Design and Analysis of Fuzzy & GA-PID Controllers for Optimized Performance of STATCOM

MUKKU CHANDANPRANEETH[1], DR. T. GOWRI MANOHAR[2]

[1]*MTech Student, Dept. of EEE, Sri Venkateshwara University College of Engineering, Tirupati, India*
[2]*Professor, Dept. of EEE, Sri Venkateshwara University College of Engineering, Tirupati, India*

Abstract:- *Static Synchronous Compensator (STATCOM) is a shunt compensating Flexible Alternating Current Transmission System (FACTS) device capable of solving the power quality problems at the power system. These problems happen in milliseconds and because of the time limitation, it requires the STATCOM that has continuous reactive power control with fast response. One of the most common controlling devices in the market is the Proportional-Integral-Derivative (PID) controller. In this paper, the STATCOM is controlled by Fuzzy Logic controllers and Genetic Algorithm based PID controllers. The best constant values for PID controller's parameters are obtained through trial and error, although time consuming. The simulation results show an improvement in current control response. These methods are tested in MATLAB, and their results are obtained.*

***Key Words*: Fuzzy Logic Controller, Genetic algorithm, PID controller, STATCOM.**

1. INTRODUCTION

Reactive power control is a critical consideration in improving the power quality of power systems. Reactive power increases transmission losses, degrades power transmission capability and decreases voltage regulation at the load end. In the past, Thyristor – Controlled Reactors (TCR) and Thyristor - Switched Capacitors were applied for reactive power compensation. However, with the increasing power rating achieved by solid-state devices, the Static Synchronous Compensator (STATCOM) is taking place as one of the new generation flexible AC transmission systems (FACTS) devices. It has been proven that the STATCOM is a device capable of solving the power quality problems. One of the power quality problems that always occur at the system is the three phase fault caused by short circuit in the system, switching operation, starting large motors and etc. This problem happens in milliseconds and because of the time limitation, it requires the STATCOM that has continuous reactive power control with fast response [3].A STATCOM provides better dynamic performance and minimal interaction with the supply grid. The STATCOM is a shunt connected device. The STATCOM consists of voltage source inverter such as Gate Turn off (GTO) Thyristor, a DC link capacitor and a controller [4]. As a promising technology, the control of STATCOM has been discussed in many literatures [5]-[8]. Many of the methods focus on decoupling the system variables and designing PI controllers. ASTATCOM is a Multiple Input Multiple Output (MIMO) system. It is not possible to totally decouple the system variables. Therefore, the control performance may sometimes be poor. Other control methods apply state feedback control techniques [7], [8], however, very little detail is given in the literature about how to choose the optimal parameters. Some control methods apply state feedback control techniques [3], [10]. For the pole placement method, the controller is based on dynamic model rather than phasor diagram which produces a fast response to the system [3], [10].In order to increase the stability of the system and damping response which makes the inverter in the STATCOM to inject voltage or current to compensate the three phase fault [8]. This type of controller is able to control the amount of injected current or voltage or both from the STATCOM inverters. The PI controller depends on the reactive power, which is the input to the controller for injection of the currents from the STATCOM and cause the controller to have slow response [3]. In PID controller method, it is able to give a fast response. In this paper, a PID control method [10] for STATCOM control is introduced. This method uses a PID controller, with assistances of genetic algorithm, in the STATCOM current control loop. The new method is tested in Matlab, and their results are obtained. The remainder of the paper is organized as follows. Section 2 describes modelling of STATCOM. The design of the proposed control algorithm (PID) is detailed in Section 3, Genetic algorithm is shown in Section 4. The computer simulation results are presented and discussed in Section 5. Finally, Section 6 concludes this paper.

