ASSESSMENT OF ENHANCED EMOTIONAL LEARNING BASED INTELLIGENT CONTROLLER FOR SECONDARY IMPEDANCE CONTROL OF SINGLE PHASE INDUCTION MOTOR

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Abstract: *In this paper a novel Enhanced emotional learning based intelligent controller (EELBIC) is proposed to control a secondary impedance of single phase induction motor. Single phase induction motor is the crucial load to a grid. Hence small improvement in performance of SPIM results in huge improvement in a grid. Powerfactor is the significant parameter in quality of electricity. In this paper improvement of powerfactor is analyzed using secondary impedance control using artificial intelligent controllers. Fuzzy gain scheduling controller is applied for secondary impedance control and compared with conventional PI based system. Less computational time based intelligent method of EELBIC is proposed and analyzed using Matlab Simulink. Benefits of EELBIC based proposed system in the aspects of motor and grid are analyzed in this paper.*

Keywords: *SPIM, PI, switched capacitor, FGS, EELBIC;*

1. Introduction:

Domestic appliances built with motors utilizing electrical energy become more, which needs enhanced efficiency and functionality. Domestic appliances using motor are food processors; mixer-grinders and pumps are developed with low technology. These loads take major contribution in total load of a grid. Therefore in this domain, even a small enhancement in efficiency of the appliances produces great improvement in overall countrywide savings of energy, which is particularly significant in the current situation of energy scarcity. The electrical energy consumed by water pumps in agriculture and domestic applications plays crucial role in grid. Single Phase Induction Motors (SPIMs) are normally used for such functions.

Single-phase induction motor (SPIM) is extensively used in subfractional or low fractional horsepower - power applications. As the induction motor (IM) is rugged, simple, reliable, less maintenance requirement and cheap it is used almost all application in every part of a home and industrial use of electrical machine. This motor has an adequate solution for drinking water supplies in rural areas as well as Grid connected areas. The single phase motors are used in huge volume due to the easy availability of the single-phase Power supply. The main limitation in this motor is, it does not run directly, as it is not a self starting motor. As a result, this motor in the beginning should be operated as a two-phase motor by auxiliary means [1]. The SPIM usually consists of main and an auxiliary winding. The capacitor-start, split-phase, capacitor-run and capacitor-start capacitor-run are the most common types of two-winding SPIM.

Capacitor start capacitor run type of single phase induction motor is used mostly for water pump application. This motor contains both a starting and running capacitor. The starting capacitor is connected via the centrifugal switch, whereas the running capacitor is permanent; the starting capacitor optimizes starting torque during the starting period, while the running capacitor optimizes the motor's current flow leading to better energy efficiency when operating at running speed. However these motors consume high electrical energy, have less significant efficiency and overall, wastage of power is high. Powerfactor is the significant criteria [2-4] in an application of induction motors as the huge load in the grid.

Even a small increment in powerfactor can bring about a considerable reduction in power losses since losses are proportional to the square of the current. It represents an extra burden on the electricity supply system and in the consumer's bill. A poor power factor is generally the result of an inductive load such as an induction motor, a power transformer, ballast in a luminaire, a welding set or an induction furnace. Powrfactor can be improved by the addition of power factor correction equipment like a capacitor in poor power factor system due to inductive loads. Permanent high capacitor for PF improvement may cause additional loss.

In each phase of the rotor circuit by inserting variable impedance, a combination of a resistor, an inductor and a capacitor in series the copper loss can be reduced. The secondary impedance will also result in enhanced torque [5]. The limitation of this method is the high value capacitance. This can be overcome by the switched capacitor. Many researchers analyzed various techniques to control switching of a capacitor [6]. In this paper switched capacitor (SC) is proposed to improve powerfactor with minimum loss.

In this paper various soft computing methods are proposed to control switched capacitor. SC is initially analyzed with PI controller, which is a conventional and simple technique to implement in real time. Fuzzy gain scheduling controller is a soft computing method applied for various applications such as speed control of induction motor, control of BLDC motor and voltage control in STATCOM [7-9]. FGS is applied in this analysis to control SC.

Brain emotional learning based intelligent controller is an effective method for various applications like SISO, MIMO and nonlinear systems [10]. The BELBIC has been analyzed by many researchers for various linear and nonlinear applications like speed ad flux control of induction motor, speed control of SRM and control of distillation column [11-14]. In this paper, a novel Enhanced emotional learning based intelligent controller (EELBIC) is proposed to control SC of capacitor start-run single phase induction motor.

2. Mathematical Modelling of SPIM:

The single-phase capacitor induction motor which cross-section is shown in Figure1 was used for computational analysis. The main (M) and auxiliary (A) stator windings are distributed in stator slots so that they form the dq axes fields [15, 16]. The capacitance is placed in the stator auxiliary winding.

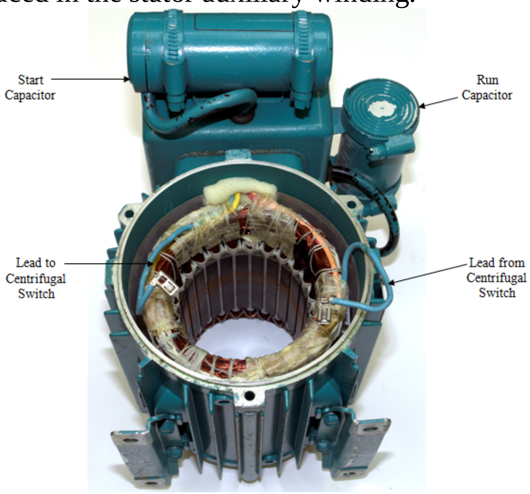

Fig. 1. Cross section view capacitor start-run single phase induction motor.

