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Bacterial Foraging Optimization에 의한 전력계통안정화

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Bacterial Foraging Optimization and Power System Stabilization

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Abstract - This paper deals with power system stabilization problem using optimal foraging theory, which formulates foraging as an optimization problem and via computational or analytical methods can provide an optimal foraging policy that specifies how foraging decisions are made. It is possible that the local environment where a population of bacteria live changes either gradually (e.g., via consumption of nutrients) or suddenly due to some other influence. This objective scrutinizes to possibilities for power system stabilization by utilizing how mobile behaviors in both individual and groups of bacteria implement foraging and optimization.

1. Introduction

The power outages and exceptional events in the power system may occur in unexpectedly. To cope with these outages or events, a supplementary control signal in the excitation system and/or the governor system of a generating unit are used to provide extra damping for the system and thus, improve the unit's dynamic performance. Power system stabilizers (PSSs) aid in maintaining power system stability and in improving dynamic performance by proving a supplementary signal to the excitation system.

A generator must be equipped with PSS to supply additional signal for exciter terminal to improve the damping of the system. An auxiliary signal is injected in the exciter input of the generator in a power system, the algorithm applied to PSS provides a damping effect as follows. First, a traditional PSS (Lead-Lag Compensator) is divided by a speed input PSS, a frequency input PSS and a power input PSS. These PSSs were developed by F. P. deMello and C. Concordia, and had been done by research[1].

This handles the basic key ideas for the frequency response characteristics of a power system stabilizer which uses an auxiliary input signal, and deals with the gap both a tuning side and a performance side. Despite the potential of modern control techniques, electric power companies still prefer the traditional Lead-Lag PSS structures. This paper deals with power system stabilization problem using optimal foraging theory, which formulates foraging as an optimization problem and via computational or analytical methods can provide an optimal foraging policy that specifies how foraging decisions are made[2].

2. Bacterial Foraging Optimization

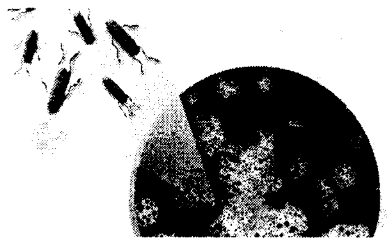


Fig. 1. Bacterial foraging

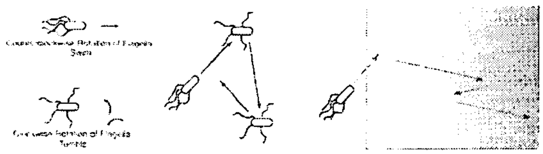


Fig. 2. Swimming, tumbling, and chemotactic behavior of E. coli

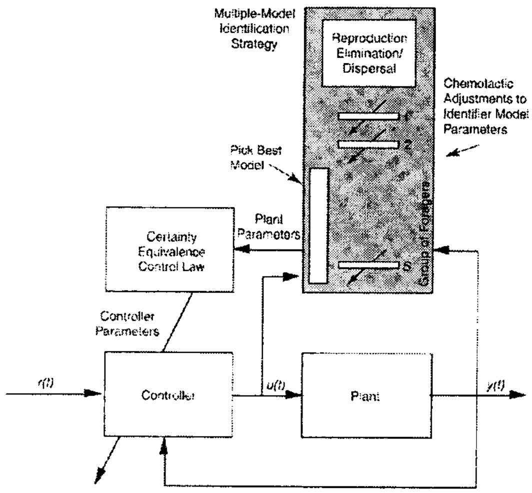


Fig. 3. Swarm foraging in adaptive control

2.1 Algorithm

1) Elimination-dispersal loop: $l = l + 1$
2) Reproduction loop: $k = k + 1$
3) Chemotaxis loop: $j = j + 1$

a) For $i=1,2,\cdots,S$, take a chemotactic step for bacterium i as follows.
b) Compute $J(i,j,k,l)$. Let $J(i,j,k,l)= J(i,j,k,l) + J_{cc}(\theta^i(j,k,l), P(j,k,l))$ (i.e., add on the cell-to-cell attractant effect to the nutrient concentration).
c) Let $J_{last} = J(i,j,k,l)$ to save this value since we may find a better cost via a run.
d) Tumble: Generate a random vector $\Delta(i) \in \mathbb{R}^p$ with each element $\Delta_m(i), m=1,2,...,p$, a random number on [1,1].
e) Move: Let

$$\theta^i(j+1,k,l)= \theta^i(k,j,l)+ C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

