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Review: Belbic In Control Engineering

#1Gunapriya.B, #2Sabrigiriraj.M

1gunapriya78@yahoo.in
2sabari_giriraj@yahoo.com

#1Department of EEE,
Coimbatore Institute of Engineering and Technology, Tamil Nadu, India

#2Department of ECE,
SVS College of Engineering, Tamil Nadu, India

ABSTRACT

Neural networks have formed a new primary edge and advanced power electronics, which is already a complex and multidisciplinary technology that create dynamic development in recent years. But recently, a new type of intelligent techniques for control and decision-making, has been introduced which is based on emotion processing mechanism in the brain, and is basically a selection of the action, which is based on sensory input and emotional cues. This intelligent control is inspired by the limbic system of the mammalian brain. This paper provides an overview of brain emotional learning based intelligent controller (BELBIC) in various control applications. Emotional learning is a great method in the control systems and real-time decision due to its low computational complexity and the rapid formation where basic evolutionary algorithms are difficult to implement because of their computational complexity high. The use of emotional control approaches in computers and control engineering specifies that the purpose of emotions in systems can efficiently overcome problems of nonlinear systems.

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I. INTRODUCTION

Artificial Intelligence techniques have recently been applied widely in power electronics and motor drives. The computational intelligence has been progressively more utilized to work out any common and complex control problems. Linear models can be identified in a simple way from processing test data. However, if the process is highly nonlinear and subject to high frequent disturbances, a nonlinear model is needed to describe the behaviour of the process. For such identification systems by nonlinear methods must be used to describe the dynamic behaviour of the system, which can be achieved by means of neural networks [1]. Nevertheless neural network controllers need a predefined organization that may show the way to extra time consuming computations during the control process. The successful adoption of dynamic systems examined by Lucas et al. [2] based on a simple but effective computational replica of an emotional learn scheme in the amygdala as introduced recently by Moren and Balkenius [2]. In the leading research carried out by Lucas et al., a simplified version of a previously developed emotional learning model of the amygdala [3, 4] was employed in order to present an adaptive control strategy. For the period of the precedent few years, this controller has been utilized in control devices for variable speed applications [5-12]. Further, BELBIC was applied on some fascinating systems and results prove its effectiveness as a controller and it has the ability to adapt to variations and disturbances of the parameters [6, 8, 12]. Lately, many engineering systems are proposed by BELBIC such as power system [13], active queue management [14], washing machine [13] aerospace launch vehicle [15], interior permanent magnet synchronous motor system [16], micro-heat exchanger [6], flight simulation servo system [17], delayed systems [18] and other uncertain nonlinear systems [19], 2-DOF Helicopter Model[12],speed and flux control of an induction motor[20], The results obtained from the algorithm to implement various applications show the effectiveness of the method in the regulation of acute processes because of its rapid learning ability. Here the performance of BELBIC in several applications is reviewed. Given the short introduction given in section 1 above, this paper also tries to have a look at the following sections: In section 2, the architecture of the Limbic System is briefly reviewed. In section 3, Brain Emotional Learning Based Intelligent Controller will be described. Review of Control system applications and control structures is illustrated in section 4&5, and finally in section 6, summary and conclusion are presented.

II. ARCHITECTURE OF THE LIMBIC SYSTEM

The two parts of brain emotional learning (BEL) is the amygdala and the orbitofrontal cortex. The amygdala is a part of the brain that should be reliable for the processing of emotions and above all match with the orbitofrontal cortex, thalamus, cortex addition sensory input in the network model. The amygdala gives input to orbitofrontal cortex and cortical areas and responsible reaction to change the event of emotions [2], [21- 23].

