SPEED CONTROL OF FOUR QUADRANT PMDC MOTOR DRIVE USING PI BASED ANN CONTROLLER

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Abstract – In recent years the availability of petroleum resources have decreased, which has paved the way for Hybrid Electric Vehicles (HEVs). The propulsion technology used in these vehicles are more eco-friendly and reduces the consumption of petroleum resources to a large extent compared to conventional automobiles. Both ac and dc motor drives are used in this field. Due to its high reliability, flexibility, simplicity and economical cost dc drives are widely used in the field of HEV’s. In order to achieve better drive range and improved performance of the motor, control techniques are necessary for dc to dc power converters in electric cars. The main problems faced during the driving operation are fluctuations in input battery voltage, load variations which decreases the performance of the drive. So it is necessary to maintain a constant output voltage of dc to dc converters irrespective of these variations for better performance. Therefore proper controlling techniques should be provided. This paper mainly focuses on the speed control of four quadrant PMDC motor using PI based Artificial Neural Network (ANN) controller.

Keywords- PMDC Motor, Hybrid Electric Vehicles, PI, ANN

I. INTRODUCTION

High performance motor drives have become the back bone of the industrial as well as in the field of other applications such as automobiles, electric trains, robotics, steel rolling mills etc. An effective high performance motor drive system should exhibit properties like dynamic speed command tracking and load regulation response. Both AC and DC motor drives are used for speed controlling and position control of motors in various fields [1]. DC. Due to its high reliability, flexibility, simplicity and economical cost DC drives are widely used for industrial and various applications, where speed and position control of motor are required. DC motor drives provide speed-torque characteristics superior to that of AC motor drives and provide excellent control of speed in case of both acceleration and deceleration.

DC motor drives are widely used in the field of Electric Vehicles. With the fast decline of available petroleum resources there arouse a need to design alternate propulsion technology for automobiles which leads to the development of “Hybrid Electric Vehicle”. It is more eco-friendly and reduces the amount of air pollution to a greater extent. An electric vehicle consists of electrical storage system (battery packs) connected to high voltage dc bus via dc to dc converters. The motor is then interfaced with the dc voltage bus using appropriate motor drives depending upon the type of motor used [2]. The main problems faced during the driving operation are fluctuations in input battery voltage, load variations which decreases the performance of the drive. So it is necessary to maintain a constant output voltage of dc to dc converters.

This problem can be solved by providing suitable control techniques to motor, so that it gives the desired performance. The various types of controllers used for this purpose are proportional integral (PI), proportional integral derivative (PID), fuzzy logic controller (FLC), fuzzy PID, artificial neural network (ANN). Among this PID controllers are widely used due to its simplicity and ease of application. The main problem in using conventional controllers (PI, PD, and PID) is that their performance gets affected by the non-linear characteristics of DC motor [2]. This paper utilizes
a PI based ANN controller for the speed control of four quadrant PMDC motor drive for Hybrid Electric Vehicle applications.

II. PMDC MOTOR

The basic configuration of a PMDC motor is similar to that of a normal DC motor. The working principle is also same as that of DC motor i.e. whenever a current carrying conductor is placed in a magnetic field it experiences a mechanical force. Therefore a strong magnetic field is an essential part for the working of DC motor which is established by using a magnet. The magnet may be either electromagnet or permanent magnet. If the magnetic field is produced by means of permanent magnet then it is referred to as “Permanent magnet DC Motor”. As the strength of the magnetic field produced by permanent magnet is fixed it cannot be varied. So speed controlling of such motors by varying the flux (flux control) is not possible.

III. FOUR QUADRANT OPERATION

Figure 1 shows the four quadrant operation of PMDC motor. This mode facilitates motor to reverse the polarity of the brushes [3], [4]. The motor could spin either in the direction of the applied torque or in the opposite direction.

Quadrant 1 represents forward motoring operation i.e. power is supplied to the motor to accelerate it. Both the speed and torque are in clock wise direction. In quadrant 2, speed is CW and torque is in CCW. Here the torque is reversed to apply brakes to slow down the motor. The motor is in reverse regenerating mode and power generated is fed back to battery in order to charge it. Quadrant 3 represents reverse motoring operation where both speed and torque are in CCW direction. Quadrant 4 gives forward regeneration operation. Here torque is CW and speed is CCW.

