GA For Improved Dynamic Response Of DSTATCOM

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ABSTRACT
The performance of D-STATCOM depends on capacitor voltage regulation. In D-STATCOM, the nonlinear controller is preferred to linear controller. Regulating and fixing the capacitor DC voltage in DSTATCOM can improve the system dynamic such as capacitor voltage response, current response and modulation index. The regulation of DC capacitor voltage based on optimal PI co-efficient. In conventional scheme, the trial and error method is used to determine PI values. In this paper genetic algorithm is applied for exact calculation of optimized PI co-efficient, to reduce disturbances in DC link voltage. Optimization and simulations are worked out in MATLAB environment

Keywords – **D-STATCOM, Genetic Algorithm, Nonlinear controller, Optimized PI co-efficient**

1. INTRODUCTION

Static compensator is the static counterpart of the rotating synchronous condenser, but it generates or absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the voltage regulation function .STATCOM is the voltage-source converter, which converts a DC input voltage into AC output voltage in order to compensate the active &reactive needed by the system[1]. It is a device connected in derivation, basically composed of a coupling transformer that serves of link between the electrical power system (EPS) and the voltage synchronous controller (VSC) that generates the voltage wave comparing it to the one of the electric system to realize the exchange of reactive power.

A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter [2]. From the d.c. side capacitor, a three phase voltage convergence is generated by the inverter. This is synchronized with the a.c supply. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM [3]. The STATCOM connected in distributed system is called as DSTATCOM. There are many possible configurations of voltage source inverters (VSI) and consequently many different configurations of DSTATCOM. Many different strategies such as proportional-Integral controller, sliding mode controller [4] and nonlinear controller have been suggested to control DSTATCOM. But in DSTATCOM, nonlinear controller is preferred in comparison with linear method [5]. In non-linear controller, the generalized averaged method [6] has been used to determine the nonlinear time invariant continuous model of the system [7]-[9].This method has been applied to implement a nonlinear control law based on exact linearization via feedback for STATCOM [10].This technique is particularly interesting because it transforms a nonlinear system into a linear one in terms of its input-output relationship. In the literature [7]-[8], only q-axis current was regulated, but it should be noted that unlike other shunt compensators, large energy storage device that have almost constant voltage, makes DSTATCOM more robust and it also enhances the response speed. Therefore, there are two control objectives implemented in DSTATCOM. First is q-axis current and the second is capacitor voltage in dc link[11].Fortunately, q-axes current tracks its corresponding reference value perfectly, but capacitor voltage is not fixed on reference ideally because of the presence of a PI controller between the reference of the d-axes current and DC link voltage error. In other words, the performance indices (settling time, rise time and over shoot) have notable values .thus; the optimized and exact determination of PI gains can lead to reduction in disturbances of system responses.

In this paper, one of the powerful and famous optimization algorithm i.e. genetic algorithm [12.]-[13] is applied to find optimized values of PI gains. Two objective functions are defined. The new PI coefficients, calculated in these ways, are implemented in controller to demonstrate the improvement of convergence speed, reduction error, the overshoot in capacitor voltage and other circuit parameters. The results are compared with trial and error method.

2. Configuration of DSTATCOM

A DSTATCOM consists of a three-phase voltage source inverter shunt-connected to the distribution network by means of a coupling transformer. In general, the DSTATCOM can be utilized for providing voltage regulation, power factor correction, harmonics compensation and load leveling. The ability of the DSTATCOM of supplying effectively extra power allows expanding its compensating actions, reducing transmission losses and enhancing the operation of the electric grid. In this paper, a simplified DSTATCOM configuration is considered. It is shown in Fig. (1).

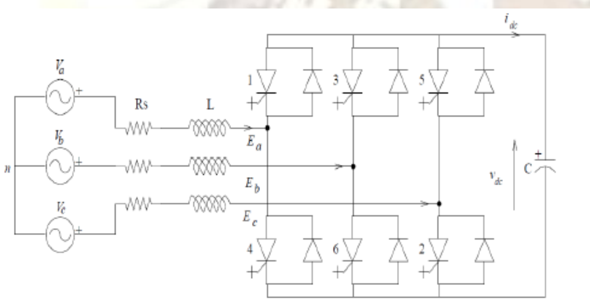

Figure 1. The Representation of DSTATCOM

It consists of a voltage source inverter, a capacitor C, an inductance L (representing the leakage inductance of the transformer and line) and a resistor R_s (representing the inverter and the transformer conduction losses) on the AC side. V_a ,V_b ,V_c are called line voltages. E_a ,E_b ,E_c are the inverter output voltages and V_{dc} is the DC voltage.

