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Optimal proportional-integral controller design for statistic VAR compensator using particle swarm optimization algorithm

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ABSTRACT

In a power system, the most crucial problem is maintaining system stability margins. The main important reasons for occurring stability problem in the system is due to the fault occurs in the power system. In this study, the effect of the statistic VAR compensator (SVC) on the voltage stability margin is investigated by a Proportional Integral (PI) controller. SVC is a parallel kind FACTS device that is used in the power system primarily for the target of voltage and reactive power control. The application of this paper is concerned with is the damping of sways of a synchronous generator and control of the power system voltage. The PI controller parameters of the SVC are of basic importance in ensuring it performs sufficiently. This article introduces a systematic method for PI controller design of an SVC using particle swarm optimization (PSO) algorithm. The PSO-PI controller sketch results in enhanced stability margin of a single machine connected to an infinite bus bar with the SVC system over the classical PI controller or non-controller.

1. Introduction

Power system stability margin enhancements are very significant for big scale power system. The AC power transmission system has diverse bounds, classified as static bounds and dynamic bounds (Ogata, 2002; Garg and Agarwal, 2011; Yousef, 2004). Classically, fixed or mechanically switched parallel and series capacitors, reactors and synchronous generators were being used to improve same types of stability augmentation (Garg and Agarwal, 2011). For many symptoms soughed operation was being unable to attain desirably.

A static VAR compensator is an electrical device for producing fast-acting reactive power compensation on high voltage transmission systems and it can help to enhance the voltage profiles in the transient state and therefore, it can improve the qualities and function of the electric services (Hammad, 1986). An SVC can be controlled externally by using properly designed various kinds of controllers which can enhance voltage stability of a big scale power system.

Researchers also proposed PI controller (Rahman et al., 2012) and system function were surveyed. With a view to getting better operation PID controller has been proposed for SVC to infuse V_{qref} foreign. The dynamic inherent of the SVC lies in the use of thyristor instruments (e.g., GTO, IGCT). So, thyristor based SVC with PI controllers have been used to enhance the function of multi-machine power system.

The PI control has been largely used in industry applications—more than 90% of the used controllers are PI controllers (O'Dwyer, 2009; Astrom and Hagglung, 2006; Visioli, 2006; Kano and Ogawa, 2009; Crowe et al., 2005; Seborg et al., 2010). PI controller was emerged in 1910 and its use and favor had enhance chiefly after the Ziegler–Nichols empirical balance method in 1942 (Ziegler and Nichols, 1942).

The growth in soft computing and digital technology has resulted in many sagacious control structure such as fuzzy logic control (Ghoshal, 2004; Lee, 1990), artificial neural network control system (Fukuda and Shibata, 1992) and adaptive control systems (Astrom and Wittenmark, 1995; Zuo, 1995). But no other method could alternative PI controller and as before said, larger than 90% of industrial applications controllers are now work based on PI control systems.

The optimally hybrid double terms functioning of PI controller can product treatment for both the transient and steady state responses. Actually, optimal control function can just be gained after detecting the finest set of three gains, that is, proportional gain (K_p) and integral gain (K_i).

In last years, many searches have been made by different workers to balance the PI controller variables by different EAs, such as genetic algorithm (GA), cuckoo optimization algorithm (COA), particle swarm optimization (PSO), imperialist competitive algorithm (ICA), tribes algorithm (TA), ant colony optimization algorithm (ACO), and artificial bee colony (ABC) (Bingul, 2004; Chang, 2007; 2009; Coelho and Bernert, 2009; Duan et al., 2006; Gaing, 2004; Mukherjee and Ghoshal, 2007; Zhang et al., 2009; Iruthayarajan and Baskar, 2009; 2010; Menhas et al., 2012).

Soft computing methods can nominate the most optimal sets of controller gains based on a given fitness function in some iterative ways from hundreds of feasible alternate out that best fit the designer's essentials. But the function of several techniques can largely vary in different areas.

It is proven that both exploration and exploitation are essentially needed for the one good optimization algorithms, such as GA, PSO, and ICA and other nature based optimization algorithms. In these optimization methods, the exploration relates to the capability to search the several pathless points in the solution boundary to reach the universal optimum point. As, the exploitation relates to the capability to apply the science of the previous best response to discover better point (Trelea, 2003). Indeed, these two item, i.e., the exploration and exploitation contradict with each other, and in order to gain

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excellent optimization function, the two capabilities might be well tuned. In this article, the PSO algorithm is proposed and used on overall system to achieve the design fitness by balancing the controller parameters at each iteration, repetitively until the favor closed-loop system function is seen.

