Modeling and implementation of brain emotional controller for Permanent Magnet Synchronous motor drive

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ABSTRACT

This paper presents a bio-inspired emotion based intelligent controller for Permanent Magnet Synchronous Machine (PMSM) drive. There are certain parts in mammal brain are responsible to generate emotions, which can be used as controller, namely brain emotional controller. The evolutionary development of brain emotional control technique is used in many applications to control nonlinearities in the system. The performance of emotional controller is analyzed by considering control of speed and stator currents harmonics of PMSM drive at different operating conditions. The performance of the controller is compared with existing controllers in offline simulations and in real-time Hardware-in-loop (HIL) simulations using OPAL-RT simulator.

1. Introduction

The control theory concepts have been applied for variety of problems namely modeling, analysis and design of controllers for a dynamical system (Bellman and Kalaba, 1965; Zhou et al., 1996; William; Denaï et al., 2007; Yadaiah and Ravi, 2011). There is significant development of control theory is available in literature, as many researchers introduced different controllers to reduce complexities of dynamical systems, one of the typical system is electrical drive. The controllers introduced with biological inspiration models shows better performance for nonlinear problems comparatively existing controllers. The controllers developed should be precise, cost effective and give superior performance compared to existing controllers. In this paper, Permanent Magnet Synchronous Machine (PMSM) is taken as dynamical model, the non-linear problems arises in PMSM motor due to variations in stator winding currents, rotor speed and in electromagnetic torque production. The PMSM drive needs a precise speed controller for modified Vector control technique, which not only controls the speed quick and accurately but also control harmonics stator windings currents and ripples produced in electromagnetic torque. In order to solve the problems of PMSM drive traditionally P, PI and PID controllers (Al Gizi et al., 2014; Rajasekhar et al., 2014; Basilio and Matos, 2002; Krajewski et al., 2004) are widely applied in industrial applications due to simplicity and functionality. The design procedure of classical controllers include exact mathematical model and contain fixed values of gain which make them not to achieve actual

response and short fall at referred response, as the PMSM machine is sensitive to parameter variations, change in speed and sudden load variations. It gives sluggish response due to variations but the drive needs a controller which reacts fast, accurate and reliable in all operation conditions. The limitations classical controllers can overcome by introducing intelligent controllers to drive such as Fuzzy Logic controllers, Neural networks, ANFIS, Genetic algorithm, Particle Swarm Optimization techniques etc., The Fuzzy logic controller is rule based one (Mishra et al., 2012; Rezaei Sadrabadi and Hossein Fazel Zarandi, 2011) and requires complete information about the system and due to lack online adaptability make controllers performance limited and even with introduction of online adaptability to Fuzzy logic controller (Liang and Mendel, 2000; Barkat et al., 2011) requires large set of data parameters for training which increases complexity in computation. The Neural networks based controllers may overcome these problems, the fixed learning rate in training algorithm of neural networks converges speed of controller and fall in local minima. The hybrid structure ANFIS, Fuzzy tuned PID, ANN tuned PID etc., are also used to limit problems. These controllers require large set of training data for weight updating (Tsoukalas and Uhrig, 1997; El-Sousy, 2014; Ding and Liang, 2008; Yu and Li, 2004). The evolutionary algorithms are applied to solve nonlinearities, these methods performance is satisfactory for the applications for where certain solution is not found and for design procedure need complete information of the system (Liu et al., 2008; Iwasaki et al., 2004). The solution of the problem changes every time and it converge to local minima or maxima.

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Nomenclature

		P	No. of Pole pairs of motor;
		Ψ_f	Rotor magnetic flux linking the stator;
V_d, V_q	Stator Voltages;	T_L	Load Torque;
I_d, I_q	Stator Currents;	T_e	Electromagnetic Torque;
ω_r	Rotor speed in angular frequency;	B_m	Friction coefficient of motor;
R_d, R_q	Stator resistance per phase;	J_m	Moment of inertia of the motor and load;
L_d, L_q	d-axis and q-axis inductance;		