The mathematical modeling of the capacitor start-run induction motor can be described by mechanical and electrical differential equations in the arbitrary reference frames as follows:

$$\frac{di_{dM}}{dt} = \frac{1}{L_\Sigma}\Big[i_{dM}L'_{rr}R_s + i_{qA}\big(-L_{ms}^2(\omega-\omega_r) + L'_{rr}L_{ss}\omega\big) - i'_{dr}R'_rL_{ms} + i'_{qr}L'_{rr}L_{ms}\omega_r - L'_{rr}V_{dM} + v'_{dr}L_{ms}\Big] \quad (1)$$

$$\frac{di_{qA}}{dt} = \frac{1}{L_\Sigma}\Big[i_{dM}\big(L_{ms}^2(\omega-\omega_r) - L'_{rr}L_{ss}\omega\big) + i_{qA}L'_{rr}R_s - i'_{dr}L'_{rr}L_{ms}\omega_r - i'_{qr}R'_rL_{ms} - L'_{rr}V_{qA} + v'_{qr}L_{ms} + v_{qc}L'_{rr}\Big] \quad (2)$$

$$\frac{di'_{dr}}{dt} = \frac{1}{L_\Sigma}\Big[-i_{dM}R_sL_{ms} + i_{qA}L_{ss}L_{ms}\omega_r + i'_{dr}R'_rL_{ss} + i'_{dr}\big(L'_{rr}L_{ss}(\omega-\omega_r) - L_{ms}^2\omega\big) - v'_{dr}L_{ss} + v_{dM}L_{ms}\Big] \quad (3)$$

$$\frac{di'_{qr}}{dt} = \frac{1}{L_\Sigma}\Big[i_{dM}L_{ss}L_{ms}\omega_r + i_{qA}R_sL_{ms} + i'_{dr}\big(L'_{rr}L_{ss}(\omega-\omega_r) - L_{ms}^2\omega\big) + i'_{qr}R'_rL_{ss} - v'_{qr}L_{ss} + v_{qA}L_{ms} - v_{qC}L_{ms}\Big] \quad (4)$$

$$\frac{dv_{qC}}{dt} = \frac{1}{C}i_{qA} \quad (5)$$

$$\frac{d\omega_r}{dt} = \frac{p^2}{J}L_{ms}\big(i_{dM}i'_{qr} - i_{qA}i'_{dr}\big) - \frac{D_f}{J}\omega_r - \frac{p}{J}T_L \quad (6)$$

$$\frac{d\theta_r}{dt} = \omega_r \quad (7)$$

$$L_\Sigma = L_{ms}^2 - L'_{rr}L_{ss}, R_s = R_M = R'_A, L_{ss} = L_{sM} = L'_{sA} \quad (8)$$

The rotor current quadrature and direct components are iqr and idr, the stator current quadrature and direct components are i_{qA}, i_{dM}, the stator voltage quadrature and direct components are v_{qA}, v_{dM}, the rotor voltage quadrature and direct components are v_{qr}, v_{dr}, the capacitor voltage is v_{qC}, the rotor winding resistance is Rr, the stator winding resistance is Rs, the rotor windings self inductance is Lrr, the stator winding self inductance is Lss, the magnetizing inductance of stator is Lms, the viscous friction coefficient is D_f, the number of pole pairs is p, the electromagnetic torque is Te, the moment of inertia is J, the load torque is T_L, the rotor electrical angular displacement is θ_r, the rotor electrical angular velocity of is ω_r. Assume ω=0 and with the help of operator s = d/dt, in the stationary reference frames, the single-phase capacitor induction motor dynamic model can be build, for which the rotor and stator currents, angular velocity, voltage across the capacitor and angular displacement of the rotor are the state variables [17]:

$$i_{Md} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[i_{qA}L_{ms}^2\omega_r - i'_{dr}R'_rL_{ms} + i'_{qr}L'_{rr}L_{ms}\omega_r - L'_{rr}v_{dM} + v'_{dr}L_{ms}\right] \quad (9)$$

$$i_{Aq} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i_{dM}L_{ms}^2\omega_r - i'_{dr}L'_{rr}L_{ms}\omega_r - i'_{qr}R'_rL_{ms} - L'_{rr}v_{qA} + v'_{qr}L_{ms} + v_{Cq}L'_{rr}\right] \quad (10)$$

$$i'_{dr} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i_{dM}R_sL_{ms} - i_{qA}L_{ss}L_{ms}\omega_r - i'_{qr}L'_{rr}L_{ss}\omega_r - v'_{dr}L_{ss} + v_{dM}L_{ms}\right] \quad (11)$$

$$i'_{qr} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[i_{dM}L_{ss}L_{ms}\omega_r - i_{qA}R_sL_{ms} + i'_{dr}L'_{rr}L_{ss}\omega_r - v'_{qr}L_{ss} + v_{qA}L_{ms} - v_{qC}L_{ms}\right] \quad (12)$$

$$v_{qC} = \frac{1}{sC}i_{qA} \quad (13)$$

$$\omega_r = p\left[\frac{1}{J_s + D_f}\right]\left[pL_{ms}\left(i_{dM}i'_{qr} - i_{qA}i'_{dr}\right)\right] - T_L \quad (14)$$

$$\theta_r = \frac{1}{s}\omega_r \quad (15)$$

The set of the motor equations after some mathematical transformations can be written as follows:

$$i_{dM} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i'_{dr}R'_r + \omega_r\left(i_{qA}L_{ms} + i'_{qr}L'_{rr}\right) - \frac{L'_{rr}}{L_{ms}}v_{dM}\right] \quad (16)$$

$$i_{qA} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i'_{qr}R'_r + \omega_r\left(i_{dM}L_{ms} + i'_{dr}L'_{rr}\right) - \frac{L'_{rr}}{L_{ms}}v_{qA}\right] \quad (17)$$

