of the neuron. It can be modeled by adding an extra input.

v is called induced field of the neuron ,

$$v = \sum_{j=0}^{m} W_j X_j \qquad (10)$$

$$w_0 = b \qquad (11)$$

The activation function of the artificial neurons in ANNs implementing the back propagation algorithm is a weighted sum as per the Eq. (8). Hence the ANN based PMSM drive is seen to reach and maintain command speeds quickly and accurately during the step increase and step decrease of command speed.

V. SIMULATION AND RESULTS

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The proposed ANN based controller has been applied to the speed control of permanent magnet synchronous motor by a voltage source inverter and verified with the conventional schemes. An ideal scenario is simulated with results confirming the correctness of the design. All simulations were performed using the Matlab Simulink toolbox 2011. Fig. 6. Shows the Matlab Simulink model of the proposed speed control scheme for the permanent magnet synchronous motor based on the artificial neural network.

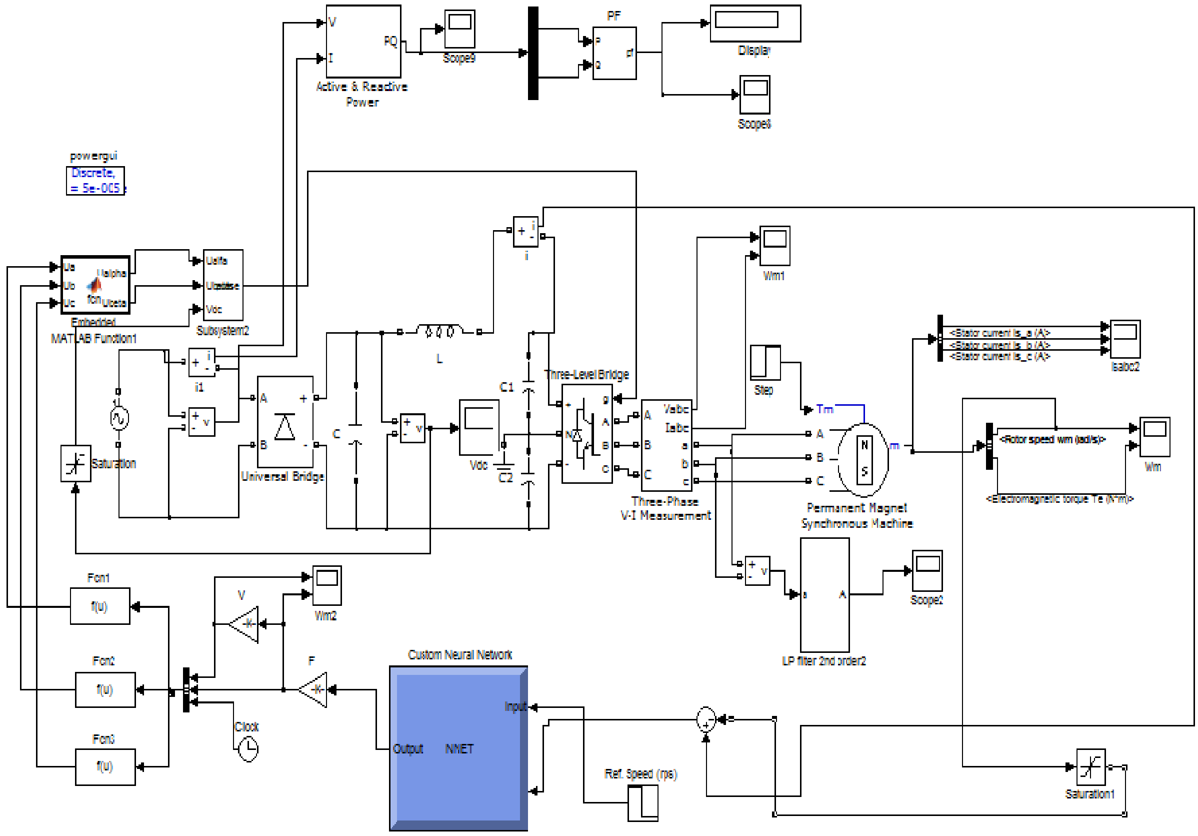

Fig. 6. Simulation circuit diagram

The Matlab diagram shows that a 230V supply is given to the three phase inverter and before that it is rectified by using the bridge rectifier. The power factor is maximized by the circuit consists of inductor, capacitor, and one switch i.e., MOSFET. Fig. 7. Shows the waveform of the input voltage and current which is given to the motor. The voltage rating is about 200V and the current rating is about 5A. The voltage and current of less ripple and with improved power factor is given to the motor. And the motor operates with certain speed. Fig. 8. Shows the waveform of stator current of the motor for each phase. It shows the less ripple content in the each phase of the current i.e., i_a, i_b, i_c. These output current from the motor are about ±5A. about 200V and the current rating is about 5A. The voltage and current of less ripple and with improved power factor is given to the motor. And the motor operates with certain speed. Fig. 8. Shows the waveform of stator current of the motor for each phase. It shows the less ripple content in the each phase of the current i.e., i_a, i_b, i_c. These output current from the motor are about ±5A.

Fig. 9. Shows the motor speed and electromagnetic torque which is the output of motor, after the control of motor using ANN technique. Here the reference speed used is about 100rpm and the torque output from motor is lie between the +5 Nm and -5 Nm. However, his behavior at low speed is only slightly better than that of the conventional observer with a PI controller. The suggested technique is suitable for real time implementation due to its simplicity, but also mainly for its different way of designing the adaptive mechanism and its ease of tuning.

