DESIGN OF PSS USING BEES COLONY INTELLIGENCE

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ABSTRACT

This paper report the development of a new optimization technique based on the biological behaviour of a colony of honey bees. The optimization method is prepared by closely imitating the foraging pattern of bees. The development of the algorithm and their validation is well documented in this work. The optimization scheme is then applied for a classical problem of design of Power System Stabilizer (PSS). Simulation results are carried out to validate the proposed algorithm.

Key words— Optimization, Bees, Power System Stabilizer.

I. INTRODUCTION

The stable operations of a synchronous machine, its ability to maintain the quality of electrical power delivered to the consumers and the economy in the generation cost with maximum possible power transfer are some of the requirements to be considered in the design of electrical power system. One of the effective means of achieving the above requirements is by providing an efficient excitation controller for synchronous machine. The realization of power system stabilizer (PSS) is based on the idea that the use of supplementary control signal in the excitation system of the generating unit can provide extra damping for the system and thus improve the machine dynamic performance [1]. This is the easy, economical and flexible way to improve power system stability. Over the past few decades, many types of PSSs have been extensively studied and some of them have been successfully used in the field.

The conventional PSS was based on a linear model of the power system at some operating point and classic control theory was employed as the design tool [2]. With the increasing demand for quality power, modern control techniques like optimal control theory [3] and high-gain control theory [4] have been proposed for supplementary excitation controllers. Power systems are dynamic systems and the operating point of the system will change with varying system load.
To improve the damping characteristics of a power system over wide operating points, adaptive stabilizers or self-tuning controllers have been proposed [5-8]. In these controllers the system model is first identified in real time using the measured system input and output variables. The gain settings are then computed based on the model and the adaptation law. Even though better dynamic response can be achieved by self-tuning controllers, the major hurdle is the need to identify system model in real time, which is very time consuming.

Recently artificial neural networks (ANN) [9] and fuzzy logic principles [10] are applied for the realization of adaptive PSS. It is shown that ANN based PSS can provide good damping of the power system over a wide operating range and significantly improve the dynamic performance of the power system. Fuzzy excitation controller also improves the dynamic response of the power system at different operating points. In addition, fuzzy controller does not require model identification and thus can be easily implemented on a microcomputer.

The contribution of this paper lies in the development of a new optimization algorithm developed by the authors which closely mimic the behavior of honey bees [11]. Literature survey shows that attempts have been made recently by the researchers to utilize the behavior of honey bees for a few applications [12-18]. The foraging behavior of honey bees is also used for optimization algorithms for various applications such as training of learning vector quantization networks [15], job scheduling [16], optimizing neural networks [17] etc.

In this work, we have developed a algorithm which fundamentally imitate natural behavior of a colony of honey bees in nectar collection and reproduction. The first proposal mimics the foraging behavior of honey bees. The randomly generated worker bees are forced to move in the direction of the elite bee, which locates the best possible solution. The movement is made based on a probabilistic approach and the step distance of flight of bees is made as a variable parameter in the algorithm [19-25].

The algorithm is used for the design of PSS for a single machine connected to infinite bus system and the results are discussed. It is shown that the newly proposed scheme is derivative-free, efficient in locating the global optima with reduced number of iterations, independent of initial values, and are robust in their convergence characteristics.


The honey bees are believed to be originated in Tropical Africa and spread from South Africa to Northern Europe and East in to India and China. A typical small hive contains approximately 20,000 bees and the bees in a hive are divided into three different types: Queen, Drone and Worker. The functions, sex, life span and physical size of these three categories are largely different. The sole function of the queen is re-production; it is female, and can live up to two years. The queen is the mother of all bees in the hive. The size of queen is larger with its abdomen noticeably longer than the other bees. Drone is a male bee which survives about 21-32 days in spring or 90 days in summer. Drones are medium in size and are designated for mating only. Drone’s eyes and antennae are specially designed for seeing, following and mating with a queen. They can fly fast to catch up with a queen. Queens and drones do not have effective body parts for harvesting honey or pollen for self feeding. Worker bees are sterile females and they have numerous functions. Worker bees make comb, clean and defend hive, gather honey and pollen, and tend queen and young drones. They are small in size and survive up to 20-40 days in summer and 140 days in winter.