$$i'_{dr} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i_{dM}L_{ms}R_s - \omega_rL_{ss}\left(i_{qA}L_{ms} + i'_{qr}L'_{rr}\right) + L_{ms}v_{dM}\right] \quad (18)$$

$$i'_{qr} = \frac{1}{L_\Sigma s - L'_{rr}R_s}\left[-i_{qA}L_{ms}R_s - \omega_rL_{ss}\left(i_{dM}L_{ms} + i'_{dr}L'_{rr}\right) + L_{ms}v_{qA}\right] \quad (19)$$

$$v_{qC} = \frac{1}{sC}i_{qA} \quad (20)$$

$$\omega_r = p\left[\frac{1}{J_s + D_f}\right]\left[pL_{ms}\left(i_{dM}i'_{qr} - i_{qA}i'_{dr}\right)\right] - T_L \quad (21)$$

$$\theta_r = \frac{1}{s}\omega_r \quad (22)$$

Where

$$v_{qA} = -\left(v(t) - v_{qC}\right) = -v(t) + v_{qC} \quad (23)$$

$$L_\Sigma = L_{ms}^2 - L'_{rr}L_{ss} \quad (24)$$

3. Switched Capacitor:

In this switched capacitor method an additional capacitor is connected to a running capacitor with the controlled thyristor. In this secondary impendence system the capacitor connected in series with resistor. The circuit of the proposed system is shown in figure 2.

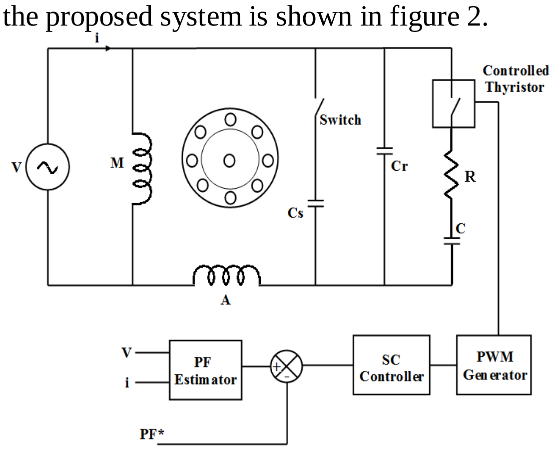

Fig. 2. Circuit of the proposed system

In the figure 2 M is the main winding and A is the auxiliary (A) stator winding, C_s is the starting capacitor and connected in series with centrifugal switch. The secondary impedance is connected with stator winding when series connected controlled thyristor is turned ON. During OFF time of thyristor motor runs with its existing capacitors. The effective capacitance connected with the winding is decided by the duty ratio or turn on time of thyristor.

$$C_{eff} = \frac{T_{on}}{T_{on}+T_{off}}\ C \quad (25)$$

$$C_{eff} = d\ C \quad (26)$$

Where T_{on} is turn on time of thyristor, T_{off} is turn off time of thyristor, d is the duty ratio decided by the SC controller. In this analysis, various control techniques such as PI controller, Fuzzy gain scheduling controller, EELBIC are proposed as SC controller to control effective capacitance and compared. The powerfactor of SPIM is estimated from source current and voltage. The estimated powerfactor is compared with reference power factor (PF*). The PF error is processed by SC controller which decides the duty ratio d. As discussed in eq(26) this d decides the effective capacitance connected with the stator winding. Since the secondary impedance is not connected permanently the consistent loss is reduced. Since the SC is controlled based on powerfactor, it is improved as well as it reduces current consumption from grid and improves torque. Artificial intelligent controllers are proposed in this analysis for deciding duty ratio which improves powerfactor and reduce losses.

4. Conventional PI Controller:

The Proportional plus Integral controller consists of simple equation to produce an output which is easy to implement in real-time [18,19]. Since simple equation it consumes less time to execute, results quick response. Steady state error produced by this controller is low even if it is a simple controller. In this paper PF error is processed by PI controller to produce duty ratio. The PI controller equation for the proposed is given in (27)

$$d = K_p\, e(t) + K_i \int e(t) \qquad (27)$$

Where K_p and K_i is proportional and integral controller gain, d is the duty ratio and e(t) is the powerfactor error. Figure 3 shows the block diagram of PI controller.

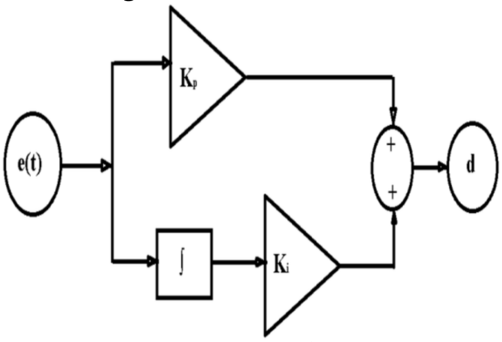

Fig. 3. Block diagram of PI controller

In this paper, the value of K_p & K_i are found using Ziegler Nichols' method of tuning.

5. Fuzzy Gain Scheduling Controller for SC:

The fixed value of K_p and K_i irrespective of input error in a PI controller produces an abrupt change in powerfactor. Soft computing tuning of K_p and K_i in a PI controller can defeat this problem. In this paper, Fuzzy Gain Scheduling controller for auto tuning of K_p and K_i [20] is proposed. Fuzzy logic controllers (FLCs) are suitable for nonlinear system and system with vague data [21]. Their advantages are a non-requirement of a mathematical model, robustness, and acceptance of nonlinearity.

In this controller, the PI controller gains such as K_p and K_i are tuned using the Fuzzy logic module. The computation speed of the controller is fast so that it can assure the quick requiring of the controlled object. Figure 4 shows the block diagram of FGS system.