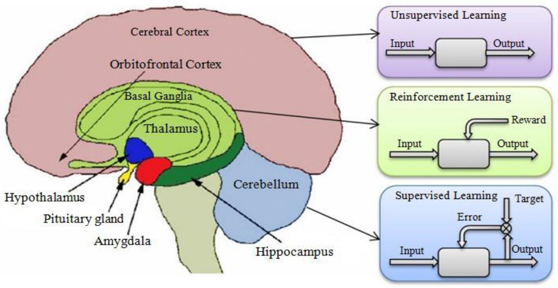


Fig 1. Anatomical view of the human brain showing the important components of the human limbic system.[24]

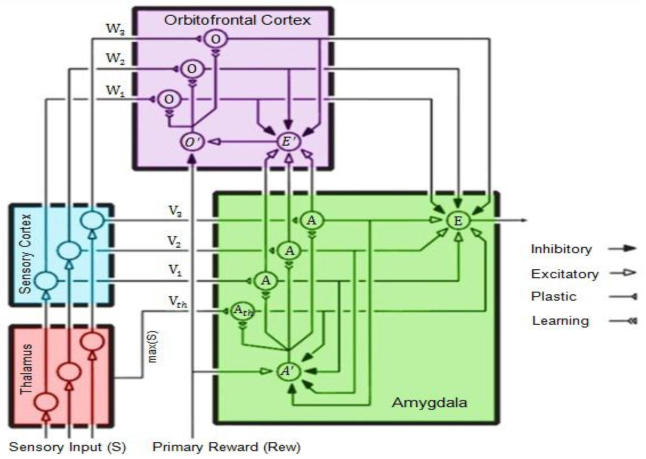


Fig 2. A Graphical depiction of the brain emotional learning process [24].

One of the primary functions of emotion is evaluating the stimuli. When an environmental stimulus occurs accompanied by an emotionally charged stimulus, the emotional system will combine this new momentum with the similar emotional content. The second function of emotional systems is to focus the attention of the system on the signals which contribute the most to reach the objectives of the system. Instead of spending the resources on all the many sensory stimuli, the emotional evaluation can help focusing on relevant stimuli which are more decisive in generating the appropriate actions. In the fields of cognitive science researches, the emotions and emotionally charged signals are distinguished as positive versus negative signals that will be automatically reflected in the output of the system through the model. The Amygdala is placed in a way to communicate with all other sensory cortices and areas within the limbic system [25]. The amygdala to assign a value to each emotional stimulus that is corresponding to a most important reinforcement signal. The output of this lobe is further transmitted to hypothalamus and previous structures. The amygdala receives three input signals: primary, the sensory information from the sense organs; next, the internal consequence of the stimuli, and finally, the type of operation for the being itself. The Orbitofrontal Cortex is another component that interacts with the Amygdala reciprocally. In general, it performs three interrelated functions which are Working Memory, Preparatory Set and Inhibitory Control ,the Orbitofrontal Cortex reacts to omit the expected reward or punishment and control the extinction of the learning the Amygdala [26]. Thus the orbitofrontal cortex regulates the mapping of the emotional response to stimuli arising from the amygdala. The orbitofrontal cortex receives the same data set that the amygdala, but it forms a kind of outer loop because it also receives the state of the amygdala. Hence the orbitofrontal cortex monitoring the difference between the predictions of the system and the actual booster amygdala and learns to inhibit the output of the system proportional to the discrepancy.The Sensory Cortex is the component next to the Thalamus and receives its inputs through this component. In fact, the information from the sensory areas is extensively processed within the Sensory Cortex. The Amygdala and Orbitofrontal Cortex receive highly analyzed input from the sensory cortex [27].

III. BELBIC
(brain emotional learning based intelligent controller)

The limbic brain is responsible for emotional learning of human beings. Figure 8 shows the block diagram of BELBIC controller.

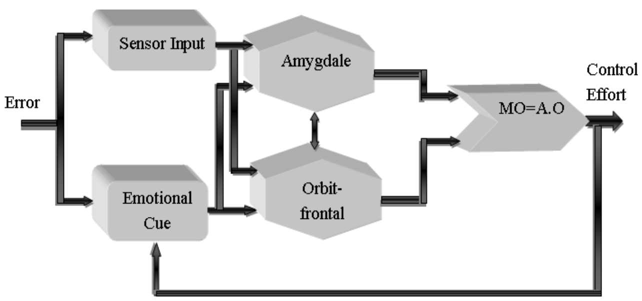


Fig 3. Block diagram of BELBIC controller. [28]