II. 1. Foraging behavior of honey bees

The foraging behavior of honey bees is quite interesting and it is found that bees are fairly adept at effective communication of food sources. In the hive, the worker bees are responsible for food collection. A few worker bees are sent to different random directions and a single bee visits many different flowers in the morning. If there is sufficiently large food, the bee makes many transits
between the flowers and its hive. The floral findings are communicated to other worker bees in the hive through a “dancing”. A bee which returns from an area which has many flowers producing much honey/pollen performs a dance on the comb. The orientation of her movements together with frequency of vibrations indicates the direction and distance of flowers from the hive. This dance serves as an effective way of communication among worker bees. The other worker bees waiting in the hive will observe this dance and will come to know the location and quantity of food source. All the worker bees, who had found flowers, will perform dances; but majority of worker bees will follow the “elite” bee- the bee which had located better and nearer food source than the remaining. This mechanism helps the colony to gather food quickly and efficiently.

II. Development of optimization algorithm based on foraging behavior

As can bee in the previous section, worker bees perform the task of food collection in an optimized manner. This makes it possible to build an optimization algorithm. The bees can be placed initially at random locations in the solution space; the bee at the “best” location- the location where the objective function is minimum- can be treated as “elite” bee. In nature, majority of worker bees follow the elite bee, while remaining bees fly to other less attractive locations. This can be perceived as a probabilistic approach. Thus, it can be assumed that, based on a probability, some fly towards the location of the elite bee and the left out bees to other locations. The complete algorithm developed by the authors is given in the following steps:

Let the optimization task is defined as follows:

Minimize: \( F(x) \) \hspace{1cm} (1)

subject to,

\[ x_l \leq x \leq x_u. \] \hspace{1cm} (2)

In the above, \( F(x) \) is a scalar valued objective function and \( x_l \) and \( x_u \) are the lower and upper bounds of the variable.

Step 1: Deploying bees initially at random locations

The initial step involved is deploying the bees in a feasible solution space subject to the constraints imposed on the solution variables. Here, position of a bee refers to one complete solution set to the problem. For generality, let the bees be described as \( B_1, B_2, \ldots, B_n \), where \( n \) is the number of bees and can be termed as population size. For \( n = 4 \), initial random position of bees is shown in figure 1(a).
Figure 1. Bee movement. (a) Initial poison of bees. (b) Indication of duration of dance. (c) Probability of movement. (d) Bee flight for $p_i \geq p_t$. (e) Bee flight for $p_i < p_t$. (f) Final position of bees.
Step 2: Evaluation of objective function value

The objective function value, \( F(\phi) \) at each bee position is evaluated using equation 1.

Step 3: Computation of duration of dance of each bee

In this step, depending on the floral findings, each worker bee performs dance on the comb. The duration of dance is a measure of quantum of food and let \( D_d \) represent the duration of dance. The duration of dance of the \( i \)-th bee in the \( j \)-th location at \( t \)-th iteration is given in equation 3.

\[
D_{di(j)}(t) = \frac{1}{F_{i,j}(\phi) + 1} \quad (3)
\]

The duration dance of bees is indicated in circles and the size of the circle is used to measure \( D_d \). This is illustrated in figure 1(b).

Step 4: Identification of elite bee.

The bee, whose location gives maximum value for \( D_d \) is designated as elite bee. Thus elite bee, \( B_e \) in the \( t \)-th iteration is given by equation (4).

\[
B_e(t) = \max_{i,j} \left( D_{di(j)}(t) \right) \quad (4)
\]

In figure 1(c), \( B_4 \) is the identified as the elite bee.

Step 5: Movement of bees

Majority of bees follow the elite bee; however, few bees may fly to other flower patches too. Hence the movement of bees can be thought of based on a probability. This will make the search more probabilistic and may yield better results. A term named as threshold probability is therefore introduced and is denoted as \( p_t \). The value of \( p_t \) is fixed at a suitable value between 0 and 1.

In order to find the direction of flight of a particular bee, a random number between 0 and 1 is generated denoted as \( i_p \) and is compared with \( p_t \).

For \( p_i \geq p_t \), then the bee flies a distance of \( R_i \) towards the elite bee. The distance of flight, denoted as \( R_i \) is a variable in the problem and is to be judicially chosen.

In figure 1(c), for bees \( B_1 \) and \( B_2 \), \( p_i \geq p_t \) and hence will move towards the elite bee. The flight of \( B_1 \) and \( B_2 \) is shown in figure 1(d) where \( B_1 \) flies a distance of \( R_1 \) towards the elite bee, \( B_4 \) and reaches the point, Y. Similarly, bee \( B_2 \) flies a distance of \( R_1 \) towards \( B_4 \) and reaches the point, X.

