Adaptive Integral-Proportional Controller in Static Synchronous Compensator Based on Genetic Algorithm

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Abstract: - Static Synchronous Compensator (STATCOM) is a 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. In this way, optimal exploitation of STATCOM by classical controllers has been a controversial issue in reputable journals. One of the most common controlling devices in the market is the Integral-Proportional (IP) controller. In this article, the STATCOM is controlled by IP controller. The best constant values for IP controller's parameters are laboriously obtained through trial and error, although time consuming. Genetic algorithm is employed to find the best values for IP controller's parameters in a very short time. The simulation results show an improvement in current control response. These methods are tested in MATLAB, and their results are obtained.

Key-Words: Genetic algorithm, IP 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 [1].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 [2]. As a promising technology, the control of STATCOM has been discussed in many literatures [3]-[6]. Many of the methods focus on decoupling the system variables and designing PI controllers. A STATCOM 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 [5], [6], however, very little detail is given in the literature about how to choose the optimal parameters. Some control methods apply state feedback control techniques [1], [7]. For the pole placement method, the controller is based on dynamic model rather than phasor diagram which produces a fast response to the system [1], [8].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 [6]. 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 [1].

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 modeling of STATCOM. The design of the proposed control algorithm (IP) 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.

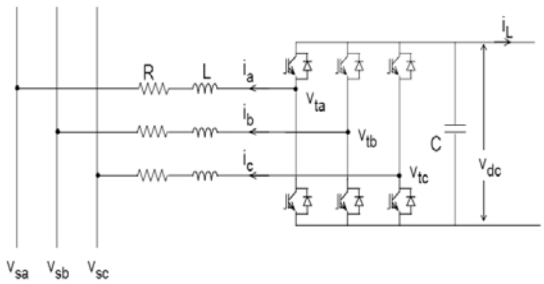

Fig. 1 STATCOM system configuration

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, [4], [9]. The variable ω is the angular power frequency, and subscripts *d*, *q* represent variables in rotating *dq*− coordinate system.

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

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

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

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

Given a linear system,

$$\dot{x} = Ax + Bu \;,$$
$$y = Cx \;. \tag{5}$$

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

$$A = \begin{bmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{bmatrix} \;, \quad B = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{bmatrix} \;, \quad C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \;. \tag{6}$$

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

$$x = \begin{bmatrix} i_d \\ i_q \end{bmatrix} \;, \quad u = \begin{bmatrix} V_{td} - V_{sd} \\ V_{tq} - V_{sq} \end{bmatrix} \;, \tag{7}$$
$$y = \begin{bmatrix} i_d \\ i_q \end{bmatrix} \;.$$

3 Controller Design of IP

One of the most common controlling devices in the market is the IP controller. The order of types of controller positioning is depicted in Fig. 2.

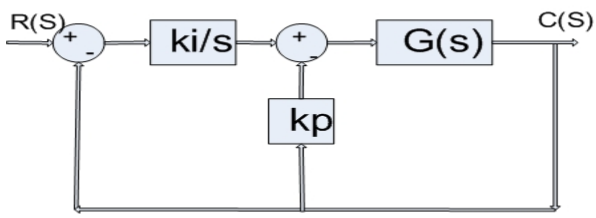

Fig. 2. Block diagram with IP controller

The closed loop transfer function between the output C (s) and the input R(s) is given in (8).

$$\frac{C(s)}{R(s)} = \frac{K_I G(s)}{s(1 + K_P G(s)) + K_I G(s)} \tag{8}$$

Such as:

G(s)= Transfer Function of plant

K_I= Integral *Gain*

K_P= Proportional *Gain*

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. The GA begins with a population of randomly generated candidates and evolves towards a solution by applying genetic operators, modeled on genetic processes occurring in nature. The GA has been used in various optimization problems including optimal control problems [11, 12]. In this paper, we employ the GA to find the best weighting matrices and location of the best poles places.