2. MODELING OF STATCOM

In designing the PID controllers, the state space equations from the STATCOM circuit must be introduced. The theory of *dq* transformation of currents has been applied in the circuit, which makes the *d* and *q* components as independent parameters. Fig. 1 shows the circuit diagram of a typical STATCOM. The STATCOM is connected in shunt with the power system and the capacitor is used to supply the voltage to the inverter to solve the power quality problems. One convenient way for studying balanced three-phase system (especially in synchronous machine problems) is to convert the three phase voltages and currents into synchronous rotating frame by *abc/dq* transformation.

The benefits of such arrangement are: The control problem is greatly simplified because the system variables become DC values under balanced condition; multiple control variables are decoupled so that the use of classic control method is possible, and even more physical meaning for each control variable can be acquired. Equations (1) to (4) give the mathematical expression of the STATCOM shown in Fig. 1, [6], [11]. The variable ω is the angular power frequency, and subscripts d, q represent variables in rotating $dq-$ coordinate system.

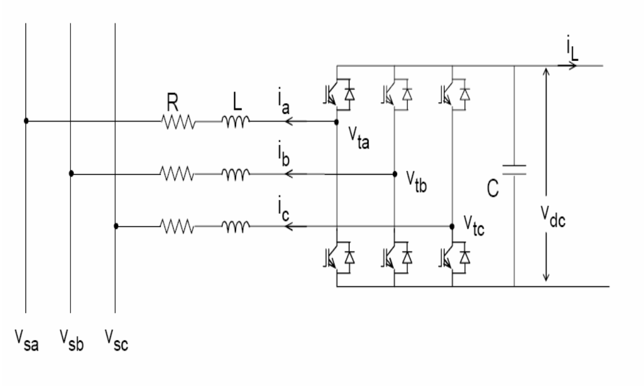

Fig. 1 STATCOM system configuration

$$\frac{di_d}{dt} = -\frac{R}{L} i_d + w i_q + \frac{1}{L}(V_{td} - V_{sd}) \quad (1)$$

$$\frac{di_q}{dt} = -\frac{R}{L} i_q - w i_d + \frac{1}{L}(V_{tq} + V_{sq}) \quad (2)$$

$$\frac{dV_{dc}}{dt} = -\frac{3(V_{td} i_d + V_{tq} i_q)}{2CV_{dc}} - \frac{i_L}{C} \quad (3)$$

$$Q = \frac{3}{2}(V_{sq} i_{sd} - V_{sd} i_{sq}) \quad (4)$$

Given a linear system,

$$\dot{x} = Ax + Bu,$$

$$y = Cx \quad (5)$$

Writing equations (1) and (2) in the state space format as (5), the corresponding matrix can be found as,

$$A = \begin{bmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{bmatrix} \quad , \quad B = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{bmatrix} \quad (6)$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Where the states x, the inputs u, and the output y,

$$x = \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad , \quad u = \begin{bmatrix} V_{td} & -V_{sd} \\ V_{tq} & -V_{sq} \end{bmatrix} \quad (7)$$

$$y = \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

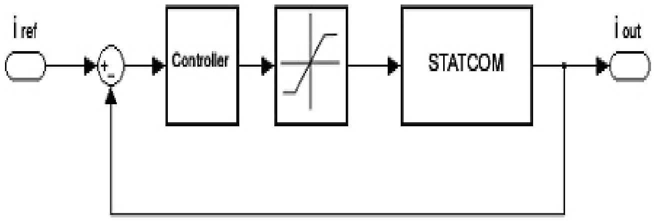

Fig. 2 STATCOM with controllers.

There are different processes for different composition of proportional, integral and differential.