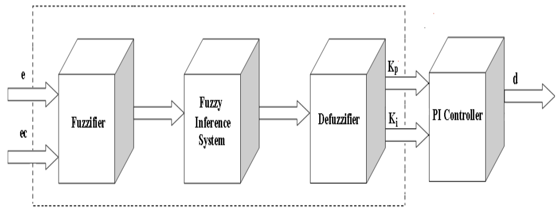

Fig. 4. Block diagram of Fuzzy gain scheduling controller

Powerfactor error "e" and change in powerfactor error "ec" are used as fuzzy input, the K_p and K_i are produced as fuzzy outputs. The outputs of the fuzzy controller are applied in (27) to find duty ratio as in figure 4. The{NB, NS, Z, PS, PB} are the five membership functions of input variables e and ec, where PB, PS, Z, NS, and NB represent Positive Big, Positive Small, Zero, Negative Small and Negative Big respectively. The output variable of K_p and K_i are configured with four membership functions such as Zero, Positive Small, positive medium, and Positive Big. Triangular distribution functions are used for all variables. The membership function for all variables is shown in Figure 5 and 6.

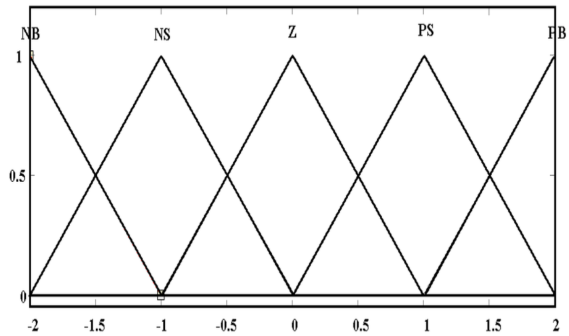

Fig. 5. e and ec membership functions

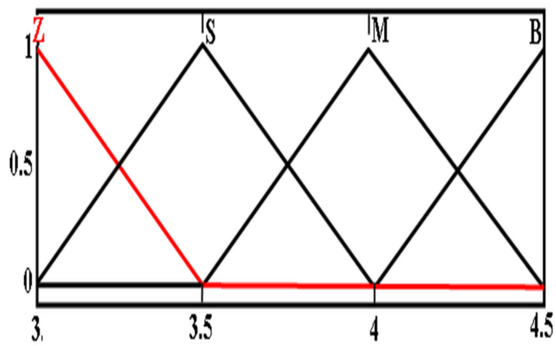

Fig. 6(a)

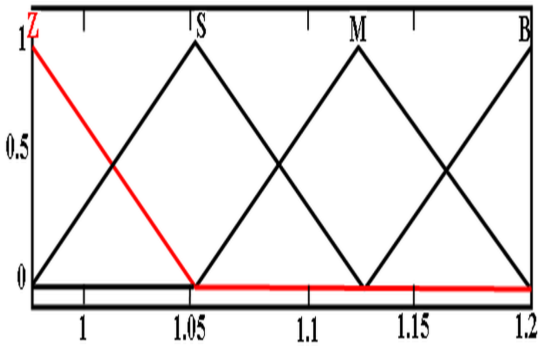

Fig. 6(b)

Figure 6 Fuzzy membership functions of K_p and K_i

In the Mamdani inference method, the fuzzy rules are framed in order to make the system output produce a required response for variable load since the load has a significant impact on powerfactor. The fuzzy rules for K_p and K_i are given in table 1and table 2. Each gain is decided by 25 rules. The MIN-MAX method of fuzzification and centroid method of defuzzification is adopted. The limits of K_p and K_i are set with some tolerance from Ziegler Nichols' method of tuning.

Table 1 The Control Rules for K_p

E \ EC	NB	NS	Z	PS	PB
NB	PB	PB	PB	PB	PM
NS	PM	PB	PS	PS	PS
ZO	PM	PB	Z	PS	PB
PS	PS	PS	PS	PS	PS
PB	PM	PB	PB	PM	PB

Table 2 The Control Rules for K_i

E \ EC	NB	NS	Z	PS	PB
NB	Z	Z	Z	Z	Z
NS	PM	PM	PM	PM	PM
ZO	PB	PB	Z	PB	PB
PS	PS	PM	PM	PM	PM
PB	Z	PS	PB	PB	PB

The Fuzzy Gain Scheduling controller reduces the amplitude of oscillations in powerfactor. FGS is an advanced controller than PI but compares to PI controller its execution time in realtime is high, so a novel controller with less processing time is proposed in this paper.

6. Enhanced Emotional Learning Based Intelligent Controller for SC:

Enhanced emotional learning based intelligent Controller (EELBIC) is proposed in this paper to reduce powerfactor error with minimum processing time compare to FGS. It is proposed to improve power factor by employing effective capacitance with minimum losses. This can be attained by proposing superior EELBIC since it is a multi feedback controller. Compare to single feedback in PI and FGS controllers, three feedbacks in EELBIC results in accurate tuning of the duty ratio based on the present powerfactor error.

"Limbic System" of the human brain is the basic architecture for EELBIC. For the emotional learning in human beings the limbic system is responsible. Amygdala and Orbitofrontal Cortex in the brain are main components for EELBIC. The block diagram of EELBIC controller is in shown figure 7. The EELBIC for SC control in SPIM is shown in figure 8.