The angular velocity of the AC voltage and current vectors is equal to ω. Let us consider a system of reference (d, q) rotating at the same speed, and let us note α the angle between d axis and line voltage vector . The system equations are:

$$\begin{bmatrix} \frac{dI_d}{dt} \\ \frac{dI_q}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & -\omega \\ \omega & -\frac{R_s}{L_s} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \frac{1}{L_s} (V_{dq} - E_{dq})$$

(1)

The model of the AC side in this system of reference is given by equation (1).

The powers are expressed by equation (2):

$$P = \frac{3}{2}(E_d I_d + E_q I_q) , \; Q = \frac{3}{2}(E_d I_q + E_q I_d) \qquad (2)$$

If α is chosen by zero, the E_q voltage is equal to zero and the reactive power becomes proportional to $E_d I_q$. To control the reactive power Q, it is sufficient to control I_q.

$$E_q = 0 \quad , \quad Q = \frac{3}{2} E_d I_q$$

(3)

Rewriting the equation (2) for capacitor voltage and substituting equation (4) in it, results in the third equation will be added to other two equations of eq.(1)

$$P = V_{dc} C \frac{dV_{dc}}{dt}$$

(4)

By applying the Averaged Model used for control, only fundamental harmonics of inverter output voltage is considered. the influence of all harmonics is ignored.

The control variable is δ the firings angle with reference to the network voltage zero crossing(E_j).

In this case, this model is used for simulation purpose, but not to choose and tune the controller. A Generalized Averaging method[6] is used to get a continuous time invariant model of the converter. The averaged equations are:

$$\frac{d}{dt}\begin{bmatrix} I_d \\ I_q \\ V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega & -\frac{M\cos\delta}{L_s} \\ -\omega & -\frac{R_s}{L_s} & -\frac{M\sin\delta}{L_s} \\ \frac{M\cos\delta}{C} & \frac{M\sin\delta}{C} & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ V_{dc} \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} V_s \\ 0 \\ 0 \end{bmatrix}$$

(5)

The nonlinear control law is based on the theory of exact linearization via feedback.

In DSTATCOM system, to compensate the reactive power and eliminating the undesired internal dynamic, Q and V_{dc} are chosen as output control variable. Consequently, the modulation index (m) and δ are chosen as two control inputs variables.

Two proportional controllers are chosen to construct the new inputs (v1 and v2) and an external PI controller is chosen to regulate dc link voltage as shown in fig.(2).Thus the system with nonlinear controller control law and three controllers is modeled.

Considering the Iq channel, the equivalent close-loop transfer function can be described as:

$$\frac{I_q}{I_q^*} = \frac{1}{1+s/\lambda} \quad (6)$$

Where λ determines the response speed of reactive power.

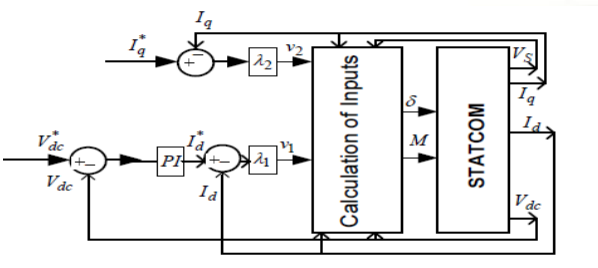

Figure 2. The detail structure of DSTATCOM controller

3. GENETIC ALGORITHM

GAs is adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems. although randomized, Gas are by no means random; instead they exploit historical information to direct the search into the region of better performance within the search space GAs are not function approximation techniques, but they are simple and powerful general purpose stochastic optimization methods(learning mechanisms),which have been inspired by the Darwinian evolution of a population, crossover and mutations in a selective environment where the fittest survive. Genetic algorithm combines the artificial survival of the fittest with genetic operators abstracted from nature to form a very robust mechanism that is suitable for a variety of optimization problems. In other words, we can describe genetic algorithm as a computational model that solves the optimization problems by imitating genetic processes & the theory of evolution. They are better than conventional algorithms in that they are more robust. Unlike older AI systems, they do not break easily even if the inputs are changed slightly or in the presence of reasonable noise[14].