The rest of article is organized as follows. Sections 2 and 3 explain the SVC. Section 4 explains the PID controller. Section 5 presents the optimization algorithm. Section 6, present the proposed method and shows simulation results and finally Section 7 concludes the paper.

2. SVC- Control concept of SVC

A static VAR compensator (var is defined as volt ampere reactive) is a set of electrical devices for supplying fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics, and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

An SVC is a controlled parallel susceptance (B) which infuse reactive power (Q_{net}) into thereby increasing the bus voltage back to its net favor voltage value. If bus voltage enhance, the SVC will infuse low (or TCR will absorb more) reactive power, and the final will be to gain the favor bus voltage magnitude (Fig. 1). where, $+Q_{cap}$is a set to capacitance value, therefore the amplitude of reactive power infused into the power system, Qnet, is governed by the amplitude of $-Q_{ind}$ reactive power suctioned using the TCR. The basis of the thyristor-controlled reactor (TCR) which conduct on alternate semi-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the tops of the supply voltage, perfect conduction results in the reactor, and the current magnitude is the same as though the thyristor controller were short circuited or SC. Fig. 1 shows the SVC based control system and its structure (Garg and Agarwal, 2011).

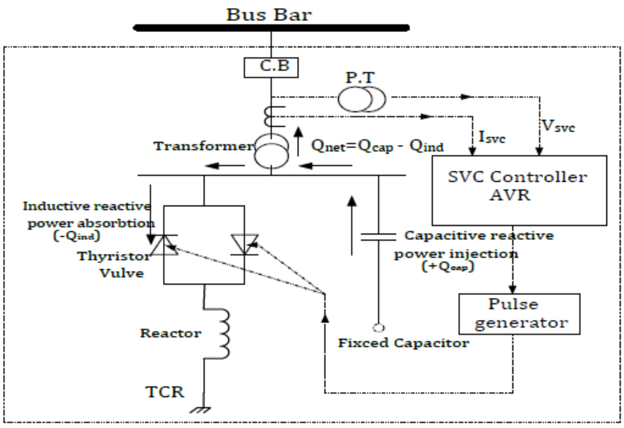

Fig. 1. SVC based control system structure.

3. SVC V-I characteristics

The SVC can be operated in two different states:

a) In voltage regulation state (the voltage is governed within boundaries as described below).
b) In VAR control state (the SVC susceptance is kept fix).

From V-I curve of SVC, and then we will have from Fig. 2.
$V = V_{ref} + X_s.I$: In regulation bound ($-B_{c,\max} < B < +B_{c,\max}$)
$V = I/B_{c,\max}$: SVC is fully capacitive or ($B = B_{c,\max}$)
$V = 1/B_{c,\max}$: SVC is fully inductive or ($B = B_{l,\max}$)

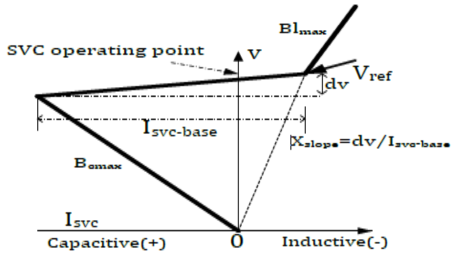

Fig. 2. Steady state (V-I) characteristic of a SVC.

4. PID controller

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) largely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

The PID controller algorithm include three separate constant variables, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. Fig. 3 illustrate a bare block diagram of a control plant controlled by a PID controller. The target of a PID controller, which is the processed fault signal, may be described as below:

$$u(t) = K_p e(t) + K_i \int_0^\infty e(t)dt + K_d e(t) \quad (1)$$

where K_p, K_i, and K_d are the proportional, integral and derivative gains, respectively.

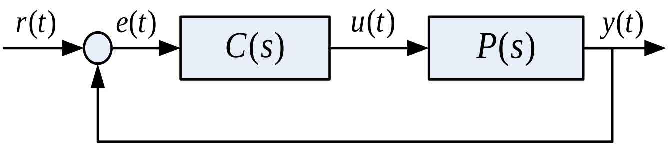

Fig. 3. A plant controlled by a PID controller.

In fact, the goal of PID controllers maxim other controllers is to supply stability and basis tracking and noise cancellation, which are all model favors related to steady boundary of response. Several items have been introduced to evaluate the function of a controller based on the above targets. The most common criteria index ones are the integrated absolute error index (IAE), integrated squared error (ISE), integrated time squared error index (ITSE), and integrated time absolute error index (ITAE). These indices are normally computed below step testing input in the time domain as:

$$\begin{aligned} IAE &= \int_0^\infty |r(t) - y(t)|dt = \int_0^\infty |e(t)|dt \\ ISE &= \int_0^\infty e^2(t)dt \\ ITSE &= \int_0^\infty te^2(t)dt \, (2) \\ ITAE &= \int_0^\infty t|e(t)|dt \end{aligned} \quad (2)$$

It is obvious as they all introduce the concept of fault; minimum value of these indices is favor.

