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Bacteria Foraging Optimization Algorithm based SVC damping controller design for power system stability enhancement

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ABSTRACT

This paper proposes Bacteria Foraging Optimization Algorithm (BFOA) based Static Var Compensator (SVC) for the suppression of oscillations in a multimachine power system. The proposed design problem of SVC over a wide range of loading conditions is formulated as an optimization problem. BFOA is employed to search for optimal controller parameters by minimizing the time domain objective function. The performance of the proposed technique has been evaluated with the performance of Genetic Algorithm (GA) to demonstrate the superior efficiency of the proposed BFOA in tuning SVC controller. Simultaneous tuning of the Bacteria Foraging based SVC (BFSVC) gives robust damping performance over wide range of operating conditions in compare to optimized SVC controller based on GA (GASVC).

1. Introduction

The power transfer in an integrated power system is constrained by transient stability, voltage stability and small signal stability. These constraints limit a full utilization of available transmission corridors. Flexible AC Transmission System (FACTS) is the technology that provides the needed corrections of the transmission functionality in order to fully utilize the existing transmission facilities and hence, minimizing the gap between the stability limit and thermal limit [1].

Recently, there has been a surge of interest in the development and use of FACTS controllers in power transmission systems [2–6]. These controllers utilize power electronics devices to provide more flexibility to AC power systems. The most popular type of FACTS devices in terms of application is the SVC. This device is well known to improve power system properties such as steady state stability limits, voltage regulation and var compensation, dynamic over voltage and under voltage control, and damp power system oscillations. The SVC is an electronic generator that dynamically controls the flow of power through a variable reactive admittance to the transmission network.

In last few years, many researchers have posed techniques for designing SVC to enhance the damping of electromechanical oscillations of power systems and improve power systems stability. A robust control theory in designing SVC controller to damp out power system swing modes is presented in [7]. An adaptive network based fuzzy inference system (ANFIS) for SVC is presented in [8] to improve the damping of power systems. A multi input, single output fuzzy neural network is developed in [9] for voltage stability evaluation of the power systems with SVC. A method of determining the location of a SVC to improve the stability of power system is illustrated in [10]. A systematic approach for designing SVC controller, based on wide area signals, to improve the damping of power system oscillations is presented in [11]. Genetic Algorithm (GA) optimization technique is employed for the simultaneous tuning of a power system stabilizer (PSS) and a SVC based controller in [12]. A state estimation problem of power systems incorporating various FACTS devices is addressed in [13]. A novel hybrid method for simulation of power systems equipped with SVC is suggested in [14]. The design of SVC with delayed input signal using a state space model based on Pade approximation method is presented in [15]. A new optimization algorithm known as Bacteria Foraging Optimization Algorithm (BFOA) for designing SVC to damp power system electromechanical oscillations for single machine infinite bus system is introduced in [16]. An application of probabilistic theory to the coordinated design of PSSs and SVC is employed in [17]. The application of the decentralized modal control method for pole placement in multimachine power system utilizing FACTS devices is developed in [18]. The parameter tuning of a PID controller for a FACTS based stabilizer employing multi-objective evolutionary algorithm is illustrated in [19]. A comprehensive assessment of the effects of the PSS and FACT device when applied independently and also through coordinated application is carried out in [20]. BFOA based Thyristor Controlled Series Capacitor (BFTCSC) for the suppression of oscillations in a multimachine power system is investigated in [21]. A robust de-

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sign algorithm for the simultaneous coordinated tuning of the SVC damping controller and PSS in a multimachine power system is addressed in [22].

Recently, global optimization technique like GA, has attracted the attention in the field of controller parameter optimization [23]. Unlike other techniques, GA is a population based search algorithm, which works with a population of strings that represent different solutions. Therefore, GA has implicit parallelism that enhances its search capability and the optima can be located swiftly when applied to complex optimization problems. Unfortunately recent research has identified some deficiencies in GA performance [24]. This degradation in efficiency is apparent in applications with highly *epistatic* objective functions (i.e. where parameters being optimized are highly correlated). Also, the premature convergence of GA degrades its performance and reduces its search capability.