In the natural evolution process of organisms, the reproduction of a set of individuals that forms a certain generation (i.e., population) is such that those individuals with to environmental adaption survive with high probability. Reproduction that is based on the degree of conformity of an individual in a GA as an artificial model that imitates the evolution process of such an organism is performed, and the next-generation population is generated through crossover and mutation. The process is carried out by repeating such genetic operations, and if the individuals of the last generation that fulfills end conditions can be found, the semi-optimal solution may be determined. The flow of the basic operation of the GA shown in Fig.3 is explained below.

1.1 Initialization: An initial population is created from a random selection of solutions (which are analogous to chromosomes).A population is a collection of individuals. A population consists of a number of individuals being tested, the phenotype parameters defining the individuals and some information about the search space. For each and every problem, the population size will depend on the complexity of the problem.

1.2. Selection*:* It is done by using a fitness function and is supposed to be able to compare each individual in the population. It consists in selecting individuals for reproduction. This selection is done randomly with a probability depending on the relative fitness of the individuals so that the best ones are often chosen for reproduction rather than the poor ones.

1.3. Reproduction: The degree of conformity of each object is calculated and an individual is reproduced under a fixed rule depending on the degree of conformity. Here, some individuals with a low degree of conformity will be screened, while individuals with a high degree of conformity will increase.

1.4. Crossover: New individuals are generated by the method of the intersection that has been set up.

1.5. Mutation: This is performed by an operation determined by the installed mutation probability or mutation, and a new individual is generated.

1.6. End judging: If end condition is fulfilled, the best individual thus obtained is the semi-optimal solution, otherwise return to 1.3

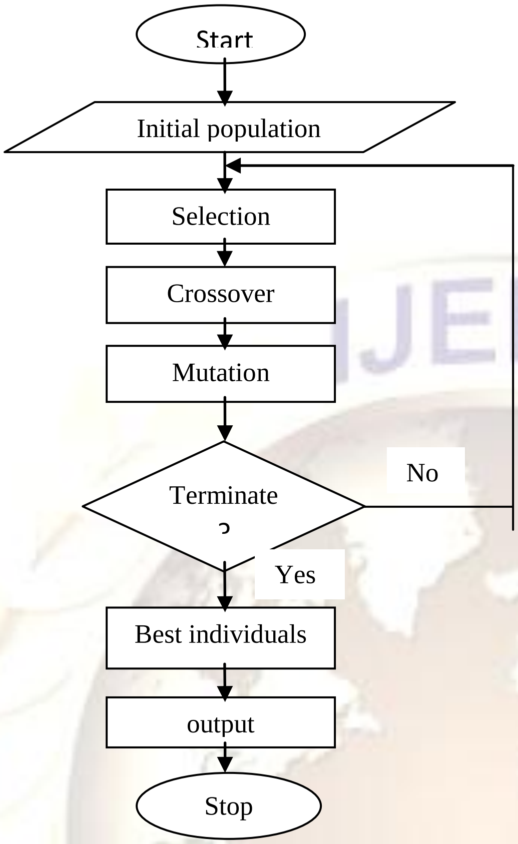

Figure3. Flowchart of Genetic algorithm

1.7. objective function:

ITAE criterion, i.e., integral time absolute error is widely adopted to evaluate the dynamic performance of the control system[15]. The index ITAE is expressed in (7):

$$J_{ITAE} = \int_0^T te(t) \quad (7)$$

Where the upper limit T is a finite time chosen so that the integral approaches a steady-state value and is usually chosen as the setting time Ts.

For the DSTATCOM system, the adopted objective function is:

$$Q_f(Z) = \sum_i m_i f_i(Z) \quad (8)$$

Where

$$f_i(Z) = \sum_j \omega_j \int_0^T t|e_j(t)| \quad (9)$$

f_i Is a performance index corresponding to the No. i objective. m_i is a weighted factor corresponding to the objective. $e_j(t)$ is the error between the real value of the No. j controlled variable and its desired value. ω_i is the weighted factor corresponding to the No. j controlled variable .Vector Z=$[Z_1, Z_2, \ldots \ldots \ldots Z_n]$ is the control system parameters ,i.e., PI parameters.

For the DSTATCOM objective function, the objective function deduced by (7) is expressed in:

$$Q_f(Z) = 1000(\int_0^T t|V_{dc}(t) - V_{dcREF}| + t|I_d((t)| \quad (10)$$

$$Q_f(Z) = f(Z) = 1000(\int_0^T t|V_{dc}(t) - V_{dcREF}| \quad (11)$$

Z=$[K_p \quad K_I]$

The Eq. (10) is used when the goal is controlling the V_{dc} and I_d.Instead, the Eq.(11) is used when V_{dc} is individually regulated.