In 1960 the first serious investigation into Genetic Algorithms (GAs) was undertaken by John Holland. Genetic algorithms have become popular due to several factors. They have been successfully applied to self-adaptive control systems and to function optimization problems. They are a powerful search technique, yet are computationally simple. The search method they use is robust since it is not limited like other search methods with regard to assumptions about the search space.

The genetic algorithm is an algorithm which is based on natural evolution and the survival of the best chromosome. There are three basic differences between genetic algorithm and optimization classical methods. Firstly, the genetic algorithm works on the encoded strings of the problem parameters. Each string is the representative of one answer to the problem, and the real quantities of the parameters are obtained from the decoding of these strings. Secondly, the genetic algorithm is a search algorithm which works on a population of search spaces. This quality causes the genetic algorithm to search different response spaces simultaneously reducing the possibility of being entrapped at local optimized points. Thirdly, the genetic algorithm does not need previous data from the problem response space such as convexity and derivable. It is only necessary to calculate a response function named fitness function. This function expresses the rate of response proximity to the goal function of the intended algorithm. Different methods are used for encoding the parameters in genetic algorithm.

One of the common methods is the binary encoding in which for each parameter depending on the precision required, a few bits are allocated. The problem with this method of encoding is the encoding of the continuous parameters. In order to provide the required precision for the continuous parameters in this method of encoding we have to increase the number of the allocated bits for each parameter which results in longer strings and an increase in the volume of calculations resulting in longer algorithm time.

Another method used in genetic algorithm for the encoding of data is the real encoding. For every parameter in this method one real number is taken into consideration and in addition to the above methods, one can use encoding methods of the genetic functioning defined for these algorithms for real numbers (conversion, value, and tree). The following stages are carried out in the genetic algorithm:

4.1 The formation of initial population

A definite number of chromosomes are randomly selected with regard to the type of the problem.

4.2 Evaluation

Each chromosome from the initial population is processed on the basis of the initial goal of the problem.

4.3 Production of new population

In this stage a new population is selected on the basis of the previous one. The stages for the manufacture of this population are:

4.3.1 Transmit: in this stage the chromosomes with high efficiency are directly transmitted to the new population.

4.3.2 Selection: Two pairs of the remaining chromosomes from the previous population are selected according to their rate of efficiency (each with higher efficiency has in fact higher chance for being selected). Different methods can be selected for the selection of the chromosomes according to their efficiency values.

4.3.3 Crossover: By selecting two chromosomes from the present population, it is tried to improve the efficiency rate of one of the produced chromosomes by employing crossover method. These operations are accompanied with a reduction probability and can happen in one or several points of chromosomes. Fig. 3, depicts the functions of crossover.

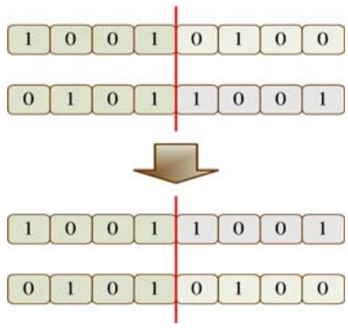

Fig. 3. Single point crossover

4.3.4 Mutation: in this stage it is tried to correct the gene in a chromosome which has caused a reduction in the competence rate of the chromosome. With regard to the kind of the employed encoding the type of this functioning is determined. This functioning is also accompanied with a reduction probability. Fig. 4, depicts the functions of mutation.

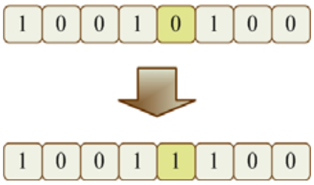

Fig. 4. Binary mutation operator

4.3.5 Reception: the obtained chromosome is placed in the new population according to the previous states.

4.4 Replacement

The newly obtained population is replaced with the previous population and then we return to stage *2*.

4.5 Stoppage

This factor determines the stoppage method of the algorithm, which can be based on the rate of competence proximity of the chromosomes to each other in the new population or is determined on the basis of the number of the produced population in the algorithm. After specifying the critical sections in this article we embark on the formation of chromosomes by binary encoding.