For the transient area of response, maximum overshoot (OS), settling time (t_s) and rise time (t_r) are normally analyzed significant as the profit of faster systems, necessitates minimum possible values for them. For balancing PID controllers that is selecting the optimum parameters for the optimum function, one or a weighted hybrid of these indices is applied. As weights and number of indices are diversely mentioned in the papers, it is commonly accepted that time weighted indices are more appropriate as the errors occurring later in the transient response are penalized heavily. In this article, selection of any of these criteria has been constrained by standard cases, though ISE index is computed and presented independently to make comparisons more sensible.

4. PSO

In computer science, particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position but, is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.

The basic operational principle of the particle swarm is reminiscent of the behavior of a group, for example, a flock of particles or school of fish, or the social behavior of a group of people. Each individual flies in the search space with a speed which is dynamically adjusted according to its own moving experience and its companions' moving experience, instead of using evolutionary operators to manipulate the individuals same in other evolutionary computational algorithms. Each individual is considered as a volume-less particle (a point) in the N-dimensional search space. At time step t, the ith particle is represented as: $X_i(t) = (x_{i1}(t), x_{i2}(t), \ldots, x_{iN}(t))$. The set of location of m birds in a multidimensional space is identified as $X = \{X_1, \ldots, X_j, \ldots, X_l, \ldots, X_m\}$. The best previous position (the position giving the best fitness value) of the ith particle is recorded and represented as $P_i(t) = (p_{i1}, p_{i2}, \ldots, p_{iN})$. The index of the best particle among all the particles in the population (global model) is represented by the symbol g. The index of the best particle among all the particles in a defined topological neighborhood (local model) is represented by the index subscript l. The rate of movement of the position (velocity) for particle i at the time step t is represented as $V_i(t) = (v_{i1}(t), v_{i2}(t), \ldots, v_{iN}(t))$. The particle variables are manipulated according to the following equation (global model) (Kennedy and Eberhart, 1995; Shi and Eberhart, 1998):

$$\begin{aligned} v_{in}(t) &= w_i * v_{in}(t-1) + c_1 * rand1(.) * (p_{in} - x_{in}(t-1)) + c_2 * rand2(.) * (p_{gn} - x_{in}(t-1)) \\ x_{in}(t) &= x_{in}(t-1) + v_{in}(t) \end{aligned} \tag{3}$$

where n is the dimension. $(1 \le n \le N), c_1$, and c_2 are positive constants, rand1(.) and rand2(.) are two random functions in the range [0,1], and w is the inertia weight. For the neighborhood ($lbest$) model, the only change is to substitute $p_{\ln}$ for p_{gn} in the equation for velocity. This equation in the global model is used to calculate a particle's new velocity according to its previous speed and the interval of its current position from its own best experience ($pbest$) and the group's best experience ($gbest$). The native model computation is identical, except that the neighborhood's best experience is used instead of the group's best experience. This algorithm has been used for techniques that may be used across a large bound of areas, and for specific applications focused on a specific essentials. Its effectiveness through nature based optimization algorithms relies in its relative simplicity because only a few variables need to be balanced.

5. Proposed method and simulation results

5.1. Proposed method

In this article, a PI controller is modeled by PSO based on the simple structure (that is PSO-PI controller). To evaluate the ability of the introduced technique the system shown in Fig. 4 will be investigated. The proposed method include of a big generator providing bulk power to an infinite bus through a transmission line in power system, with an SVC fixed at its special bus. SVC is connected by a step down power transformer that shown in figure. The mentioned SVC has govern features identical to synchronous condenser as continuous control action in contrast with existing switched parallel capacitor banks that mentioned before in sections three and four. As illustrated in Fig. 4, the SVC include of a Fixed Capacitor (FC) and Thyristor Controlled Reactor (TCR) in parallel position which can be seen in figure. By governing thyristor, firing angle a variable susceptance is gained (CIGRE, 1986; Chen and Hsu, 1995). To test the effectiveness of proposed technique, some simulations of two cases were done and investigated. In next lines the details of proposed method and obtained results is presented.

- Case 1: System with SVC device and PSO based PI controller or the proposed method.
- Case 2: System with SVC and Conventional or classical PI controller or without optimization.