Initially, sensory input signals are in the thalamus for the pre-treatment on them. In this article, the speed error is considered to sensory input. Sensory cortex and amygdala then receive their processed form and their outputs are calculated by amygdala and Orbitofrontal based on the received signal from the emotional environment. Final output is the subtraction of the amygdala and orbitofrontal cortex. One of the amygdala entries is named as connection and thalamic sensory input is calculated as maximum overall S that equation (15). This particular entry is not projected in the orbitofrontal part and can not in itself be inhibited which differ among other means amygdalas.

$$A_{th} = i_{max} S_i \tag{15}$$

Every input is multiplied by a soft weight V_i in each node in Amygdala to give the output of the node. The O nodes' behaviors turn out their output signal by applying a weight W to the input signals as well as nodes. To adjust the V_i difference between the reinforcement signal rew and the activation of the A nodes is been made use. For instance, V_i can just be increased.

$$\Delta_{vi} = \alpha\left(s_i \max\left(o, rew - \sum A_j\right)\right) \tag{16}$$

α Image is the learning step in the Amygdala. The reason for this adjustment limitation is that, after the formation of the emotional reaction, the result of this training must be permanent, and is managed through the Orbitofrontal game when it is inappropriate [29]. Subtraction of reinforcing signal from the previous output E makes the signal of reinforcement for O nodes. The learning equation of the Orbitofrontal Cortex is drawn in Eq. (17).

$$\Delta w_i = \beta\left(s_i \sum\left(o_j - rew\right)\right) \tag{17}$$

The amygdala and Orbit frontal learning rules are much alike, but the Orbitofrontal weight W will be modified in both ways to extend and reduce as needed to track the proper inhibition.

The Linear Model of BEL Controller is mathematically represented by the following simplified Equations

$$A = G_A . SI \tag{18}$$

$$O = G_{OC} . SI \tag{19}$$

$$\frac{dG_A}{dT} = \alpha S \tag{20}$$

$$\frac{dG_{OC}}{dT} = \beta . S \tag{21}$$

$$MO = A - OC \tag{22}$$

Where MO is the Model Output, SI is the Sensory Input, ES is the Emotional Sensor, A is the Amygdala Output, O is the Orbitofrontal Cortex, α is the Learning rate of Amygdala,

β is the learning rate of Orbitofrontal cortex, G_A is the Gain

for Amygdala and G_{OC} is the Gain for Orbitofrontal Cortex.

IV. REVIEW OF CONTROL SYSTEM APPLICATIONS

Ehsan Drayabeigi1 and Gholamreza Arab Markadeh [30], presents an emotional controller for brushless DC motor (BLDC) drive. Simulation using MATLAB software and it results show that equally accurate steady state and quick momentary speed responses can be achieved in wide range of speed and the performance of the proposed control scheme is compared with various controllers. The implementation of emotional controller shows excellent control performance and good robustness and adaptability, even in presence of a disturbance signal.

Masoudinejad, Mojtaba, Rahman Khorsandi, Alireza Fatehi, Caro Lucas, S. Fakhimi Derakhshan, and Mohammad Reza Jamali. 31, presented a mathematical description of BELBIC is investigated and improved to avoid internal instability. Simulation and implementation results shows that instability of model has been solved. Improved BELBIC with integral anti-wind up is introduced for this problem. Simulation and implementation result show that the system is stable and obtained results are reasonable.

Jinfeng, Xiao, and Zhu Feihui. [32], presents an improved emotional controller for a brushless DC motor drive. The implementation of emotional controller shows excellent control performance and good robustness and adaptability, even in presence of a disturbance signal. At a comparison to a conventional PID controller, was seen that, the conventional PID can't operate at wide range of work points and in disturbance condition, properly. Also in the proposed control method the conventional PI and PID controllers, which are conventionally used in the vector control of BLDC drive, are eliminated. A simple structure of brain emotional learning based intelligent controller with its fast auto learning, model-free and good tracking features is used. The proposed emotional intelligent technique can be easily adapted for large scale industrial applications.

Marjanian, Ali, Soodabeh Solaymani, and Ghazanfar Shahgholian. [33], the convenient operation and control of IPFC for transient stability improvement are considered. IPFC energy function optimization used in order to access the utmost of transient stability. The utilization of the new belbic is based on the emotion-processing mechanism in the brain, that depend on sensory inputs and emotional cues. Simulation confirms the ability of BELBIC controller compared with convention PI controller.