BFOA is proposed as a solution to the above mentioned problems and drawbacks [25]. Moreover, BFOA due to its unique dispersal and elimination technique can find favorable regions when the population involved is small. These unique features of the algorithms overcome the premature convergence problem and enhance the search capability. Hence, it is suitable optimization tool for power system controllers.

This paper proposes a new optimization algorithm known as BFOA for optimal designing of the SVC damping controller in a multimachine power system to damp power system oscillations. BFOA is used for tuning the SVC controller parameters. The design problem of the proposed controller is formulated as an optimization problem and BFOA is employed to search for optimal controller parameters. By minimizing the time domain objective function, in which the deviations in the speed mode are involved; stability performance of the system is improved. Simulations results assure the effectiveness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions. Also, these results validate the superiority of the proposed method in tuning controller compared with GA.

2. Bacteria Foraging Optimization: a brief overview

The survival of species in any natural evolutionary process depends upon their fitness criteria, which relies upon their food searching and motile behavior. The law of evolution supports those species who have better food searching ability and either eliminates or reshapes those with poor search ability. The genes of those species who are stronger gets propagated in the evolution chain since they posses ability to reproduce even better species in future generations. So a clear understanding and modeling of foraging behavior in any of the evolutionary species, leads to its application in any nonlinear system optimization algorithm. The foraging strategy of *Escherichia coli* bacteria present in human intestine can be explained by four processes, namely chemotaxis, swarming, reproduction, and elimination dispersal [25,26].

2.1. Chemotaxis

The characteristics of movement of bacteria in search of food can be defined in two ways, i.e. swimming and tumbling together knows as chemotaxis. A bacterium is said to be 'swimming' if it moves in a predefined direction, and 'tumbling' if moving in an altogether different direction. Mathematically, tumble of any bacterium can be represented by a unit length of random direction $\varphi(j)$ multiplied by step length of that bacterium $C(i)$. In case of swimming, this random length is predefined.

2.2. Swarming

For the bacteria to reach at the richest food location (i.e. for the algorithm to converge at the solution point), it is desired that the optimum bacterium till a point of time in the search period should try to attract other bacteria so that together they converge at the desired location (solution point) more rapidly. To achieve this, a penalty function based upon the relative distances of each bacterium from the fittest bacterium till that search duration, is added to the original cost function. Finally, when all the bacteria have merged into the solution point, this penalty function becomes zero. The effect of swarming is to make the bacteria congregate into groups and move as concentric patterns with high bacterial density.

2.3. Reproduction

The original set of bacteria, after getting evolved through several chemotactic stages reaches the reproduction stage. Here, best set of bacteria (chosen out of all the chemotactic stages) gets divided into two groups. The healthier half replaces with the other half of bacteria, which gets eliminated, owing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process.

2.4. Elimination and dispersal

In the evolution process, a sudden unforeseen event can occur, which may drastically alter the smooth process of evolution and cause the elimination of the set of bacteria and/or disperse them to a new environment. Most ironically, instead of disturbing the usual chemotactic growth of the set of bacteria, this unknown event may place a newer set of bacteria nearer to the food location. From a broad perspective, elimination, and dispersal are parts of the population level long distance motile behavior. In its application to optimization, it helps in reducing the behavior of *stagnation* (i.e. being trapped in a premature solution point or local optima) often seen in such parallel search algorithms. The detailed mathematical derivations as well as theoretical aspect of this new concept are presented in [27,28].

3. Problem statement

3.1. Power system model

A power system can be modeled by a set of nonlinear differential equations are:

$$\dot{X} = f(X, U) \tag{1}$$

where X is the vector of the state variables and U is the vector of input variables. In this study $X = [\delta, \omega, E'_q, E_{fd}, V_f]^T$ and U is the SVC output signals. Here, δ and ω are the rotor angle and speed, respectively. Also, E'_q, E_{fd} and V_f are the internal, the field, and excitation voltages respectively.

In the design of SVC, the linearized incremental models around an equilibrium point are usually employed. Therefore, the state equation of a power system with n machines and m SVC can be written as:

$$\dot{X} = AX + Bu \tag{2}$$

where A is a $5n \times 5n$ matrix and equals $\partial f/\partial X$ while B is a $5n \times m$ matrix and equals $\partial f/\partial U$. Both A and B are evaluated at a certain operating point. X is a $5n \times 1$ state vector and U is an $m \times 1$ input vector.