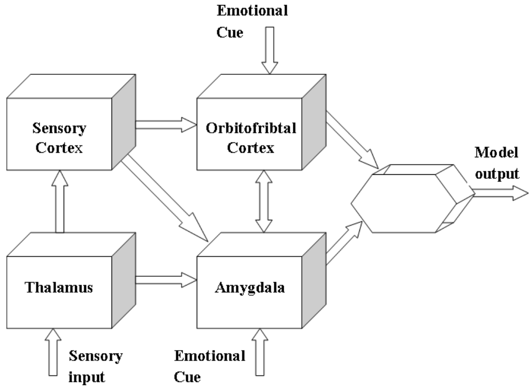

Fig. 7. Block Diagram Of EELBIC

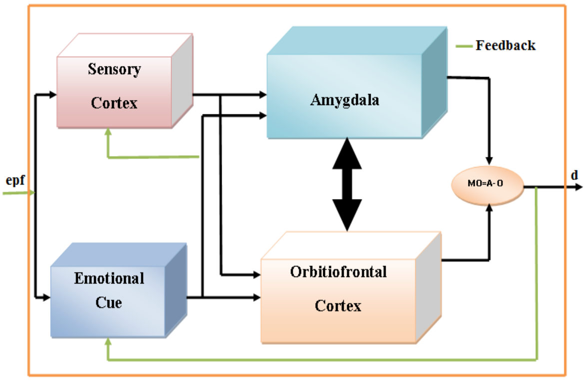

Fig. 8. EELBIC for SC control

From the figures 7 and 8 it is noted that powerfactor error (e_{pf}) is the input to the controller to produce dutyratio (d) as model output. A simple limbic system of the brain [22, 23] is shown in Figure 9.

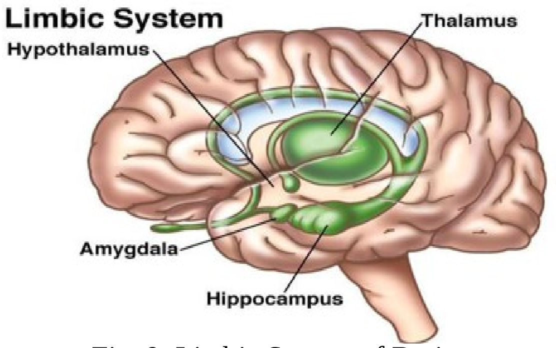

Fig. 9. Limbic System of Brain

On sensory input signals pre-processing like filtering or noise reduction is done in Thalamus. Amygdala is a small part in the medial temporal lobe in the brain which carries emotional evaluation of stimulus signal. This mechanism is a basis for emotional reactions and states.

In this paper, PF error is considered as Sensory input. Sensory cortex receives pre-processed output from Thalamus. The equation of sensory cortex is

$$SCT = k1.e + k2\int x - SCT \qquad (28)$$

In equation (28) SCT is the sensory cortex, k1 is the proportional gain, k2 is the integral gain and x is an output of integral controller alone. The EELBIC for SC control in SPIM is shown in figure 8.

Then processed output from Sensory Cortex will be computed by Orbitofrontal Cortex and Amygdala based on the environment Emotional Signal received. The final output of this control system is the difference between Amygdala and Orbitofrontal Cortex. Thalamic connection is one of the inputs to Amygdala's and computed as the utmost overall Sensory Cortex (S) as equation (29).

$$A_{th}=i_{max}S_i \qquad (29)$$

To attain the output Amygdala a soft weight G_A of each A node is multiplied by every input. Similarly, output of Orbitofrontal Cortex is estimated with the soft weight G_O. The deviation between the activation of the A nodes and reinforcement signal rew is applied to adjust the G_{Ai}. α is the parameter with stable value to tune the learning rate. Equation (30) shows the learning rule of Amygdala which is a simple associative learning system with almost monotonic weight adjusting rule.

$$G_{Ai} = \alpha(s_i \max(o, rew - \textstyle\sum A_j)) \qquad (30)$$

$$A = G_A.SCT \qquad (31)$$

α is the learning step in the Amygdala. The result of this training should be stable; therefore the limitation is adjusted after training of emotional reaction, and in case of an inappropriate result it is handled by the Orbitofrontal part [11]. Difference between previous output and reinforcing signal makes the signal of reinforcement for O nodes. Difference between required and actual reinforcement signals in nodes O produces the model output [24]. The Orbitofrontal Cortex learning equation is given in Eq. (32).

$$G_{Oi} = \beta(s_i \textstyle\sum(o_j - rew)) \qquad (32)$$

$$O=G_{OC}.SCT \qquad (33)$$

The learning rules of amygdala and Orbitofrontal Cortex are much alike, but the Orbitofrontal weight G_{Oi} is not monotonic as desired to follow the proper inhibition. The rule of β in (32) is alike to the α ones.

$$MO=A–O \qquad (34)$$

MO is Model Output, with the aid of equations discussed in this section, EELBIC is formed. As EELBIC is modeled using only by the arithmetic equations, it is simple to put into practice and consumes less execution time. This is the benefit of a proposed system which can be implemented by low cost, simple processors like Microcontroller, PIC, etc. in real time, does not require a high speed processor.

7. Simulation Results and Analysis:

To analyze the performance of proposed switched capacitor in SPIM initially, the motor is run without any control. The powerfactor of SPIM without any control system is shown in figure 10. Then SC control is analyzed with various controllers such as PI, FGS and EELBIC.

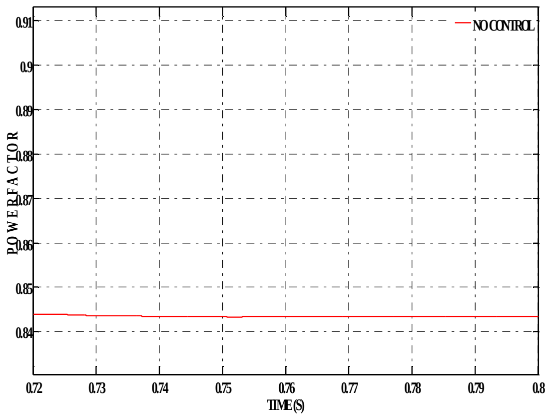

Fig. 10. Powerfactor of SPIM without SC control

From the figure 10 it is noted that PF of the motor load is 0.844. For the same load condition PI based SC control is analyzed and the Powerfactor is shown in figure 11.