The application of IPFC with belbic controller to improve the transient stability is more effective than PI controller. The emotional intelligent controller with a model less and uncomplicated structure has an improved affect on the oscillation damping, overshot reduction and CCT improvement.

Sadeghi, Mohamad-Ali, and Ehsan Daryabeigi[34], (BELBIC) was developed for speed control of synchronous motors interior permanent magnet (IPMSM). A novel and simple model of the drive IPMSM structure is established with the intelligent control system, which controls the speed of the motor with precision, without the use of all conventional PI controllers and is independent of engine parameters. The DSP-based drive system is then compared to classical BELBIC and optimized classic PI controller. The results show that the proposed method is more efficient than other controllers and has excellent control characteristics, such as a rapid, simple implementation, and robustness with respect to disturbances and manufacturing imperfections. Simulation and real-time implementations were conducted to test the effectiveness of new emotional controller (BELBIC). The proposed emotional controller has a number of advantages, including the freedom to choose desired responses in terms of overshoot, settling time, static error, and softness. These advantages make the emotional efficient and flexible controller in high performance applications. In addition, simple structure, rapid automatic learning and high power monitoring BELBIC were used to present a new control plant that is independent of engine parameters and eliminates the use of conventional PI controllers. These features make BELBIC an ideal candidate for implementation on an industrial scale.

Daryabeigi, E., G. R. Markadeh, and C. Lucas [35],

The electric drives control application examples that are discussed in this paper. In the experimental and simulation works, implementations of the drives system were attained by the intelligent controller, which control the motor speed accurately in different operating points. Emotional controller has been experimentally implemented in electrical laboratory training, and has excellent promise for use on an industrial scale with its fast machine learning is used without a pattern and good monitoring functions.

Rouhani, Hossein, Mahdi Jalili, Babak N. Araabi, Wolfgang Eppler, and Caro Lucas. [6], an intelligent controller is applied to govern the dynamics of the micro heat exchanger plant electrically heated. To construct the fuzzy model, a locally linear training algorithm, i.e., linear fashion local shaft (LoLiMoT) is used. BELBIC contribution in improving the performance of the control system is demonstrated by comparison with the results obtained from conventional PID controller without BELBIC. The results demonstrate excellent improvements of the action control, without any significant increase in the effort to control PID + BELBIC. It has been shown that BELBIC could solve faster with less distortion while its control effort has not been higher than PID controller. In addition, the selection of a PID signal as BELBIC sensory input in addition to the easy adjustment could provide some advantages such as robustness against noise and model uncertainties, use of BELBIC in this application also includes a considerable improvement over our previous uses of this model, especially in terms of control efforts required to achieve the desired performance levels.

Jafarzadeh et al. [12], proposed an intelligent autopilot for a 2-DOF helicopter model based on BELBIC. In this method, the states of the system have been separated into two parts, and each part has been controlled by one of the control inputs. It can be seen from these controller simulations that the tracking performance of BELBIC for the height is better than Feedback linearization controller, but in the sense of steady state the performance of both controllers is satisfactory. However,
stability guarantee is an important drawback for this controller.

Christian Balkenius and Jan Morén in 1998[36], describes work in progress in order to build a computational model of learning and emotional transformation inspired by the neuro physiological results. Main parts are orbitofrontal cortex and the modeled amygdala and the interface between both. They showed that there is sufficient physiological data to suggest the overall architecture of a calculation model, and emotion plays a clear role in learning and behavior.

Ali Reza Mehrabian, Caro Lucas and Jafar Roshanian [15], Theoretical analysis of the adaptive tracking controller in Intelligent Autonomous line based on the model of emotional learning in mammalian brain (BELBIC) for aerospace launch vehicle is proposed. With sensory inputs and reward signals, control algorithm seeks independently own control signal to be executed by actuators, eliminating the tracking error without prior knowledge of the dynamics of factory.

Ali Reza Mehrabian, and Caro Lucas, a new control strategy based on emotional learning (BEL) brain model was introduced. BEL ,a modified model was proposed to increase the degree of freedom to control the capacity, reliability. The performance of the proposed controller BEL has been illustrated by the application on different nonlinear uncertain systems, showing a very good adaptability and robustness while maintaining stability.