The duty of control engineering is to adjust the coefficients of gain to attain the error reduction and dynamic responses simultaneously. The PID controlling Coefficients are the same as (5).

$$G_{PID}(S) = K_p + \frac{K_1}{s} + K_D s = \frac{K_D s^2 + K_p s + K_1}{s} \quad (8)$$

For PI and PD controllers, the coefficient gain, which is not required, is taken as zero. The above equations can only be applied for complex pole of s_1, *in* case s_1 is real, the zero controller PD, $(Z_0 = K_P / K_D)$, and the zero controller PI, $(Z_0 = K_I / K_D)$, is definite and then their gain are obtained to satisfy the angle criteria and size. In the design of PID controller the amount of *KI* is identified to reach to an intended error in steady state. In PID controller design, *KP*, *KI*, and *KD*, related to the closed loop feedback system within the least time is determined and requires a long range of trial and error. PID control is a linear control methodology with a very simple control structure (see Fig. 2).

This type of controller operates directly on the error signal, which is the difference between the desired output and the actual output, and generates the actuation signal that drives the plant. PID controllers have three basic terms: proportional action, in which the actuation signal is proportional to the error signal, integral action, where the actuation signal is proportional to the time integral of the error signal, and derivative action, where the actuation signal is proportional to the time derivative of the error signal. To design a particular control loop, the values of the three constants (KP, KI, and KD) have to be adjusted so that the control input provides acceptable performance from the plant. In order to get a first approach to an acceptable solution, there are several controller design methods that can be applied. For example, classical control methods in the frequency domain or automatic methods like Ziegler–Nichols, which is the most well-known of all tuning PID methodologies. Although these methods provide a first approximation, the response produced usually needs further manual retuning by the designer before implementation.

3. FUZZY LOGIC CONTROLLER

Fuzzy logic uses fuzzy set theory, in which a variable is member of one or more sets, with a specified degree of membership. Fuzzy logic allow us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague and in complete data, yet by applying a "defuzzification" process, arrive at definite conclusions[2]. The FLC mainly consists of four blocks

- Fuzzification
- Inference
- Defuzzification
- Rule Base

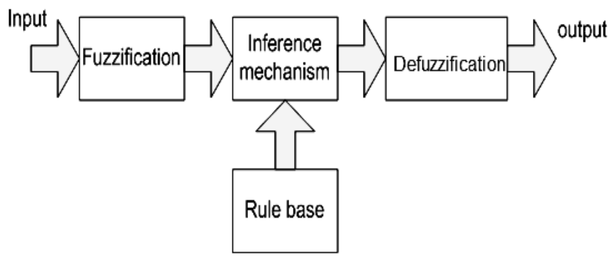

Fig. 3 Block Diagram of a Fuzzy Logic Controller

3.1 Fuzzification

It is the process that converts conventional expressions to fuzzy membership functions. Here triangular membership functions with five levels are taken with membership functions of error and change in error. The best performance of the membership functions can be determined by the trial and error method. The five levels can be described as Negative Big (NB), Negative Small (NS), Zero (ZO), Positive Big (PB), and Positive Small (PS).

3.2 Inference

Fuzzy Inference System is the key unit of a fuzzy logic system having decision making as its primary work. It uses the "IF…THEN" rules along with connectors "OR" or "AND" for drawing essential decision rules. The output from Fuzzy Inference System is always a fuzzy set irrespective of its input which can be fuzzy or crisp set.

3.3 Deffuzification

It is the process that converts fuzzy terms into conventional expressions quantified by real-valued functions.

3.4 Rule Base

The each input variable has five membership functions and each membership function has five levels. Therefore a total of twenty five rules can be formed. The Mamdani's type fuzzy reference system is employed in the rule editor to get the output fuzzy set for every rule.

Table.1 Fuzzy Logic Controller Rule Base

e/ce	**NB**	**NS**	**ZO**	**PS**	**PB**
NB	NB	ZO	ZO	ZO	NB
NS	NB	NS	NS	NS	NB
ZO	NS	NB	NB	PS	NB
PS	PS	PS	NB	PB	PS
PB	PB	PB	NB	NB	PB

4. GENETIC ALGORITHM

GA as a powerful and broadly applicable stochastic search and optimization techniques is perhaps the most widely known types of evolutionary computation method today. In this paper, the GA is employed to find the best *KP*, *KI*, and *KD* parameters. Genetic Algorithms are heuristic search algorithms based on the mechanics of natural selection, genetics and evolution. [11], [12].