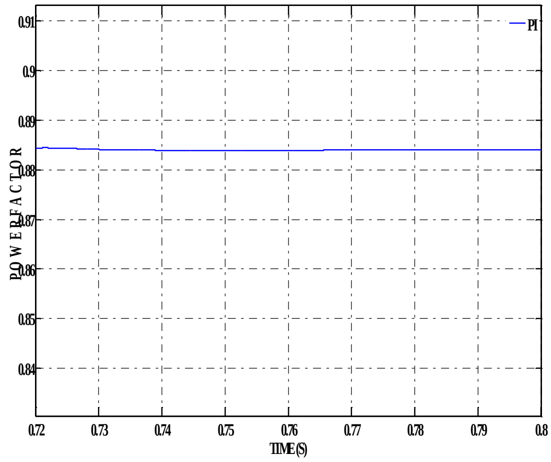

Fig. 11. Powerfactor of SPIM using PI based SC control

From the figure 11 it is noted that PF is 0.884 by the effect of PI based SC control. It is noted that PI based SC system improves PF from 0.844 to 0.884. The same system is analyzed using FGS and PF is shown in figure 12.

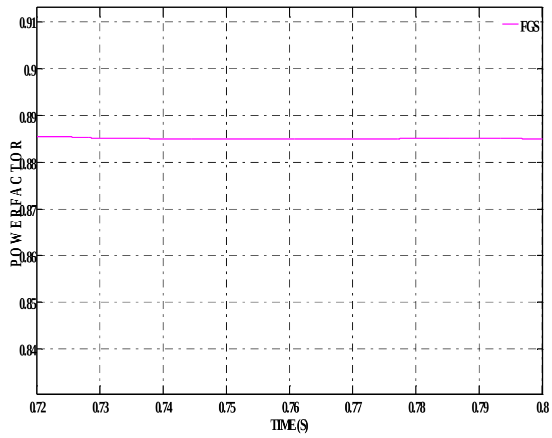

Fig. 12. Powerfactor of SPIM using FGS based SC control

From the figure 12 it is noted that PF by the effect of FGS based SC is 0.886 which is improved than PI. Figure 13 shows the Powerfactor of SPIM using EELBIC based SC control.

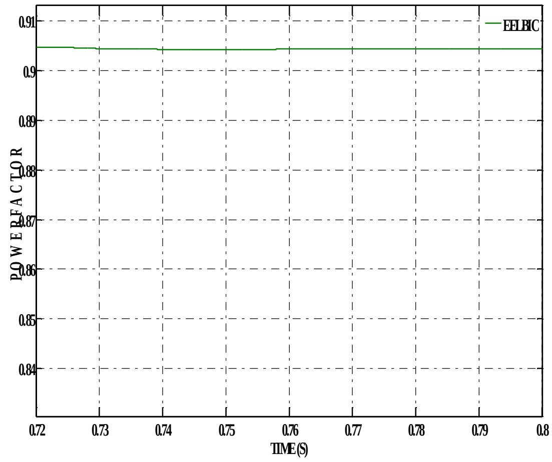

Fig. 13. Powerfactor of SPIM using EELBIC based SC control

Comparative performance of power factor of all methods with full load is shown in figure 14.

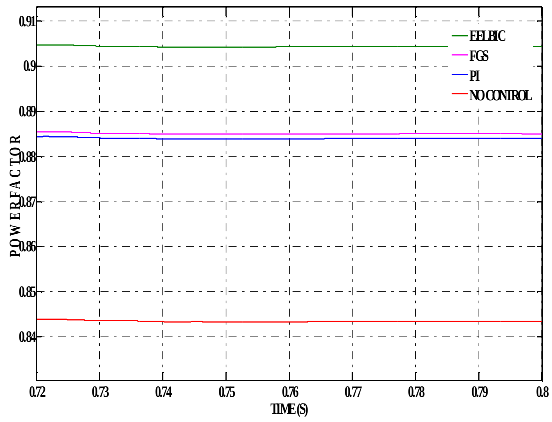

Fig. 14. Comparative analysis of various controllers based SC

From the figure 13 and 14 it is observed that PF is 0.905 which is increased compared to all other controllers such as PI and FGS based SC control of SPIM. The torque performance of SPIM using various methods analyzed is shown in figure 15.

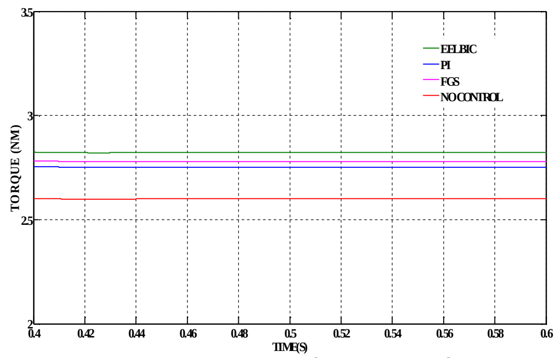

Fig. 15. Torque performance of SPIM using various methods

From the figure 15 it is noted that PI and FGS results increased torque compared to the existing uncontrolled system. In an existing system the motor produces 2.6Nm, whereas PI and FGS based SC controlled system improve torque to 2.75 Nm and 2.78 Nm respectively. EELBIC produces 2.85Nm for the same load which is improved torque compared all other systems.

The speed performance of the motor using various methods is shown in figure 16.