Carlos Dominguez, Houcine Hassan and Alfons Crespo[37], Recent research in the emotional systems identified the important role of emotions in the control and organization of the behavior of robotic systems. RTEA is an emotional architecture in real time for robotic agents. Emotions modulate the motivation to RTEA thoughts that affect the behavior of final agents. An emotional state is reached from the assessment of the environmental situation. The way this evaluation contributes to the emotional state and how this condition affects the behavior depends on the emotional sensitivity.

Maziar Sharbafi A. Caro and Lucas in 2006 [38],the combination of path planning and the following path is the main purpose of this article. This document describes the practical approach developed for motion control of MRLs small robots. An intelligent controller is applied to control robots omnidirectional movement in the simulation and the real environment, respectively. The Learning Brain Emotional Intelligent Controller Based (BELBIC), based on the LQR control is adopted for the omnidirectional robots.

Shahmirzadi D., R. Langari, LJ Sanchez Ricalde and EN 2006 [39], BELBIC algorithm is used to control a model of a semi tractor trailer. The model has been derived previously validated and a sliding mode control is also tested demonstrating reasonable performance. The oscillatory movements of the vehicle using a motivating alternative control algorithm to improve the comfort and safety of passengers. The sliding mode control provides improved performance in certain respects limited, control performance is compared for three simulations braking, acceleration and cornering.

Guoyong Huang, and Wang Zhen Ziyang Daobo in 2008 [40], BELBIC is studied in implementing the attitude control of unmanned aerial vehicle (UAV) in the document. The drone is flying in the flat under the perturbation of the wind. The intelligent controller based BEL (BELBIC), which is based on emotional learning processes in the amygdala, orbitofrontal system (AO) of the mammalian brain, is proposed to develop the performance of the loop stability control of The attitude of the UAV. A drone control system with nonlinear dynamic properties based on BELBIC is built. Simulation results illustrate that BELBIC has good adaptability characteristics, high strength, and a small computational cost, so the BELBIC will be attractive in nonlinear systems control applications in real time.

Saeed Jafarzadeh, R.M.Mohammad, Reza Jahed Motlagh and Mojtaba Barkhordari in 2008 [41]
Their paper proposes a new approach to intelligent control the trajectory tracking of a vehicle used in automated highway systems. Controller based intelligent brain emotional learning (BELBIC) is an intelligent controller

based on the model of the emotional part of the brain. BELBIC modified controller was applied to a sixth model of vehicle control which must follow any normal way. A model with the coupling terms between the steering angle and the tensile force is considered.

Saeed Jafarzadeh, Rooholah Mirheidari Mohammad Reza Jahed Motlagh and Mojtaba Barkhordari in 2008 [12],
they introduced a new intelligent control approach called Emotional Learning Brain Based Intelligent Controller (BELBIC). BELBIC is a controller based on the emotional model of the human brain that was introduced not so long. This controller has been applied to a non-linear model of a helicopter. Feedback linearization method has also been applied to the system, and the performance of both controllers was compared as an intelligent and a conventional control method. An input state linearization method with some modifications was used to control the system. The performance of controllers has been justified by the simulation.

Mr. Masoudinejad, R. Khorsandi, A. Fatehi, C. Lucas, S. Fakhimi Derakhshan and Mr. Jamali in 2008 [31] in previous studies, internal instability of the controller was not considered and task control were carried out in limited time. In this article, mathematical description of BELBIC is studied and improved to prevent internal instability. Simulation and improved model implementation was done on the level of facilities. The results obtained showed that the instability of the model has bee n solved in the new model without loss of performance using Integral Anti-saturation (AIF).

AM Yazdani1, S. Buyamin1, Mahmoudzadeh2 S., Z. Ibrahim1 and MF Rahmat1 [42], presented a novel cognitive strategy based on emotional learning in the limbic system of the mammalian brain is used to establish an intelligent controller to provide the necessary control measures to achieve trajectory tracking rotor speed under different circumstances. To check the attributes, test benches were simulated in Matlab Simulink environment and performance BELBIC is studied. PID controller is also applied to the model and then an exhaustive comparison, both certain and uncertain state, between the results of the proposed controllers is done. Uncertain situation is provided by the disturbance load torque application and variation of parameters of PMSM. Simulation results clearly show the unique ability of BELBIC in monitoring the speed with high accuracy for arbitrary reference signals and the remarkable robustness of this control device in the presence of uncertainties.