4. SIMULATION RESULTS

The system parameters of DSTATCOM are as follows:

C=6000(μF), F=50 Hz, Rs=.28 (Ω),L=.0013 (H),

V_a=110 rms(L-L) (V), V_{dc}=200 (V),Initial voltage=200v.

The normal solution for determination of PI gains is trial and error method. Many pairs should be tested. Best of them are selected. Here a set of pairs are tested and finally PI are given as K_p=2 and K_I=90.Due to being certain of optimized PI gains, GA as a powerful, famous and applicable method is applied. In this paper the objective function defined as two types. The first one focuses on capacitor voltage to regulate it independently and the second type according to the fluctuations of I_d and M attempts to insert I_d into objective function. So, both I_d and V_{dc} are regulated in a same weighted factor .The first type of objective function leads to K_p=617.9668 and K_I=39.1076 and the second type of objective function leads to K_p=1.7748 and K_I=150 .The above obtained PI co-efficient are implemented to DSTATCOM. The overshoot is very small and voltage is fixed on 200v.Thus, if the objective is controlling V_{dc} only, this method is very effective and should be chosen, but if the objective is to reduce oscillations in addition to voltage regulation, the double-objective function has to be chosen.

Figs (4-8) describes the simulation results of trial and error method, where the values of K_P=2 and K_I=90.These values cause divergence of DC voltage from steady state quantity. It is obvious that these values are improper for controlling the DSTATCOM. Everyone may select a unit pair and there is no guaranty for them, so to get optimized value genetic algorithm is applied. By doing genetic algorithm programming we got the optimized value that is K_P=617.9668 and K_I=39.1076 and K_P=1.7748 and K_I=150 . Figs (9-18) describes the simulation results of optimized PI gains. However double-objective function technique is preferred option rather than trial and error method because the overshoot and rise time of the system decrease.