In this paper, to overcome the limitations of existing controllers, the brain emotional controller is introduced to control the PMSM drive. The brain emotional controller is introduced by Caro Lucas to solve complex nonlinear problems (Lucas et al., 2004). The design of controller includes certain parts of Limbic system of mammalian brain so it is called as center of emotions. The brain emotional controller is used in many industrial applications such as washing machines, cranes and air conditioners. The brain emotional controller is introduced in power system applications by Soreshjani et al. (2015) for FACTS device Thyristor- controlled series capacitance (TSSC) for active power flow control of transmission line. Arab Markadeh et al. (2011) extended the brain emotional controller application to control electrical drives, the Induction motor speed and flux is controlled with brain emotional controller strategy and Rahman et al. (2008) used brain emotional controller to control Interior PMSM(IPMSM) drive. Abdi et al. (2012) has implemented brain emotional controller strategy to predict traffic control for a short period of duration to achieve improved performance against to classical intelligent controller. In this paper brain emotional controller is used to control Surface mounted PMSM (SPMSM) drive to overcome limitations of exiting classical and intelligent controllers. The brain emotional controller designing contains sensory signal and emotional or reward functions which plays key role in emotional signal generation, the sensory signal and emotional signal used by Rahman et al. is modified in this paper and applied in to SPMSM drive to achieve faster response time of speed signal, less harmonics in stator phase windings and reduced torque ripples. The results obtained with brain emotional controller compared with existing PI and Fuzzy logic controllers. The Fig. 1 shows the proposed brain emotional controller based speed controller for PMSM drive, the difference of reference speed and actual speed command is fed as input to controller. The input of the controller is modified as sensory signal with a function and processed further to achieve emotional response signal.

This paper organized as Follows: In Section 2 Development of Emotional controller is explained, Brain emotion based PMSM drive discussed in Section 3 in which mathematical modeling of PMSM Machine with existing speed control techniques and design of proposed brain emotional controller is explained, in Section 4, implementation of emotional controller for PMSM is presented, in Section 5, Results and Discussions are presented and finally Section 6 includes conclusion.

2. Development of brain emotional control scheme

The bio-inspired brain emotional intelligent controller is designed by mimicking the limbic system of mammalian brain. The outcome of limbic system called as emotional response for particular action, which plays vital role in decision making process of mammalian brain. The emotions are generated with the associated parts of limbic system namely amygdala, orbitofrontal cortex, thalamus and sensory cortex. These parts can be modeled with mathematical functions to control problems of real world applications. As the emotional intelligence reaction is very faster the same analogy is extended to control engineering applications to exhibit fast decision making process compare to other conventional controllers.

The mammalian brain and its parts shown in Fig. 2, the limbic system contains small almond shaped part called amygdala, which plays vital role in decision making process of mammalian brain such as

it has connections with other sensory parts of brain as per the neurobiological aspect. Sensory cortex is located at outmost layer of mammalian brain which is in cerebral cortex portion to sense the information. The information process is divided into two sensory cortices namely Primary sensory cortex and Secondary sensory cortex. The Primary sensory cortex senses signals from organs and stops the neural signals to take action. The information is sent to secondary sensory cortex to process and gives signals to the part at where action is to be taken. Thalamus is located in forebrain and has connection with cerebral cortex to process different functions and acts as relay between subcortical areas. The thalamus has direct connection with amygdala to process sensory signal to generate emotion response. The Orbitofrontal Cortex (OFC) is located in frontal lobe of mammalian brain which plays key role in decision making process with association of amygdala of limbic system. The association of amygdala and OFC enhances the learning and emotional capability of mammalian to take early action. Stimulus or emotional cue is a reward signal to generate emotional signal according to the action. The emotional cue function attains to new value for every action depends up on the sensory signal for onward transmission of decision making process. The emotional cue function is common to amygdala and OFC and it can be treated as energy changing module for corresponding sensory signal to generate the emotional signals.

The process of emotional signal generation is shown in Fig. 3; the input of the controller is converted as sensory signal (1) with the function f and processed to generate emotional signal from thalamus, in this paper thalamus is designed in superficial way to allow the sensory signal to reach the sensory cortex (SC) and amygdala. In SC (3) the sensory signal processed with function g, the output of the sensory cortex is send to amygdala and OFC. The amygdala receives inputs from thalamus, sensory cortex and a high value of stimulus as emotional cue or reward function. The amygdala learning model (5) contains amygdala gain connection for the sensory signal. The amygdala gain connection (6) is modeled with learning rate (α) and Emotional cue (EC). The outcome of the amygdala is primary reinforce signal which is further aided by the orbitofrontal cortex to overcome the inappropriate and noisy reinforce from amygdala to generate appropriate emotional signal to complete action. OFC (7) receives inputs from sensory cortex, amygdala and a high value of emotional cue. The OFC learning model contains gain connection (8) with learning rate of β and $E^{'}$. The emotional cue (9) is generated with the function of h, with emotional signal (12).

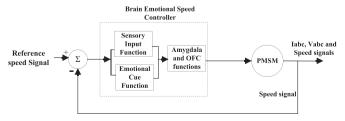The input to the controller is sensory signal (S_i) can be represented with the function of f,

Fig. 1. Brain emotional controller as speed controller for PMSM drive.