This results in a step of size $C(i)$ in the direction of the tumble for bacterium i.
f) Computer $J(i,j+1,k,l)$, and then let $J(i,j+1,k,l)+ J_{cc}(\theta^i(j+1,k,l), P(j+1,k,l))$.
g) Swim (note that we use an approximation since we decide swimming behavior of each cell as if the bacterial numbered $\{1,2,...,i\}$) have moved and $\{i+1,i+2,...,S\}$ have not; this is much simpler to simulate than simultaneous decisions about swimming and tumbling by all bacterial at the same time):
i) Let $m=0$(counter for swim length).
ii) While $m < N_s$(if have not climbed down too long)
- Let $m=m+1$.
- If $J(i,j+1,k,l) < J_{last}$(if doing better), let $J_{last} = J(i,j+1,k,l)$ and let $$\theta^i(j+1,k,l)= \theta^i(j+1,k,l)+ C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$ and use this $\theta^i(j+1,k,l)$ to compute the new $J(i,j+1,k,l)$ as we did in f).
- Else, let $m=N_s$. This is the end of the while statement.

h) Go to next bacterium $(i+1)$ if $i \neq S$ (i.e., go to b) to process the next bacterium).
4) If $j < N_c$, go to step 3. in this case, continue chemotaxis, since the life of the bacteria is not over.
5) Reproduction:
a) For the given k and l, and for each$i=1,2,...,S$, let

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i,j,k,l)$$

be the health of bacterium i (a measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances). Sort bacterial and chemotatic parameters $C(i)$ in order of ascending cost J_{health}(higher cost means lower health).
b) The S_r bacterial with the highest J_{health}values die and the other S_r bacteria with the best values split (and the copies that are made are placed at the same location as their parent).
6) If $k < N_{re}$, go to step 2. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
7) Elimination-dispersal: For $i=1,2,...,S$, with probability p_{ed}, eliminate and disperse each bacterium(this keeps the number of bacteria in the population constant). To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain.
8) If $l < N_{ed}$, then go to step 1; otherwise end.

3. Power System Model

In this section, Fig. 4 represents the modelling for generator and PSS connected one-machine infinite and the equivalent circuits at faults.

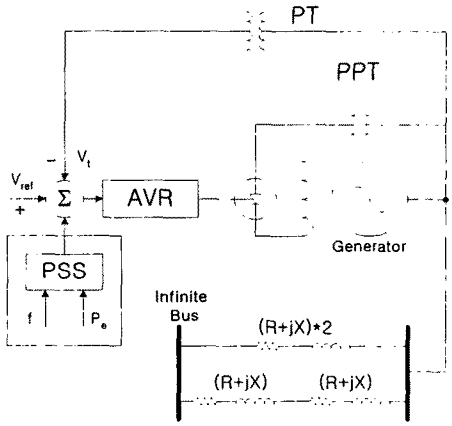
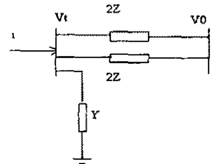


Fig. 4. Generator and PSS connected one-machine infinite bus system

3.1 d-axis and q-axis armature currents

Fig. 5 represents double-transmission lines for one-machine infinite bus power system. If fault is generated line-to-ground position at point d, Fig. 6 is divided original impedance by Z' and Z'' by considering equivalent circuits.

$Z'=d*(2Z)$
$Z''=(1-d)*(2Z)$



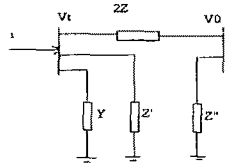


Fig. 5. Transmission line model. Fig. 6. Equivalent circuit at fault

The impedance, admittance and generator terminal voltage and current are presented by

$$Z = R + jX \tag{1}$$

$$Y = G + jB \tag{2}$$

$$v_t = v_d + jv_q \tag{3}$$

$$i = i_d + ji_q \tag{4}$$

$$[\text{phasor } v_0] \equiv v_0(\sin\delta + j\cos\delta) \tag{5}$$

$$\delta = \angle(e'_q,\ v_0) \tag{6}$$

3.2 Ground fault

By using KCL, we are arranged by

$$i = v_t Y + v_t / Z' + (v_t - v_0)/2Z = v_t Y + v_t / 2dZ + (v_t - v_0)/2Z$$

$$= v_t Y + 0.5(1 + \frac{1}{d})\frac{v_t}{Z} - 0.5\frac{v_t}{Z} \tag{7}$$

$$Zi = ZYv_t + 0.5(1 + \frac{1}{d})v_t - 0.5v_0 = (C_1 + jC_2)v_t - 0.5v_0 \tag{8}$$

where $ZY + 0.5(1 + \frac{1}{d}) = C_1 + jC_2$.