Sadeghieh Ali, Jafar Roshanian and Farid Najafi. [24] (BELBIC) for an electro-hydraulic servo system (EHS) is presented. A mathematical model of the system is derived and the model parameters are identified. The BELBIC is designed on the basis of the dynamic model and used to control the real system laboratorial EHS. The experimental results are compared with those obtained from an optimal PID controller to prove that conventional linear controllers fail to get a good tracking the desired output.Finally the BELBIC is able to respond quickly to any disruption and the change in the parameters of the system, showing a high degree of adaptability and robustness thanks to its ability to learn online.

V. CONTROL STRUCTURE OF SYSTEMS

The various structures that were stated by different researchers in this field are depicted in figures below:

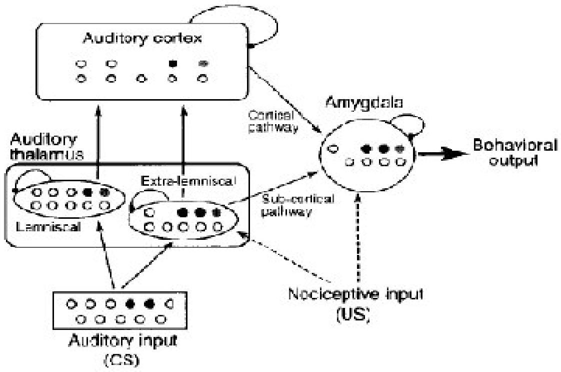


Fig 4. Armony 1997 [44]

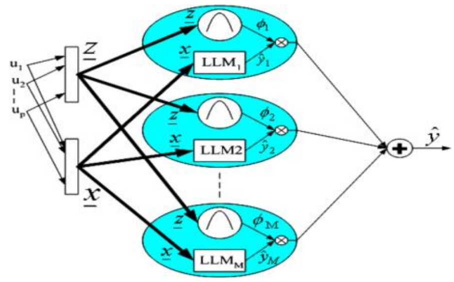


Fig 5. Structure of a local linear neurofuzzy model [6]

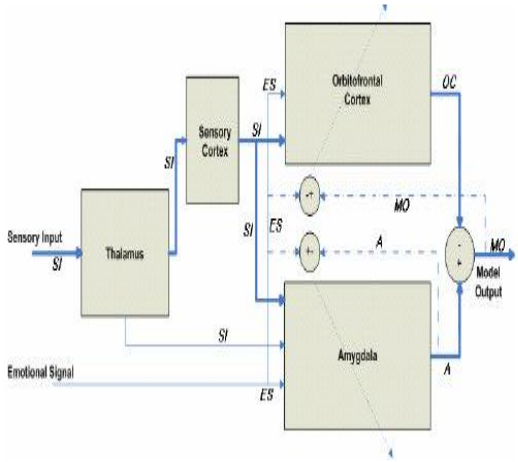


Fig 6. Balkenius, Moren [4]

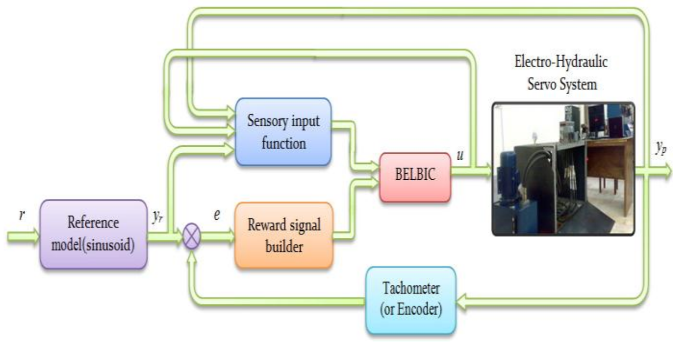


Fig 7. System configuration using the brain emotional controller.[24]