4.1 Genetic algorithm procedure

The main procedure of applying GA's to search the optimum parameters of the controller's include:

4.1.1 Encoding:

The first step in applying GA's to the selection of STATCOM controller parameters is Encoding, which maps the parameters of the controller's into a fixed-length string.

4.1.2 Fitness Computation:

According to the comprehensive design objectives as mentioned above.

4.1.3 New Population Production:

New populations are created using three operators: Reproduction, Crossover and Mutation. Reproduction is a process in which individual strings are copied according to their fitness value. Reproduction directs the search toward the best existing individuals but does not create any new individuals. The main operator working on the parents is Crossover, which happens for a selected pair with a crossover probability. Multi-point crossover has been applied to solve combinations of features encoded on chromosomes. Although Reproduction and Crossover produce many new strings, they do not introduce any new information into the population. As a source of new bits, mutation is introduced and is applied with a low probability.

4.1.4 Stopping Criterion:

If all of the objectives are met, the generation cycles will terminate. Otherwise, go to step (2), and compute the fitness for each population.

4.1.5 Decoding:

This process converts binary alphabets into digital numbers, which gives meaning to the strings, after which the controller parameters are finally determined.

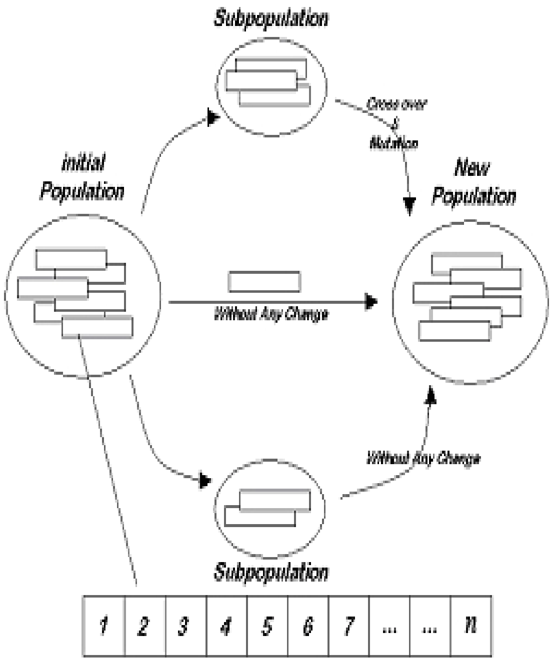

Fig. 4 Schematic of GA operation.

4.2 PID controller design by genetic algorithm

The target function is as follows,

$$F_{obj} = \{(100Ess^{0.5} + 5Mp^2) + (10ts + tr)\} \quad (11)$$

That tr is rise time, ts is settling time, Mp is overshoot and Ess is steady state error.

The genetic algorithm flowchart for PID controller is shown in Fig.5,

The members of every individual are K_P, K_I and K_D,

Population size M=20,

Crossover rate P_C=0.9,

Mute rate P_m=0.01,

The number of generation is 1000.