IV. PI CONTROLLER

Proportional Integral (PI) controller is commonly used in a system to eliminate the steady state error resulting from P controller. But it has a negative impact on the speed of the response and overall stability of the system. This controller is mostly used in areas where speed of the system is not an issue. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations [4]. The basic block diagram of the P-I controller is shown in the figure 2 below.

Fig 1. Four quadrant mode operation of dc motor

Quadrant 1 represents forward motoring operation i.e. power is supplied to the motor to accelerate it. Both the speed and torque are in clock wise direction. In quadrant 2, speed is CW and torque is in CCW. Here the torque is reversed to apply brakes to slow down the motor. The motor is in reverse regenerating mode and power generated is fed back to battery in order to charge it. Quadrant 3 represents reverse motoring operation where both speed and torque are in CCW direction. Quadrant 4 gives forward regeneration operation. Here torque is CW and speed is CCW.

Fig 2. Block diagram of PI controller
PI controller consists of two basic coefficients; proportional coefficient ($K_P$) and integral coefficient ($K_I$). The values of these coefficients are varied or tuned to get optimal response as shown in fig 9.1. The ideal version of PI controller is expressed by,

$$u(t) = K_P e(t) + K_I \int e(t)$$

The PI controller fuses the properties of P and I controllers. It shows a maximum overshoot and settling time similar to the P controller but no steady-state error.

V. ARTIFICIAL NEURAL NETWORK

Human body has a highly interconnected set of neurons which facilitates and controls the various actions such as motion, thinking, reading, writing, eating etc. Scientists have only just begun to understand how biological neural networks operate. It is generally understood that all biological neural functions, including memory, are stored in the neurons and in the connections between them. They also conducted extensive study on establishing new connections between neurons or the modification of existing connections. This leads to the development of Artificial Neural Network (ANN). In ANN, the neurons that we consider here are not biological. They are extremely simple abstractions of biological neurons, realized as elements in a program [5]. Networks of these artificial neurons do not have a fraction of the power of the human brain, but they can be trained in a particular manner to perform useful functions.

An artificial neural network is composed of many artificial neurons that are linked together according to specific network architecture. The objective of the neural network is to transform the inputs into meaningful outputs. ANN consists of single or multiple layers of neurons depending upon the level of training to be provided. A layer whose output is the network output is called an output layer. The other layers are called hidden layers. The number of hidden layers increases depending on the complexity of training of neurons [5].

VI. SINGLE INPUT NEURON

A single-input neuron is shown in Figure 3. The scalar input $P$ is multiplied by the scalar weight $w$ to form $Pw$, and it is given as one of the input to the summer. The other input $1$ is multiplied by a bias $b$ and then passed to the summer. The summer output is often referred to as the net input, goes into a transfer function, which produces the scalar neuron output $T$.

$$T = f(Pw + b)$$
This simple model can be related to the biological neuron. The weight (w) corresponds to the strength of a synapse, the cell body is represented by the summation and the transfer function, and the neuron output T represents the signal on the axon [6]. The bias is similar to a weight, except that it has a constant input of 1. The parameters w and b are adjustable scalar parameters of the neuron. The transfer function f will be either a linear or a nonlinear function of net output n. A particular transfer function is chosen such that it satisfies some specification of the problem that the neuron is trying to solve.

**VII. MODELING OF FOUR QUADRANT PMDC MOTOR**

Figure 4 shows the Mat Lab modeling of four quadrant PMDC motor drive. Four IGBT switches are provided for the control of motor drive which is marked as D1, D2, D3 and D4. Each IGBT switch is provided with pulses to activate it at appropriate times. In the input side a nickel-metal-hydride type battery of nominal voltage 220 V is used. The motor and battery control parameters are shown in the table 1 below:

![Fig 4. Modeling of 4-quadrant PMDC motor in MATLAB Simulink](image)