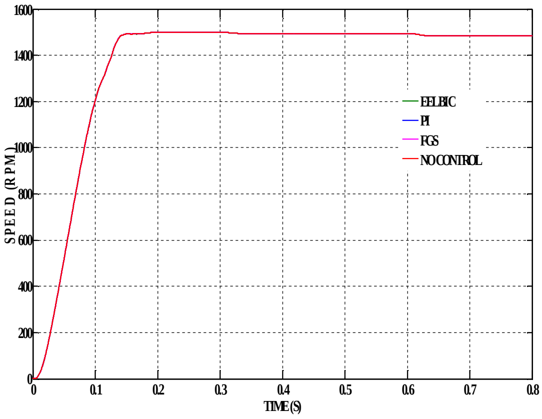

Fig. 16. Speed performance of the motor using various methods

From the figure 16 it is noted the speed of the existing system and SC controlled system various techniques are same. Therefore it is noted that the SC method does not affect the speed from existing system. For the same speed motor torque and powerfactor are improved by proposed EELBIC based SC system without any speed variation.

The objective of improving powerfactor is to reduce the current consumed from the grid. For analysis, the motor considers in this paper is 185W. The analysis was done for a full load and power factor is noted for the full load. Therefore the current consumed from the grid by the motor without control is calculated as follows,

$$I = \left(\frac{185}{(230*0.844)}\right)A = 0.953A$$

The stator winding resistance is 2.2 Ω, then I^2R losses by uncontrolled SPIM is

$$P_{LM} = I^2R = 0.953^2 * 2.2 = 2w.$$

Consider a domestic/small workshop having four motor loads of rating 0.25HP. Then a power loss per domestic/small workshop is

$$P_{LD/W} = 4*2 = 8w.$$

In the above $P_{LD/W}$ equation, 4 is number of motor loads and 2 is the I^2R loss in the stator winding.

Assume in a day accumulated run time of all motors is 8hours. Then an Energy loss per domestic/small workshop for a month is

$$E_{LD/W}/month = 8*8*30 = 1920w/h = 2Kw/h.$$

Similarly current consumed and loss by the SC controlled motor using various controllers are estimated and presented in table3.

Table 3 Tradeoff of SC controlled SPIM for domestic/small workshop load

SC controller	PF	Torque (Nm)	Current consumed (A)	P_{LM} (w)/motor	$E_{LD/W}$ (w/h)/month
Without control	0.844	2.6	0.953	2	1920
PI	0.884	2.75	0.9099	1.82	1747
FGS	0.886	2.78	0.9078	1.81	1737
EELBIC	0.905	2.85	0.8888	1.74	1670

From the table 3, it is noted that EELBIC improves PF, torque compare to other systems and reduces the current consumed and power loss in a grid. SC with conventional control can reduce power loss up to 173w/h for small load in a month. Proposed system reduces power loss around 250w /h compared to the existing system. This loss minimization is based on four, 0.25HP motor for a load, in real time the power rating is greater than 0.25HP for many applications, it will save more power. As a result implementation of the proposed system will reduce the power consumption of consumer and effectively reduce the electricity bill.

Consider a distribution line of 10km with resistance of 0.1Ω/km, then I^2R losses by uncontrolled SPIM in 10km line P_{LG} is,

$$P_{LG/m} = I^2R = 0.953^2 * 1 = 0.90284w.$$

Consider in a small distribution feeder of a 10Km line having 500 consumers; each consumer has 3 or 4 motor loads rated 0.25HP. Assume each consumer load two motors run for an hour, then the energy of copper loss on a feeder is

$$E_{LG} = 0.9028*1000 = 903w/h$$

1000 is the number of motors in a feeder. Assume a distribution transformer of 11KV/230V supplying the above discussed load has a secondary resistance of 5m Ω. For the above discussed load secondary current of distribution transformer is

$$I_{DTS} = 1000*0.953 = 953A.$$

Copper loss of distribution transformer can be estimated as follows

$$P_{DTS} = I^2R = 953^2 * 0.005 = 4541w.$$

Energy consumed by distribution transformer for copper loss in the secondary winding is

$$E_{DTS} = 4541w/h$$

Total energy loss (E_L w/h) supplied by the source is sum of loss in feed line and distribution transformer which does not include copper loss of motor. Similarly current consumed and loss by the SC controlled motor using various controllers are estimated and presented in table4.

Table 4 Tradeoff of SC controlled SPIM

SC controller	PF	Current consumed (A)	P_{LG} (w)/motor	E_{LG} w/h	E_{DTs} w/h	E_L w/h
Without control	0.844	0.953	0.90284	903	4541	5444
PI	0.884	0.9099	0.82791	828	4140	4968
FGS	0.886	0.9078	0.82418	824	4120	4944
EELBIC	0.905	0.8888	0.78993	790	3950	4740

From the table 4, it is noted that with the effect of SC in a SPIM reduces energy in a feeder line/ hour is reduced by 75 w/h by PI controlled SC. FGS reduces around 80w/h whereas proposed EELBIC system reduces energy loss by 113w/h compared to the existing system.

Energy loss consumed by a transformer in the existing system is 4541W/h, proposed EELBIC based SC reduces it to 3950 w/H. Compare to the existing system proposed EELBIC minimizes loss of energy in feeder and transformer around 704w/H.

Conclusion:

SPIM is a widely used motor in various domestic and industrial applications. In this paper switched capacitor control is analyzed using various controllers to improve the performance of capacitor start-run single phase induction motor. PI and fuzzy gain scheduling controllers are applied to control SC and compare with existing non-control motor performance in the aspect of Powerfactor, the current consumed and power loss in a grid. Novel EELBIC is proposed in this paper to improve PF. This controller is proposed for its multi feedback system which fine tunes output and arithmetic equations easy to implement and consumes less time in execution. From the analysis, it is noted that SC control in a SPIM improves PF and reduces current and losses. Compare to all other controllers EELBIC produces better performance. As a result of a consumer point, a domestic/small workshop proposed system reduces power loss around 250w /h compared to the existing system. In generator point, feeder and transformer loss is reduced around 704w/H. Therefore power supplier and consumer both are benefitted by the proposed system.