For \( p_i < p_t \), then that bee flies a distance of \( R_1 \) towards any other bee location, which is randomly decided between 1 and \( n \). This is demonstrated in figure 1(e). The bee, \( B_3 \) falls in the category of \( p_i < p_t \) and hence flies a distance of \( R_1 \) towards any other bee location. For this, a random number between 1 and \( n \) is generated. Let the number be 1 so that \( B_3 \) moves towards the past location of \( B_1 \).

Thus, \( B_3 \) reaches point Z. When all bees make a flight of distance \( R_1 \), one iteration is completed. The final position of all bees after one iteration is shown in figure 1(f).

Step 6: End the program, if termination criterion is reached; else go to step 2.
III. APPLICATION OF THE ALGORITHMS FOR PSS DESIGN

III. 1. Single machine infinite bus system model

For developing dynamic model, a single machine synchronous generator connected to infinite busbar is considered [1] and is shown in figure 3(a).

Figure 3 shows the effect of speed through the stabilizing function $G(s)$ through the voltage regulator loops affecting $\Delta E_q$, which produces component of torque $\Delta T$. In figure 3(b) speed deviations $\Delta \omega$ is given as input of PSS. It produces an output, which is a voltage signal $\Delta V_{op}$. The output from the PSS is given to AVR, which produces a corresponding change in torque. In other words stabilizing signal derived from machine speed is processed through a device called the power system stabilizer (PSS) with a transfer function $G(S)$ and its output connected to an input of the exciter. Contribution of PSS to the torque–angle loop [1] is given by

$$\frac{\Delta T (s)}{\Delta \omega (s)} = \frac{G(s)K_pK_a}{(1/K_a + K_\omega K_a) + s(T_a / K_a + T_{m0}) + s^2 T_{m0} T_a}$$

(6)

For the usual range of constants, this function can be approximated by

$$\frac{\Delta T (s)}{\Delta \omega (s)} \approx \frac{G(s)K_pK_a}{(1/K_a + K_\omega K_a)[1 + s(T_{m0} / K_a)]}[1 + s T_a]$$

(7)

For large values of $K_a$ it can be further approximated by

$$\frac{\Delta T (s)}{\Delta \omega (s)} = \frac{K_2}{K_6}[1 + s(T_{m0} / K_a)[1 + s T_a]}$$

(8)

$$\frac{\Delta T (s)}{\Delta \omega (s)} = \frac{K_2}{K_6}[1 + s(T_{m0} / K_a)[1 + s T_a]} = G(s)GEF(s)$$

(9)

The transfer function of a PID controller is

$$G(s) = (K_p + \frac{K_i}{s} + sK_d).$$
III. 2. SIMULATION RESULTS

A generalized controller structure is considered for the PSS with the objective of achieving the best dynamic response at all operating points. Let the controller structure be

\[ G(s) = \sum_{n=-n}^{n} K_n s^n \]  

In the above equation \( K_n \) represents the controller parameters and \( n \) decides the order of the controller. For simplicity a PID controller is chosen, i.e., \( n = 1 \). The task is to identify the parameters of the controller so as to obtain optimum performance at all operating points using the above mentioned method.

Thus the problem is formulated as follows:

Find \( F(\phi) \) such that

\[ \text{Minimize} \quad F(\phi) = \Delta \omega_{ip} + t_s \]  

Subject to \( \phi_{\text{min}} \leq \phi \leq \phi_{\text{max}} \)

Where \( F(\phi) \) is the objective function, \( \Delta \omega_{ip} \) and \( t_s \) denotes the peak overshoot and settling time respectively.

\( \phi \) is a set of controller parameters to be determined and is denoted as \( [K_p, K_i, K_n] \), the subscripts \( \text{min} \) and \( \text{max} \) represent the lower and upper bounds of the variables.

The minimization of the objective function in equation (11) is now carried out using the two new optimization method described in the previous section. For this, a typical operating point given in Table 1 is considered.