A. Resultant Waveform

Motor Input Voltage and Current

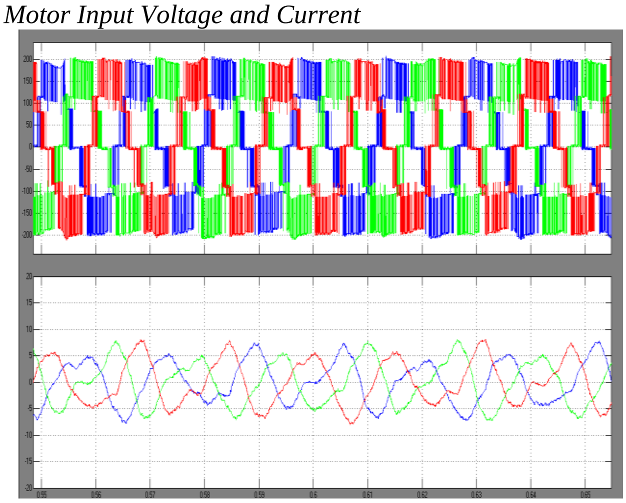

Fig. 7. Waveform of input voltage and current

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Output Current

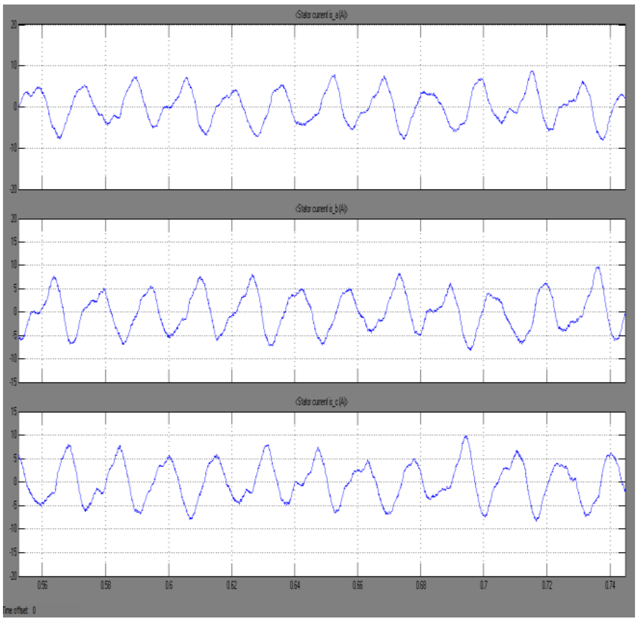

Fig. 8. Waveform of output current

Motor Speed and Torque

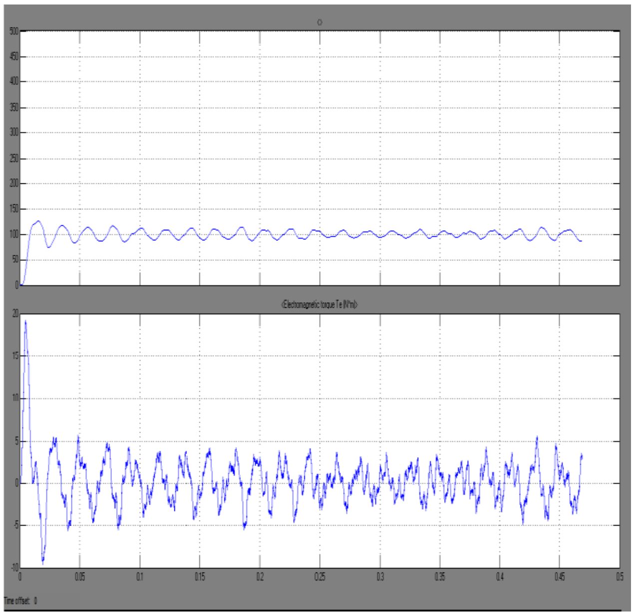

Fig. 9. Waveform of motor speed and torque

VI. CONCLUSION

An effective control technique is presented for the speed control of three phase PMSM drive. In this proposed work the artificial neural network based controller is used to regulate the speed of PMSM and also to reduce the torque ripples. The system uses single artificial neuron. Inputs to the SAN are command speed, speed error, and change of speed error and it produces the single output from that the gate pulses are produced. The simulation result of both conventional and proposed technique was carried out for three phase PMSM drive among both of them proposed technique is more robust than the PI and fuzzy logic controller when load disturbances occurred. The simulation result shows the low torque ripple, good speed regulator and high efficiency with proposed ANN controller than the conventional.

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REFERENCES