The way of finding the controller variables to meet given function features is called PID tuning. PSO is used to gain the optimum of K_p, K_i values to the PI controller. In the single machine-infinite bus system that shown in figure with SVC, the method combining PI controller with PSO algorithm is as follow. The variables of PI controller are made as one string and the solution population is composed as N strings. And the fitness function used for the each string evaluation of solution population uses the absolute magnitude summation of speed deviation.

$$Fitness = \sum_{m=1}^{M} |\omega_{\triangle}| \tag{4}$$

Here m is a sampling in case of system application voltage as is combined a string with PI controller variables and M is total sampling number.

The main scheme of optimum PSO-PI controller of SVC system is given as Fig. 4 or the proposed method. The starting operating situation and SVC variables are mentioned in Table 1.

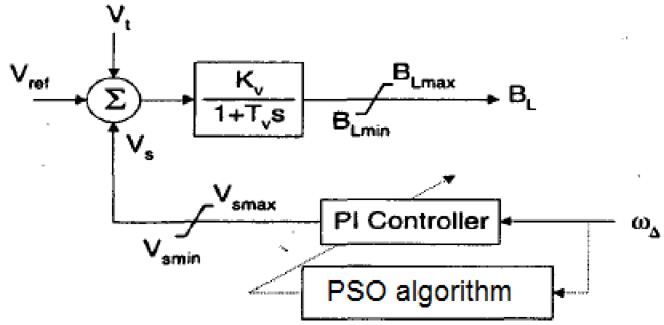

Fig. 4. PSO-PI controller of SVC system.

Table 1
SVC parameters and initial conditions.

$K_v[p.u]$	T_v[sec]	$B_c[p.u]$	$X_T[p.u]$	$B_{L0}[p.u]$	$B_{Lmax}[p.u]$	$B_{Lmin}[p.u]$	$V_{smax}[p.u]$	$V_{smin}[p.u]$
10	0.15	0.6	0.08	-0.45	-0.3	-0.9	0.12	-0.12

5.2. Obtained results

The starting state applied to achieve the variables optimization of PSO-PI controller is in case of the load growth to the nominal output 3% oscillation of power during 100 millisecond in rated load ($P_e = 1.0, Q_e = 0.595$). To test the operation of introduced PSO-PI controller, it is used in single machine infinite bus system with SVC device. The simulations and tests are done in cases of heavy (Study Case one), normal or nominal (Study Case two) and light loads or not heavy load (Study Case three). Each generator reply is collated in cases of the power system with SVC device and PSO-PI controller system that mentioned before (Case one) and system with SVC device and classical PI controller system (Case two).

The bird number applied was 100, $C_1 = 2.2, C_2 = 1.8$ and max iteration is hundred. The optimized PI variables by PSO algorithm are $K_p = 43.76$ and $K_I = 4.15$. The fitness function is shown in Fig. 5. The variation of PI parameters had shown in Figs. 6 and 7.

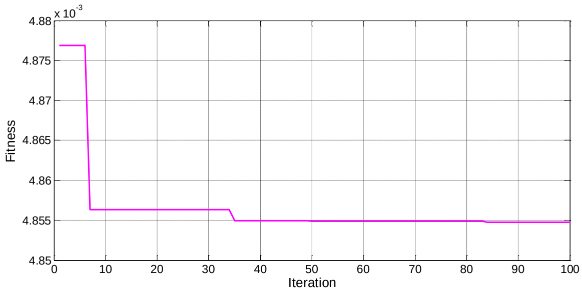

Fig. 5. Fitness.

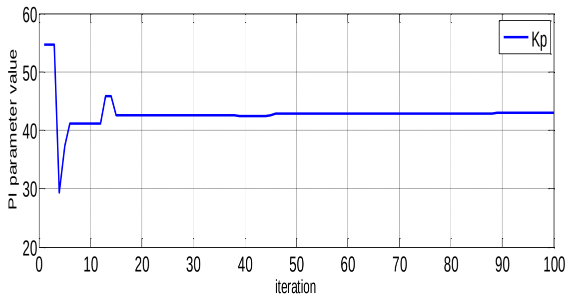

Fig. 6. K_p variation during the PSO search.

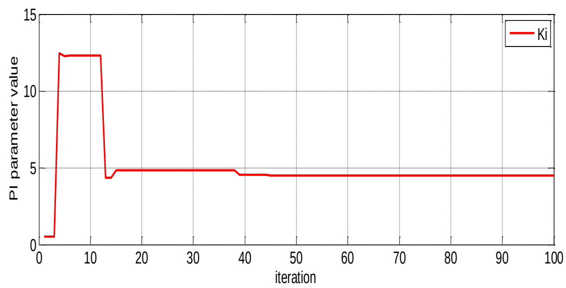

Fig. 7. K_I variation during the PSO search.