### Table-1. Parameters of single machine system

<table>
<thead>
<tr>
<th>Machine Data (p.u)</th>
<th>Transmission line (p.u)</th>
<th>Exciter</th>
<th>Operating Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xd=0.973</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X'd=0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xq=0.55</td>
<td>Re=0.0</td>
<td>K_A=50</td>
<td>Vto=1.0</td>
</tr>
<tr>
<td>T'do=7.765s</td>
<td>Xe=0.997</td>
<td>T_A=0.05</td>
<td>Po=0.8 p.u</td>
</tr>
<tr>
<td>D=0.0</td>
<td></td>
<td>Qo=0.4 p.u</td>
<td></td>
</tr>
<tr>
<td>H=4.62</td>
<td></td>
<td>( \delta_0=72.8383^{\circ} )</td>
<td></td>
</tr>
</tbody>
</table>

### Table-2. Parameters of bee food foraging approach

<table>
<thead>
<tr>
<th>Bee population size</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold probability</td>
<td>0.7</td>
</tr>
<tr>
<td>( Step \text{ size} ) of movement of bees, ( R_i )</td>
<td>8.2</td>
</tr>
</tbody>
</table>
Dedicated software Matlab is developed for the optimal design of the PSS at the above mentioned operating point using the bees algorithm. The computed results are delineated in figure 4. The parameters employed in each algorithm are tabulated through tables 2 and 3. All the parameters are obtained by trial and error and no attempt has been made to optimize them. Figure 4(a) shows the variation of objective function at each iterative step of the two novel optimization algorithms. This figure also shows objective function variation employing GA which is included for comparison. It is important to mention that for fairness of comparison the initial population is taken as same for all the three optimization methods to commence with.

**Table- 3. Parameters of genetic algorithm approach**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>15</td>
</tr>
<tr>
<td>Crossover probability</td>
<td>0.8</td>
</tr>
<tr>
<td>Mutation probability</td>
<td>0.06</td>
</tr>
</tbody>
</table>

![Figure 4. Convergence characteristics](image)

Figure 5 illustrates the convergence characteristics of two novel optimization methods. The variation of objective function of each bee against iterative step as shown in figure 5(a) is a clear indication of effective communication through “waggle dance”. While each bee starts at random location they all converge coherently to the best position of high quality flower batches. However such a mechanism is absent in the reproduction algorithm and this scheme relies on the survival of the fittest mechanism. For completeness, the variation of controller constants with each iterative step is also included in figure 5. At the end of iteration the optimal PSS structure identified and is given in table 4.

**Table-4. Optimum PSS structure**

<table>
<thead>
<tr>
<th></th>
<th>$K_p$</th>
<th>$K_I$</th>
<th>$K_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBF</td>
<td>22.72</td>
<td>1.11</td>
<td>4.12</td>
</tr>
<tr>
<td>GA</td>
<td>22.12</td>
<td>1.782</td>
<td>3.21</td>
</tr>
</tbody>
</table>

The dynamic response of single machine connected to infinite busbar with optimized PSS is now studied and is available in figure 6. Figure 6 (a) shows the variation $\Delta \omega$ of the machine, when subjected to 0.05 p.u. step disturbance in $\Delta T_m$ at rated operating conditions. From this dynamic response the peak value is limited to 0.0006 and settling time is 1.6 seconds. Figure 6(b) shows the variation of terminal voltage of the generator delivering rated load when subjected to a dip in $\Delta T_m$ of amplitude 0.05 p.u. step.
Figure 5. Colony behaviour of bees. Variation of controller parameters (a) $K_P$, (b) $K_I$, (c) $K_D$ and (d) Convergence characteristics.

The response shows that the proposed controller effectively stabilizes the machine terminal voltage with a settling time of 1.4 seconds. Also, the maximum dip in machine voltage is as low as 0.06 p.u. It is evident that the proposed schemes are on a par with that of GA.

Figure 6 (a) Variation $\Delta \omega$ of the machine, when subjected to 0.05 p.u. step disturbance in $\Delta T_m$ at rated operating conditions. (b) Variation of terminal voltage of the generator delivering rated load when subjected to a dip in $\Delta T_m$ of amplitude 0.05 p.u.
V. CONCLUSION

The prospective method based on honey bees presented in this paper supplements the present wealth of recently developed optimization techniques and knowledge. The novel concept promise confirmed convergence with random initial guess, simple computational steps, derivative-free operation etc. Results obtained from computer simulations of a single machine connected to infinite busbar indicate that the bee tuned excitation controller can yield good damping characteristics over a wide range of operating conditions.

REFERENCES