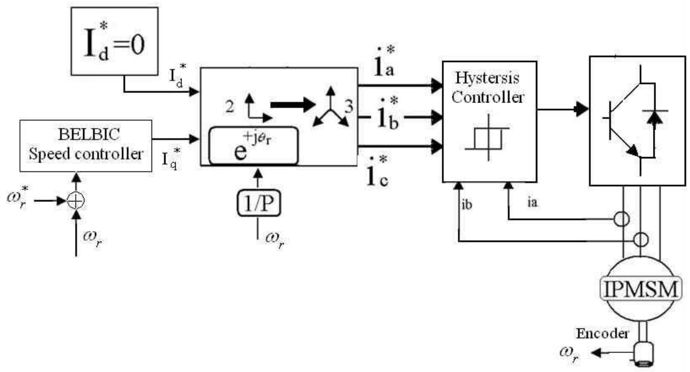
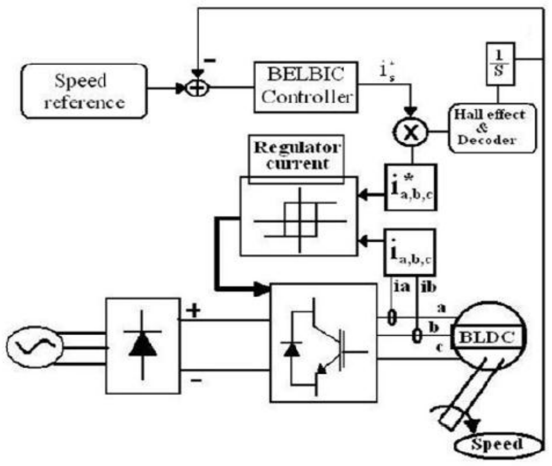


Fig 8. System configuration using the brain emotional controller.[26]



Fig(8). Control system structure of BLDC drive using BELBIC.

Fig 9. System configuration of bldc drive using BELBIC[30]

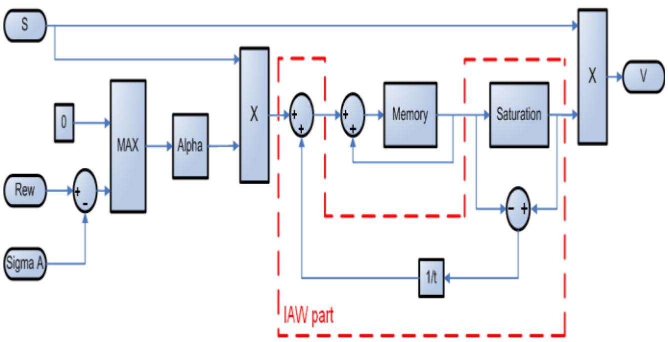


Fig 10. System configuration of bldc drive using BELBIC[31]

VI. SUMMARY AND CONCLUSION

Our review of BELBIC in many applications encompasses considerable improvement in terms of the required control efforts for achieving desired performance. The scheme of using BELBIC for industrial control system applications having advantages such as low computational complexity, fast training, high degree of the adaptability of the control system and the robustness of the performance with respect to the initial error in relation to modelling and identification. The main short coming of model is free controllers with a learning ability without any prior knowledge of the system's dynamics, such as through reinforcement learning and the BELBIC is that in the early phases of the learning process, they may cause poor performance because they may produce a wrong control signal. Future research can focus on a hybrid control to solve this problem and accelerate the learning phase. Undoubtedly, the proposed approach is not an optimal solution; however with simple implementation, reasonable computational effort, fast response and insensitivity to disturbances, this method proves to be both efficient and acceptable. The implementation of emotional controller in reviewed papers shows excellent control performance and good robustness and adaptability. For future works, there are several suggestions that can be done for improvement of BELBIC. Besides, in reality, some other components function in the real Limbic System affect the emotional learning and not considered in the current models. Thus, it is very useful to design a self-tuning algorithm to find the gains and weights in the emotional and sensory signals. Thus, a simple structure of the brain emotional learning based intelligent controller Thanks to its rapid self-learning, without a model and good tracking capabilities is used to control many engineering applications with some improvement BELBIC model.

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