[1] Kazuya Inazuma, Hiroaki Utsugi, Kiyoshi Ohishi, and Hitoshi Haga. "High-power-factor single-phase diode rectifier driven by repetitively controlled IPM motor," *IEEE Trans, Ind, Electron.*, vol.60, no.10, pp.4427-4437. Oct, 2013.

[2] H.B.Shin and J.G.Park. "Anti-windup PID controller with integral state predictor for variable-speed motor drives," *IEEE Trans, Ind, Electron.*, vol.59, no.3, pp. 1509-1516. Mar,2012.

[3] K.Inazuma, K.Ohishi, and H.Haga, "High-power factor control for inverter output power of IPM motor driven by inverter system without electrolytic capacitor," in Proc. *IEEE ISIE*, 2011, pp. 619-624.

[4] Yue Zhao, Wei Qiao and Long Wu, "An adaptive Quasi-Sliding-Mode rotor position observer-based sensorless control for interior permanent magnet synchronous machines," *IEEE Trans, Power Electron.*, vol.28, no.12, Dec. 2013.

[5] Y.C.Li and C.L.Chen, "A novel single-stage high power-factor ac to dc LED driving circuit with leakage inductance energy recycling," *IEEE Trans, Ind, Electron.*, vol.59, no.2, pp.793-802. Feb, 2012.

[6] Mahmoud M. Saafan, Amira Y. Haikal, Sabry F. Saraya, Fayez F.G. Areed, "Artificial Neural Network Control of Permanent Magnet Synchronous Motor," *International Journal of Computer Applications*, Volume 37– No.5, January 2012.

[7] Dr.T.Govindaraj, and R.Venkatesh Kumar, "AFLC Based Speed Control of PMSM Drive," *International Journal Of Advanced and Innovative Research.*ISSN: 2278-7844, *pp* 433-439, Dec-2012.