The study case situation is the 3% oscillation of starting power during 100 milliseconds shown in Figs. 8-10. From Fig. 8, the reply feature of the bus voltage of heavy load ($P_e = 1.3, Q_e = 0.595$) is most best to those of Case two or normal load that mentioned before. The setting time of Case one or heavy load is better response features as setting time is 0.4 seconds. Figs. 9 and 10 show the output features of generator bus voltage for normal load or case two ($P_e = 1, Q_e = 0.595$) and light load or case one ($P_e = 0.7, Q_e = 0.595$) respectively. Case 1 or heavy load shows very intelligent response performance as setting time is 1.8 and 1 seconds.

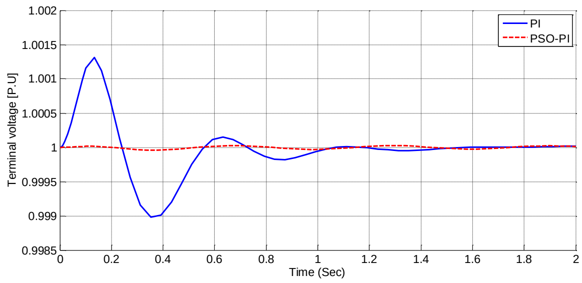

Fig. 8. Terminal voltage for Heavy load.

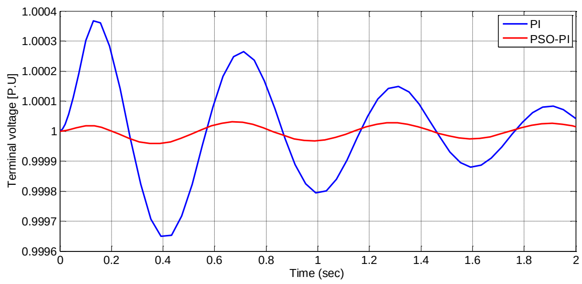

Fig. 9. Terminal voltage for normal load.

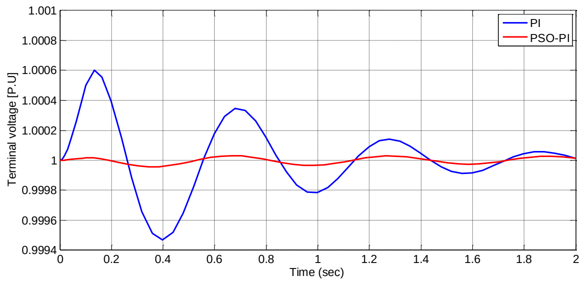

Fig. 10. Terminal voltage for light load.

5.3. Operation test with optimization algorithm in several execution

In this section, for testing the operation of the optimization algorithm, several independent runs have been done. Fig. 11 shows a rate of decrease of the fitness (speed deviation) of the best birds fitness of the generation achieved from introduced system for several runs. As illustrated in this figure, its fitness curves normally enhanced from iteration 0 to 100, and exhibited no notable improvements after iteration 20 for the several independent runs. The optimal stopping iteration to get the best validation accuracy for the several independent runs was about iteration 20–30.

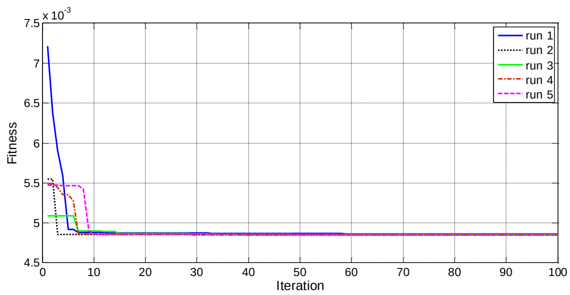

Fig. 11. Evolution of recognition accuracy for different runs.

6. Conclusion and discussion

In this article the application of particle swarm optimization algorithm to optimize the variables of a SVC's PI controller system has been investigated. The powerfulness of the introduced approach for the system dynamic stability margin has been shown computer simulation by two different cases.

- Case one: System with SVC device and PSO-PI controller system.
- Case two: System with SVC device and classical PI controller system.

The dynamic output of generator bus voltage oscillation was investigated. From the simulation results, the notable results were as next:

1) The power distribution system with SVC device has better transient operation stability profile.
2) The variables finding of PI controller using PSO algorithm was very powerful.
3) Appling PSO-PI controller to power system with SVC might result in operation.

Future researches for multi-machine system and high voltage direct current transmission with SVC should be done to evaluate the powerfulness of this system on other systems.

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