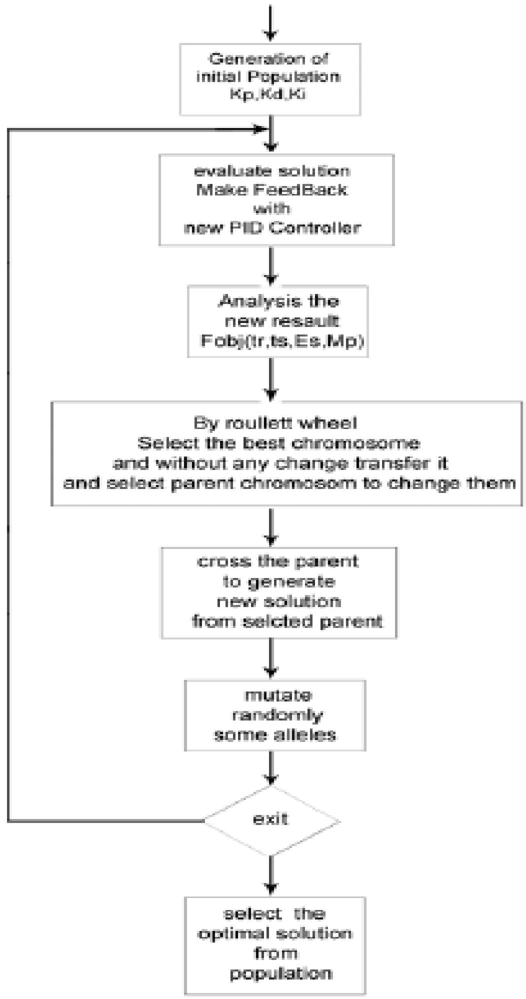

Fig. 5 Genetic algorithm flowchart for PID controller.

5. THE RESULT OF SIMULATION

The system parameters chosen are listed below [9]:

Source line-line voltage: 460 V

DC linkage voltage dc: 800 V

Rated power: 140 KVA

Frequency: 50Hz

Line resistance R: 2mΩ

Line inductance L: 400uH

DC linkage capacitance C 7.8mF

Therefore A, B matrices,

$$A = \begin{bmatrix} -5 & 314.16 \\ -314.16 & -5 \end{bmatrix}, B = \begin{bmatrix} 2500 & 0 \\ 0 & 2500 \end{bmatrix} \quad (9)$$

The STATCOM open loop response will be in the form of Fig. 6. To optimize the id, PID controller method with GA is used.

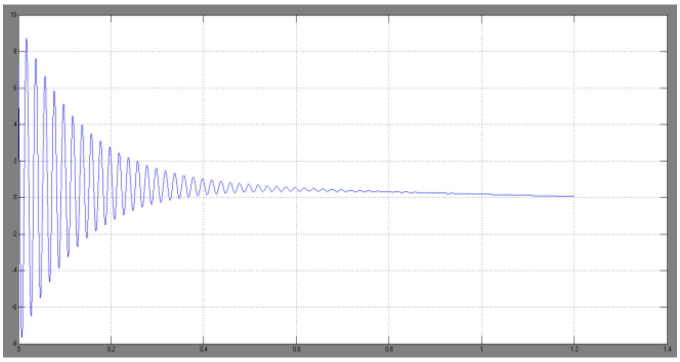

Fig. 6 STATCOM open loop response.

5.1 The result of simulation with PID controller

With various *KP*, *KI*, and *KD* designs, the following results the current response of STATCOM are obtained, The *KP*, *KI*, and *KD* in PID control method in the form of manual and genetic algorithm are presented in Table.1, and their outcomes are illustrated in Fig. 7~9.

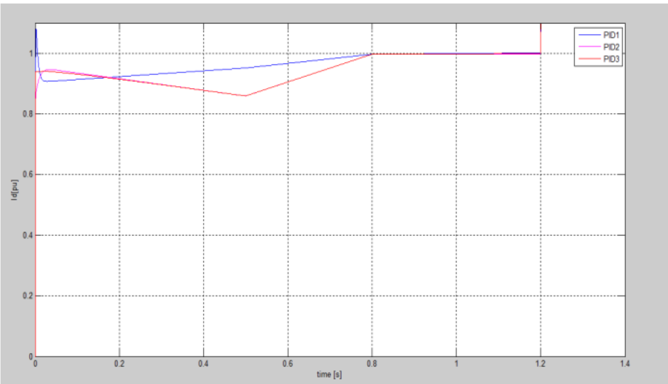

Fig. 7 STATCOM response with PID controllers (PID1,PID2,PID3).