References:

1. Fitzgerald A.E., Kingsley C., Jr., Umans S.D. *Electric Machinery*. Sixth edition, McGraw-Hill Companies; 2003.
2. Mehta, V. K., and Mehta, R. *Principles of power system*. S. Chand; 1982.
3. Fuchs, Ewald, and Mohammad AS Masoum. *Power quality in power systems and electrical machines.* Academic press;2011
4. Heydt, Gerald Thomas. Electric power quality: a tutorial introduction. *IEEE Computer Applications in Power* . 1998; 11(1): 15-19. **DOI:** 10.1109/67.648490
5. Sunter, Sedat, Mehmet Ozdemir, and Bilal Gumus. Modelling and simulation of single phase induction motor with adjustable switched capacitor. *Proceedings of 9th International Conference on Power Electronics and Motion Control, Kosice, Slovakia*. 2000:1-5.
6. M.P.Mohandass and Dr.S.Manoharan. Neural Network Controlled Switched capacitor for improving the powerfactor in an inductive circuits using PSO Algorithm. *Advances in Natural and Applied Sciences.* 2014; 8(21): 85-90.
7. Othmani, Hichem, D. Mezghani, and A. Mami. Fuzzy Gain-Scheduling Proportional-Integral control for Improving the speed behavior of a three-phases induction motor. *International Journal of Power Electronics and Drive Systems.* 2016; 7(4): 1161-1171**. DOI:** 10.11591/ijpedsv7i4.pp1161-1171
8. Bousserhane, I. K., Hazzab, A., Rahli, M., Mazari, B., & Kamli, M. Optimal fuzzy gains scheduling of PI controller for induction motor speed control. *Acta Electrotechnica et Informatica*.2007; *7*(1):1-10.
9. Syed, F. U., Kuang, M. L., Smith, M., Okubo, S., & Ying, H. Fuzzy gain-scheduling proportional–integral control for improving engine power and speed behavior in a hybrid electric vehicle. *IEEE transactions on vehicular technology*. 2009; *58*(1):69-84.
10. Lucas C, Shahmirzadi D, and Sheikholeslami N. Introducing BELBIC: Brain emotional learning based intelligent control. *Intelligent Automation & Soft Computing.* 2004; 10(1): 11–22.DOI: 10.1080/10798587.2004.10642862.
11. Markadeh GRA, Daryabeigi E, Lucas C, Rahman MA. Speed and Flux Control of Induction Motors Using Emotional Intelligent Controller. *IEEE Transactions on Industry Applications.* 2011; 47(3):

1126-1135. **DOI:** 10.1109/TIA.2011.2125710.

12. Zarchi HA, Daryabeigi E, Markadeh GRA, Soltani J. Emotional controller (BELBIC) based DTC for encoderless Synchronous Reluctance Motor drives. *Power Electronics, Drive Systems and Technologies Conference (PEDSTC). Tehran, Iran.* 2011; 478-483. **DOI:** 10.1109/PEDSTC.2011.5742466
13. Dorrah HT, El-Garhy AM, El-Shimy ME. PSO-BELBIC scheme for two-coupled distillation column process. *Journal of Advanced Research*. 2011; 2: 73-83. **DOI**: 10.1016/j.jare.2010.08.004
14. Senthilkumar, S., and S. Vijayan. Review of Emotional Intelligent Controller. *International Journal of Computer Application*. 2013;3 (5): 47-52.
15. Williamson S., Smith A.C.A unified approach to the analysis of single-phase induction motors. *IEEE Transactions on Industry Applications*. 1999; 35(4): 837-843. **DOI:** 10.1109/28.777192
16. Jawad Faiz, Ojaghi M., Keyhani A. PSPICE simulation of single-phase induction motors. *IEEE Transactions on Energy Conversion*. 1999; 14(1): 86-92. **DOI:** 10.1109/60.749152
17. MakowskI, Krzysztof, and Marcin J. Wilk. Determination of dynamic characteristics of the single-phase capacitor induction motor. *Prezglad Electrotechniczny* . 2011; 87(5): 231-237.
18. Jain, J. K., Ghosh, S., Maity, S., & Dworak, P. PI controller design for indirect vector controlled induction motor: A decoupling approach. *ISA transactions*. 2017; 70: 378-388. **DOI**: 10.1016/j.isatra.2017.05.016
19. Shin, E. C., Park, T. S., Oh, W. H., & Yoo, J. Y. A design method of PI controller for an induction motor with parameter variation. *Industrial Electronics Society, 2003. IECON'03. The 29th Annual Conference of the IEEE*. 2003; 1: 408-413. **DOI**: 10.1109/IECON.2003.1280015
20. Zhen-Yu Zhao, Masayoshi Tomizuka, and Satoru Isaka.: Fuzzy gain scheduling of PID controllers. *IEEE transactions on systems Man and Cybernetics*. 1993:23(5):1392-1398. **DOI:** 10.1109/21.260670
21. Hazzab A, Laoufi A, Bousserhane IK, Rahli M. Real time implementation of fuzzy gain scheduling of PI controller for induction machine control. *International Journal of Applied Engineering Research*. 2006; 1(1):51-60.
22. Rahman MA, Milasi RM, Lucas C, Araabi BN, Radwan TS. Implementation of emotional controller for interior permanent-magnet synchronous motor drive. *IEEE Transactions on Industry Applications*. 2008; 44(5):1466-76. **DOI:** 10.1109/TIA.2008.2002206
23. Gunapriya, B. and Sabrigiriraj, M. Real-Time Implementation and Performance Evaluation of Brain Emotional Learning Developed for FPGA-Based PMBLDC Motor Drives. *Journal of Testing and Evaluation*. 2017; 45(3):987-1004. **DOI:** 10.1520/JTE20150269.
24. Shakilabanu, A., and R. S. D. Wahidabanu. BELBIC based high performance IPMSM drive for traction. *Journal of Theoretical & Applied Information Technology*. 2013; 57(3): 631-639.