[8] Sibel Partal, Ibrahim Senol, Ahmet Faruk Bakan, "Online speed control of a brushless AC servomotor based on artificial neural networks," Turk Journel of Elec Eng & Comp Sci, Vol.19, No.3, 2011.

[9] Flah Aymen, Ben Hamed Mouna, Farhat Mayssa, and Sbita lassâd, "A Robust PMSM Speed Control using an Artificial and a Recurrent Neural Network," *International Journal of Research and Reviews in Computer Science (IJRRCS)* Vol. 2, No. 4, August 2011.

[10] D. Ould Abdeslam, P. Wira, J. Mercklé, D. Flieller, and Y. A. Chapuis, "A unified artificial neural network architecture for active power filters," *IEEE Trans. Ind. Electron.*, vol. 54, no. 1, pp. 61–76, Feb. 2007.

[11] C. B. Butt, M. A. Hoque, and M. A. Rahman, "Simplified fuzzy logic based MTPA speed control of IPMSM drive," *IEEE Trans. Ind. Appl.*, vol. 40, no. 6, pp. 1529–1535, Nov./Dec. 2004.

[12] Y. Yi, D. M. Vilathgamuwa, and M. A. Rahman, "Implementation of an artificial-neural-network-based real-time adaptive controller for an interior permanent-magnet motor drive," *IEEE Trans. Ind. Appl.*, vol. 39, no. 1, pp. 96–104, Jan./Feb. 2003.

[13] R.Krishnan, "Electric Motor Drives Modeling, Analysis, and Control", *Pearson Education Edition*, 2004.

[14] Li Min Fu, "Neural Networks In Computer Intelligence", *McGraw-Hill Publication*, Edition, 1994.

[15] Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli,"Design, Development and Control of an Axial Flux Permanent Magnet Linear Oscillating Motor using FE Magnetic Analysis Simulation Models," Int. Journal of Electrical and Electronics Engineering, Oradea, Romania, October 2010

[16] Dr.T.Govindaraj, and A.Sasipriya, "Solar Inverter Fed Special Electric Drive, " International Journal Of Advanced and Innovative Research,Dec-2012 ,pp 511-517.

[17] Dr.T.Govindaraj, and M.Jagadeesh, "Resonant Converter Fed PMDC Drive Using Soft Switching Techniques," International Journal of Advanced and Innovative Research ISSN: 2278-7844, Dec-2012, pp 535-541.

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INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 1, January 2014

[18] T.Govindaraj, Rasila R,"Development of Fuzzy Logic Controller for DC – DC Buck Converters", International Journal of Engineering Techsci Vol 2(2), 192-198, 2010

[19]Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli," Design, Development and Finite Element Magnetic Analysis of an Axial Flux PMLOM," *International Journal of Engineering and Technology,* Vol.2 (2), 169-175 , 2010

[20]Govindaraj Thangavel, Ashoke K. Ganguli and Debashis Chatterjee,"Dynamic modeling of direct drive axial flux PMLOM using FEM analysis" International journal of Elixir Electrical Engineering Vol.45 pp 8018- 8022, April 2012

[21 G. Thangavel and A. K. Ganguli,"Dynamic Modeling of Directive Drive Axial Flux PM Linear Oscillatory Machine Prototype Using FE Magnetic Analysis", Iranian Journal of Electrical and Computer Engineering, Vol. 10, No. 2, Summer-Fall 2011

[22] Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli,"FEA based Axial Flux permanent Magnet Linear Oscillating Motor," International Journal THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI F ASCICLE III, ELECTROTECHNICS, ELECTRONICS, AUTOMATIC CONTROL, INFORMATICS , July 2010

[23] Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli, "FEA Simulation Models based Development and Control of An Axial Flux PMLOM,"International Journal of Modelling and Simulation of Systems, Vol.1, Iss.1, pp.74-80, 2010

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