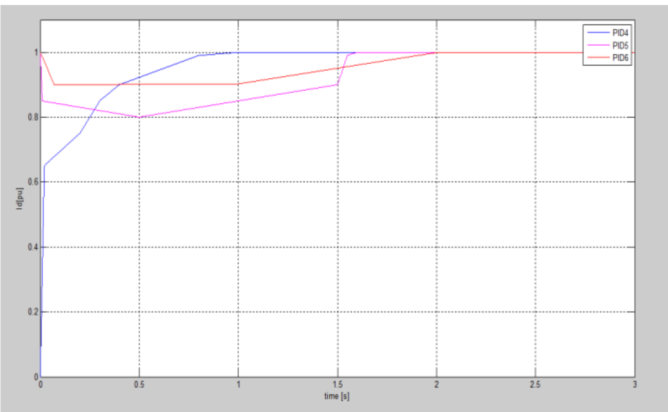

Fig. 8 STATCOM response with PID controllers (PID4,PID5,PID6).

By applying genetic algorithm for placement optimization of the system poles for the improvement of STATCOM response, we obtain the conclusions in Fig.7

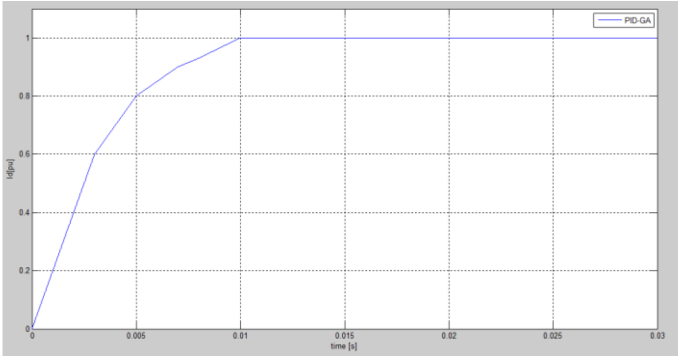

Fig. 9 STATCOM response of PID control methods with GA.

With regard to the results presented in Fig. 9, it is observed that by applying genetic algorithm, PID controller response will improve.

Table.2 PID controller's parameters

	KP	KI	KD
PID 1	0.728	151.64	0
PID 2	1.1	105	0
PID 3	11	105	0
PID 4	0.5	105	0
PID 5	126.8	137.5	0.001
PID 6	26.81	37.55	0.605
PID-GA	782.189	1.65	0

5.2 When sensor noise or system disturbance exist

Although these control methods show us almost the same good performance on the operating point, it is necessary to investigate their robustness. So we need to see the system performance when change from its operating point (*id*=1 pu). First we make the *id* as a step change from 1 pu to 1.5 pu (increase50%).

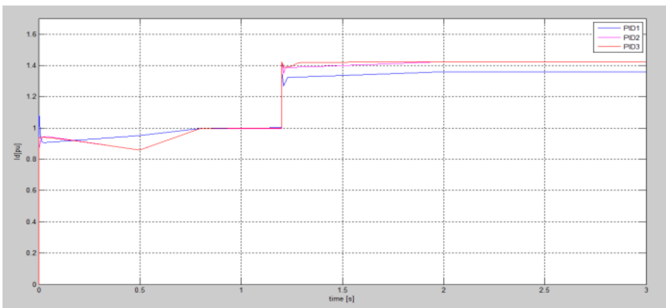

Fig. 10 PID controller(1,2,3) response to a change in the reference active current id from 1 pu.