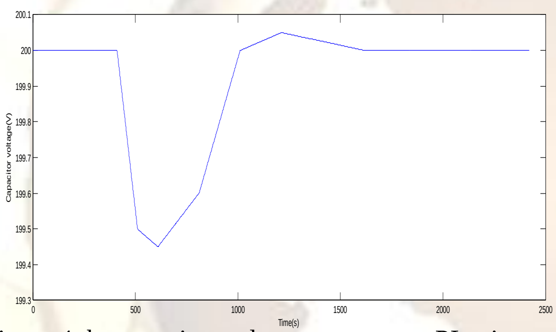

Figure 4 the capacitor voltage response to PI gain

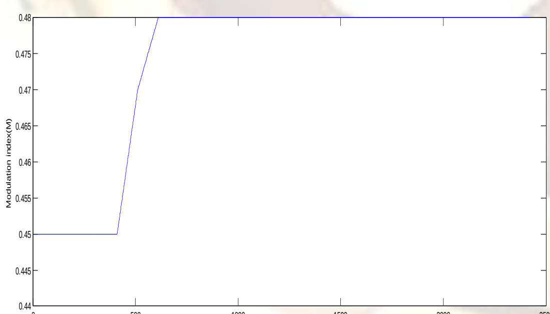

Figure 5 . Modulation index response to PI gain

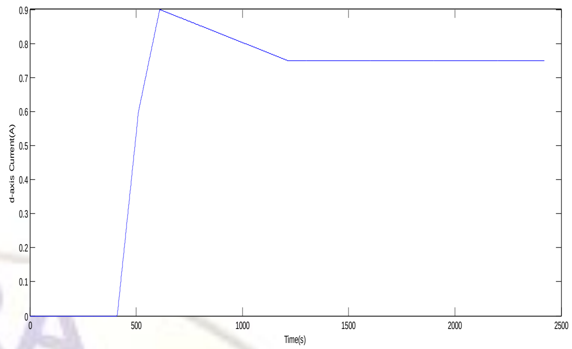

Figure 6. d-axis current response to PI gain

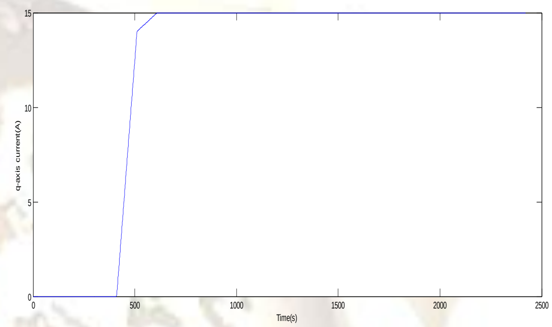

Figure 7. q-axis current response to PI gain

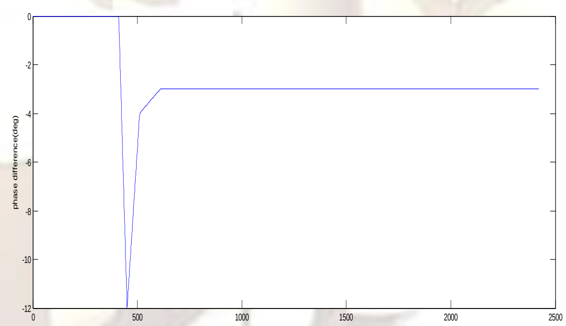

Figure 8. The phase difference response to PI gain

Figs. (9-13), describes the simulation results of single-objective function at K_P=617.9668 and K_I=39.1076.

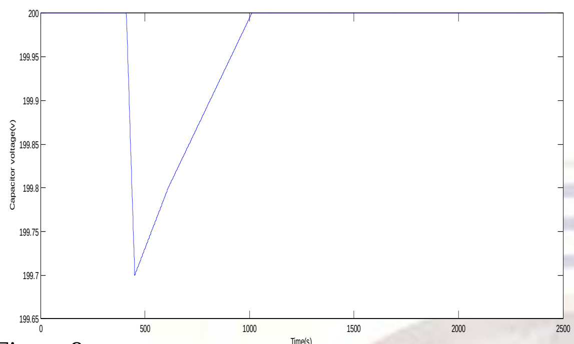

Figure 9.
The capacitor voltage response to optimized PI gain

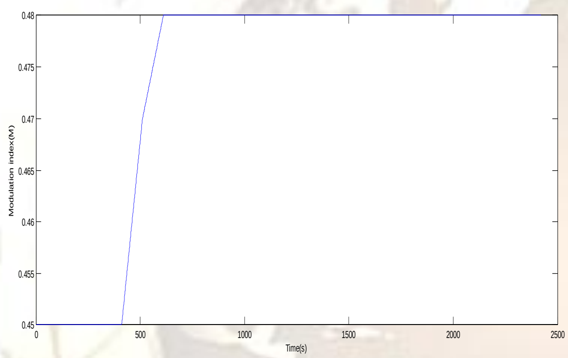

Figure 10. Modulation index response to optimized PI gain

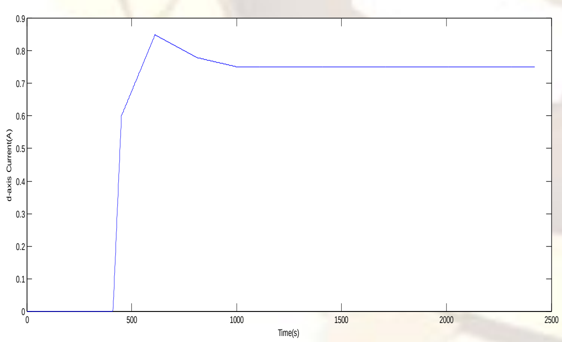

Figure11.d-axis current response to optimized PI gain

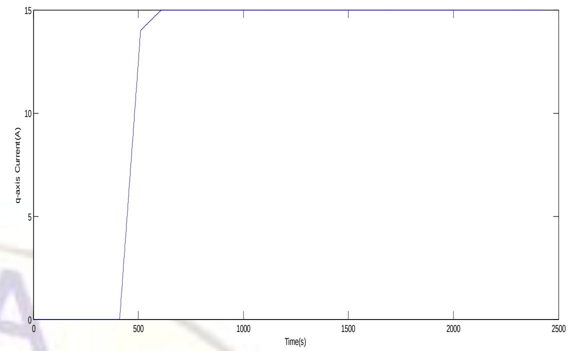

Figure12. q-axis current response to optimized PI gain

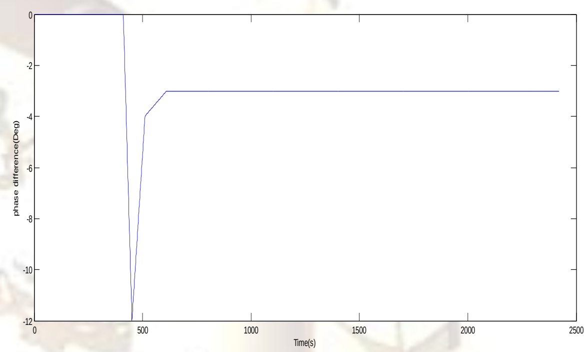

Figure13. The phase difference response to optimized PI gain

The results of implementing double-objective function are shown in figs. (14-18).This double-objective leads to K_P=1.7748 and K_I=150.It completely removes high frequency oscillations.