After the determination of the amount of the processing function related to each of the chromosomes, we get on the production of a new population on the basis of the previous population.

Then produce a new population and determine the optimization function rate of the produced chromosomes in the new population. Then, with regard to the amount of optimization function we continue to produce a new population until we reach to the desired point.

4.6 IP Controller Design by Genetic Algorithm

The configuration of the proposed gain-tuning control system for the STATCOM is depicted in Fig. 5, in which the reference model is chosen according to the prescribed time-domain control specifications.

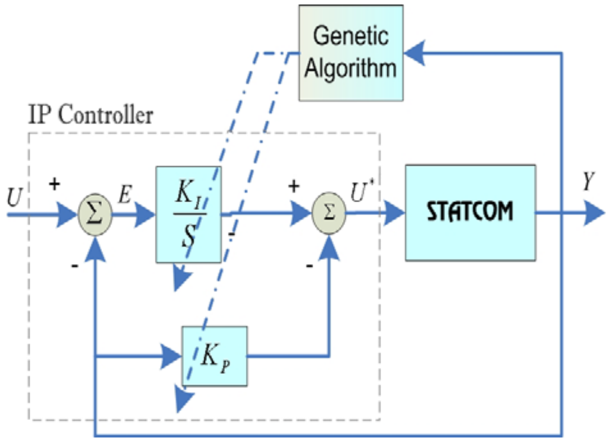

Fig. 5. Block diagram an Adaptive IP control system using GA

Additionally, the set of the number of generations is dependent on the problem. Usually, some simulation has to be done in advance to decide the best number of generations. The target function is as follows,

$$F_{obj} = \left\{ (100 Ess^{0.5} + 5Mp^{2}) + (10ts + tr) \right\} . \quad (9)$$

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

The genetic algorithm flowchart for IP controller is shown in Fig. 6,The members of every individual are K_P ,K_I,,

Population size M=20,

Crossover rate Pc=0.9,

Mute rate Pm=0.01,

The numbers of generation is 1000.

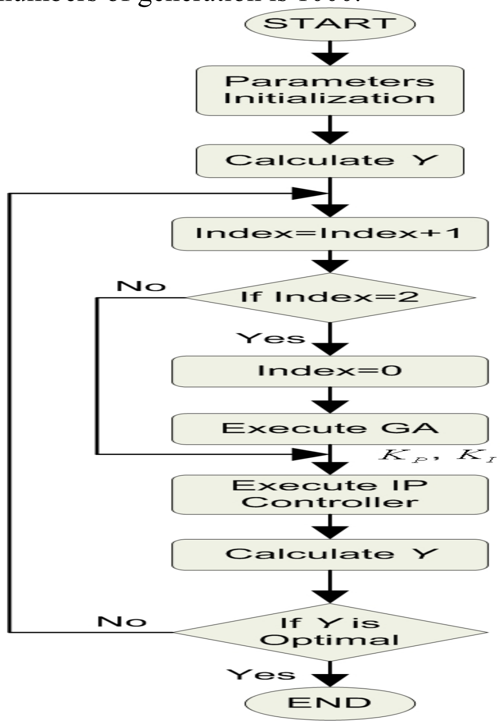

Fig. 6. Genetic algorithm flowchart for IP controller

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: 400μH
DC linkage capacitance C 7.8mF

Therefore A, B matrices,

$$A = \begin{bmatrix} -5 & 314.16 \\ -314.16 & -5 \end{bmatrix}, \; B = \begin{bmatrix} 2500 & 0 \\ 0 & 2500 \end{bmatrix}. \qquad (10)$$

The STATCOM open loop response will be in the form of Fig. 10. To optimize the i_d, IP controller method with GA is used.