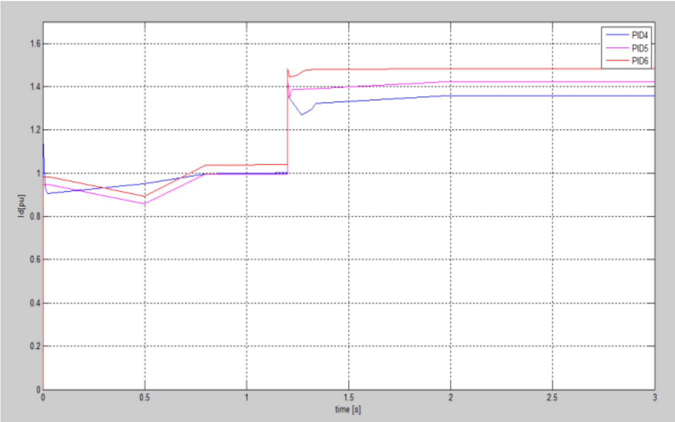

Fig. 11 PID controller(4,5,6) response to a change in the reference active current id from 1 pu.

5.3 The result of simulation with FUZZY controller

Fig. 12, show the system response by using Fuzzy control method. In GA-Fuzzy loop we set *id* have step change from 1 pu to 1.5 pu is less than $1/Fs$ sec.

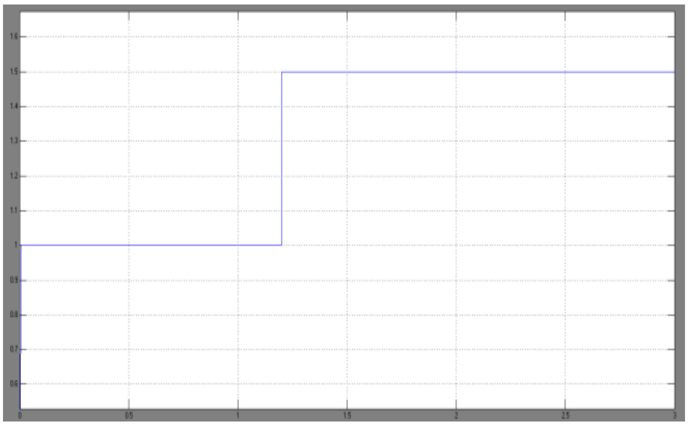

Fig. 12 Fuzzy controller response to a change in the reference active current id from 1 pu.

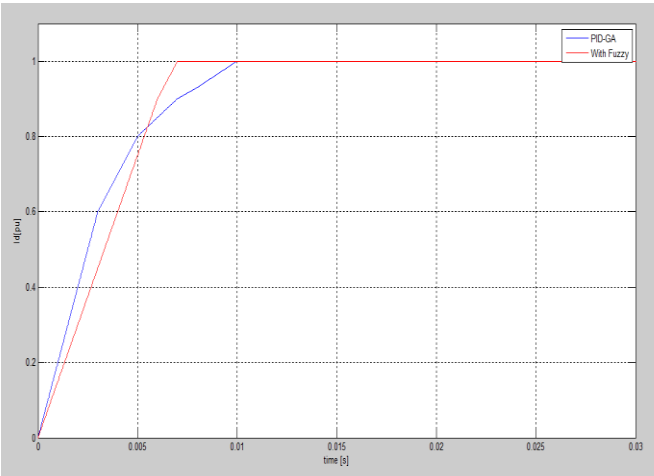

Fig. 13 Comparison of STATCOM response of GA-PID & Fuzzy controllers

6. CONCLUSION

The reduction of output current ripple of the STATCOM is very important. One of the most common controlling devices in the market is the PID controller and Fuzzy Logic Control is able to control the dynamic behavior of the STATCOM. This paper presents a novel design method for determining the PID controller parameters and Fuzzy logic Design. The results can show that the proposed Fuzzy Controller method can obtain high quality solution with good computation efficiency. Therefore, the proposed method has robust stability and efficiency, and can solve the controller parameters more easily and quickly. The system response is reduced by the introduction of Fuzzy Self Tuning controller. While considering the STATCOM currents, the Fuzzy Self Tuning controller plays an important role by increasing the injection ratio. The results of simulation prove the improvement of the performance of Proposed Fuzzy method.

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