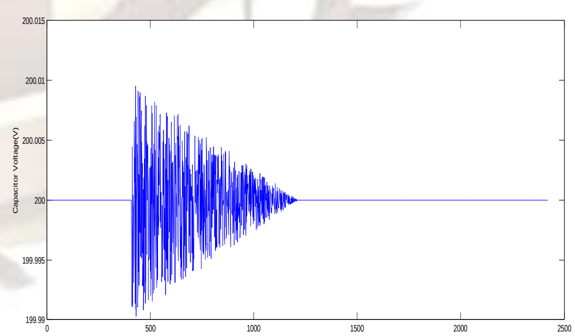

Figure 14. capacitor voltage response to optimized PI gain

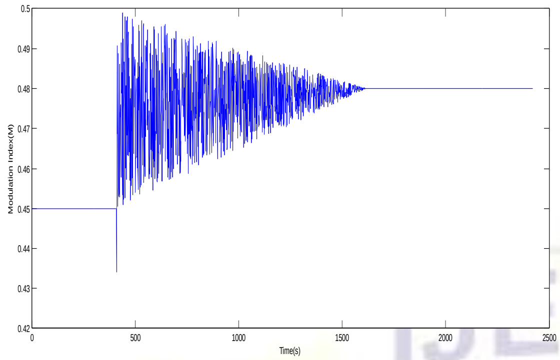

Figure 15. Modulation index response to optimized PI gain

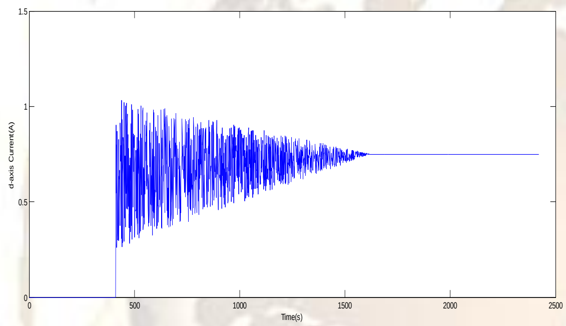

Figure16.d-axis current response to optimized PI gain

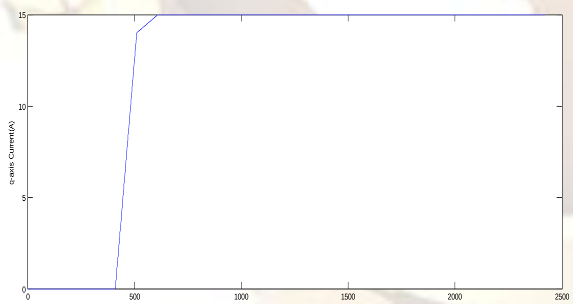

Figure17. q-axis current response to optimized PI gain

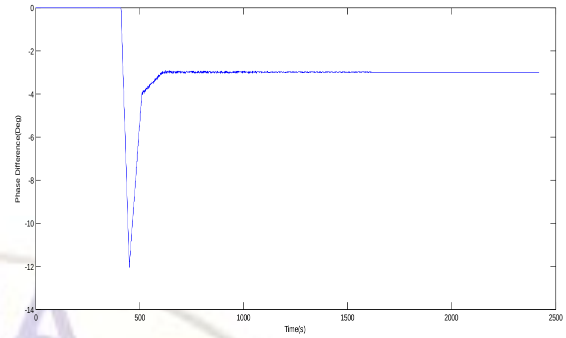

Figure18. The phase difference response to optimized PI gain

5. CONCLUSION

The nonlinear control method of the DSTATCOM which is based on the exact linearization via feedback uses one proportional-integral controller. Normal way to calculate modulation index, capacitor voltage, phase difference and DC link voltage coefficients is using trial and error method. In this paper, genetic algorithm with two types of objective function is suggested. Using this method leads to a better regulation of DC link voltage, d and q-axis currents and other circuit parameters. Actually the time of reaching to steady state value, the fluctuations and overshoot decrease

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