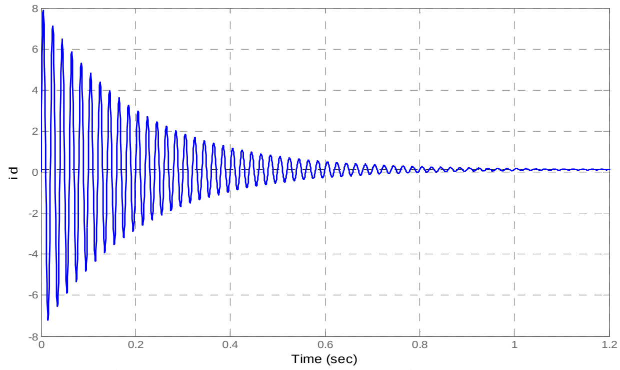

Fig. 10. STATCOM open loop response

As it is evident from the study of outputs, the open loop system has not a good dynamic response, and ideal conditions, for example Mp is higher than 200%. Of course, the outputs will eventually approximate ideal rate with regard to the stability of the system.

5.1 The Result of Simulation with IP Controller

The K_I, K_P in IP control method in the form of manual and genetic algorithm are presented in Table 1, and their outcomes are illustrated in Fig. 11.

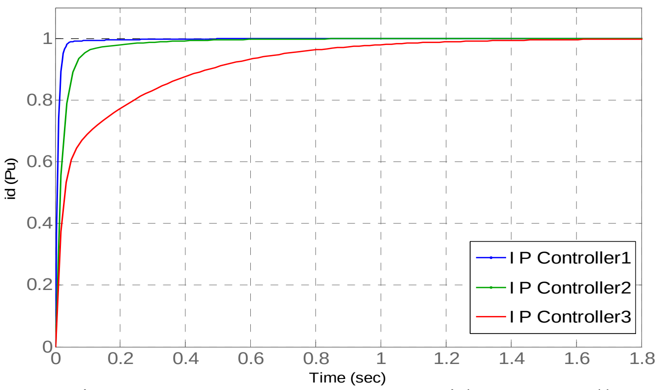

Fig. 11. STATCOM response with IP controllers (IP1, IP2, IP3).

5.1 The Result of Simulation IP Controller with Adaptive Method

By applying genetic algorithm based on the IP controller for the improvement of STATCOM response, we obtain the conclusions in Fig. 12.

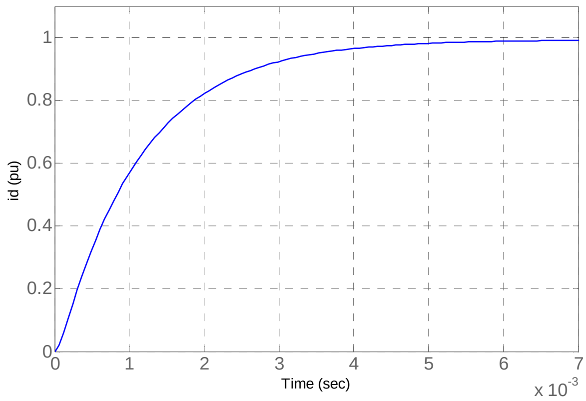

Fig. 12. STATCOM response of IP control methods with adaptive controller.

TABLE 1
IP CONTROLLER'S PARAMETERS

	KI	KP
IP control 1	900.6596	19.498
IP control 2	66.906	1.9498
IP control 3	1282	7.873
IP control -GA	5965.96	6.98

6 Conclusion

The reduction of output current ripple of the STATCOM is very important. One of the most common controlling devices in the market are IP controller and is able to control the dynamic behavior of the STATCOM. In this paper , GA combines with IP controller. So a new control method the Model Reference Adaptive Control method based on the combination of them is presented. The results can show that the proposed GA method can obtain high quality solution with good computation efficiency.

Therefore, the proposed method has robust stability and efficiency, and can solve the searching and tuning problems of IP controller parameters more easily and quickly. The use of genetic algorithm for the calculation of optimum coefficients of IP in the designing of controllers can bring about optimum dynamic response, in a very short time. The results of simulation prove the improvement of the performance of this method.

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