Table 1. Parameters used for simulation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery nominal voltage</td>
<td>220 V</td>
</tr>
<tr>
<td>Battery rated capacity</td>
<td>16 Ah</td>
</tr>
<tr>
<td>$C_L$</td>
<td>470 $\mu$F</td>
</tr>
<tr>
<td>Armature Inductance ($L_a$)</td>
<td>28 mH</td>
</tr>
<tr>
<td>Armature Resistance ($R_a$)</td>
<td>1.4 $\Omega$</td>
</tr>
<tr>
<td>Moment of inertia (J)</td>
<td>0.002953 N.m.s</td>
</tr>
<tr>
<td>Viscous friction co-efficient ($B_m$)</td>
<td>0.05215 Kgm$^2$</td>
</tr>
<tr>
<td>Torque constant ($K_t$)</td>
<td>0.5 Nm/ A</td>
</tr>
</tbody>
</table>

**VIII. PI BASED ANN CONTROLLER**

![Fig 5. PI based ANN controller](image)
The Mat Lab simulation of PI based ANN controller is shown in figure 5. At first the actual speed of the motor (ω_m) and the reference speed (ω_ref) are sensed and are fed as inputs to the PI controller which is actually a speed discrete controller. The controller produces a speed error signal and converts it into current signal corresponding to the speed error. The output signal of the controller is termed as reference armature current signal. This discrete signal is given as the input to the neural network for training the neurons. The trained output of the neural network and the actual armature current is compared. The gate pulse for each IGBT is obtained by using PWM technique using a high frequency signal.

![Fig 6. Neural network](image)

Figure 6 shows the neural network used in this work. It is actually a feed forward layer which consists of one hidden layer and one output layer. Each layer consists of single neuron. The output of the PI controller is fed as input to the network. The inputs are discrete current values. A large number of inputs are given to the network for training. In order to show how to train the inputs, a certain number of input samples (p) and the corresponding target output (t) are shown below:

\[ p = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13\} \]
\[ t = \{0, 1.1, 2.2, 3.3, 4.4, 5.5, 6.6, 7.7, 8.8, 9.9, 11, 12.1, 13.2, 14.3\} \]

The weight w is chosen as 1.1 and bias b is taken as zero in this case (both are adjustable parameters). In the hidden layer, log sigmoid function is used to evaluate the network output and in the output layer pure linear function is used. The network is trained using back propagation algorithm.

**IX. TRAINING OF NEURAL NETWORK**

Before training the network, the inputs (p) and the corresponding targets (t) should be selected. Here both input and target consists of 13 samples. These 13 samples are then divided into three subsets i.e. training, validation and testing. Out of 13 samples, 9 samples for training and 2 sample each for validation and testing. The samples under training subset are provided to the network during training of neural network. The samples under validation are used to measure the network generalization and to stop the training when generalization improves [5], [6]. The sample that comes under testing has no effect on training and is an independent measure of network performance after training. After training the network the performance of training is analyzed by using regression plot. The regression plot obtained in this training is shown in the figure 7. In each case the value of R (correlation coefficient) is 1 which implies training is successful [6].

![Fig 7. Regression plot](image)
X. SIMULATION RESULTS

The four quadrant PMDC motor drive and the PI based ANN controller part are simulated using MATLAB / SIMULINK software. The reference speed of the motor is set at -110 rpm during reverse and +110 rpm during the forward operation. Initially speed rises from zero in the negative side showing reverse motoring operation. Then it catches up with the reference speed. After sometime the speed gets reduced to zero showing the reverse braking operation. Then the speed increases in the positive direction from zero to +110 showing the forward motoring operation and catches the reference speed. Then after sometime again the speed gets reduced from 110 to zero showing forward braking operation and this series of actions get repeated. The current and torque waveforms follows the same pattern. The results obtained are shown below:

![Fig 8. Speed vs. time](image1)

![Fig 9. Current vs. time](image2)

![Fig 10. Torque vs. time](image3)

XI. CONCLUSION

This paper focussed on the speed control of four quadrant PMDC motor drive using PI based ANN controller. The conventional controllers (P, PI, PD, PID) are usually used for spee control purposes in dc drives. But the main disadvantage is that their performance gets affected due to the non-linear characteristics of dc motor. Also they give high overshoot and settling time. In this paper intellig speed control of PMDC motor drive is done using PI based ANN controller. The results obtained implies that the performance of the drive has improved far better compared to results of
conventional controllers. It has lowered the peak overshoot and rise time and settling time of the speed response curve has improved.

REFERENCES