$Z = R + jX$, $Y = G + jB$

$$C_1 = RG - BX + 0.5(1 + \frac{1}{d}) \tag{9}$$

$$C_2 = RB + GX \tag{10}$$

$$\begin{bmatrix} R & -X \\ X & R \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} C_1 & -C_2 \\ C_2 & C_1 \end{bmatrix}\begin{bmatrix} v_d \\ v_q \end{bmatrix} - 0.5v_0\begin{bmatrix} \sin\delta \\ \cos\delta \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} e'_q - \begin{bmatrix} 0 & -x_q \\ x'_d & 0 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{Z_e^2}\begin{bmatrix} Y_d \\ Y_q \end{bmatrix} e'_q - \frac{0.5v_0}{Z_e^2}\begin{bmatrix} R_2\sin\delta + X_1\cos\delta \\ -X_2\sin\delta + R_1\cos\delta \end{bmatrix} \tag{13}$$

$$R_1 = R - C_2 x'_d \tag{14}$$

$$X_1 = X + C_1 x_q \tag{15}$$

$$R_2 = R - C_2 x_q \tag{16}$$

$$X_2 = X - C_1 x'_d \tag{17}$$

$$Z_e = R_1 R_2 + X_1 X_2 \tag{18}$$

$$Y_d = X_1 C_1 - R_2 C_2 \tag{19}$$

$$Y_q = X_2 C_2 - R_1 C_1 \tag{20}$$

$$v_d = x_q i_q \tag{21}$$

$$v_q = e'_q - x'_d i_d \tag{22}$$

$$v_t^2 = v_d^2 + v_q^2 \tag{23}$$

$$T_e \approx P_e = i_d v_d + i_q v_q = e'_q i_q + (x_q - x'_d) i_d i_q \tag{24}$$

$$P_e + jQ_e = (i_d + ji_q)^*(v_d + jv_q) \tag{25}$$

$$P_e = i_d v_d + i_q v_q \tag{26}$$

$$Q_e = i_d v_q - i_q v_d \tag{27}$$

$$Pv_q - Q_e v_d = i_d v_t^2 \tag{28}$$

$$P(v_t^2 - v_d^2)^{1/2} - Q_e v_d = v_d(v_t^2 / x_q) \tag{29}$$

$$v_d = P_e v_t [P_e^2 + (Q_e + v_d^2 / x_q)^2]^{-1/2} \tag{30}$$

$$v_q = (v_t^2 - v_d^2)^{1/2} \tag{31}$$

$$i_q = v_d / x_q \tag{32}$$

$$i_d = (P_e - i_q v_q)/v_d,\ (Q_e + i_q v_d)/v_q \tag{33}$$

$$e'_q = v_q + x'_d i_d \tag{34}$$

$$v_{0d} = v_0 \sin\delta = C_1 v_d - C_2 v_q - Ri_d + Xi_q \tag{35}$$

$$v_{0q} = v_0 \cos\delta = C_2 v_d + C_1 v_q - Xi_d - Ri_q \tag{36}$$

$$\delta = \tan^{-1}(v_{0d} / v_{0q}) \tag{37}$$

$$v_0 = (v_{0d}^2 + v_{0q}^2)^{1/2} \tag{38}$$

3.3 4-th differential equation for nonlinear power system

$$\dot{\omega}(t) = \frac{1}{M} T_m - \frac{1}{M} T_e(t) \tag{39}$$

$$\dot{\delta}(t) = \omega_o(\omega(t) - 1) \tag{40}$$

$$\dot{e}'_q(t) = -\frac{1}{T'_{do}} e'_q(t) - \frac{(x_d - x'_d)}{T'_{do}} i_d(t) + \frac{1}{T'_{do}} e_{fd}(t) \tag{41}$$

$$\dot{e}_{fd}(t) = -\frac{1}{T_A} e_{fd}(t) + \frac{K_A}{T_A}(V_{ref} - v_T(t) + u_E(t)) \tag{42}$$

$$e_{fd\,\min} \le e_{fd} \le e_{fd\,\max}\ \text{과}\ u_{E\,\min} \le u_E \le u_{E\,\max} \tag{43}$$

$$e_{fd\,\max} = 6.0,\ e_{fd\,\min} = -6.0\ \text{과}\ u_{E\,\max} = +0.2,\ u_{E\,\min} = -0.2$$

The general d-axis and q-axis current component of synchronous generator can be represented by

$$i_d(t) = con_1 e'_q(t) - con_2(R_2 \sin\delta(t) + X_1 \cos\delta(t)) \tag{44}$$

$$i_q(t) = con_3 e'_q(t) - con_4(-X_2 \sin\delta(t) + R_1 \cos\delta(t)) \tag{45}$$

$$v_d(t) = x_q i_q(t) \tag{46}$$

$$v_q(t) = e'_q(t) - x'_d i_d(t) \tag{47}$$

$$v_T^2(t) = v_d^2(t) + v_q^2(t) \tag{48}$$

$$T_e(t) \cong P_e(t) = i_d(t) v_d(t) + i_q(t) v_q(t)$$

$$= e'_q(t) i_q(t) + (x_q - x'_d) i_d(t) i_q(t) \tag{49}$$

$$con_1 := \frac{(C_1 X_1 - C_2 R_2)}{(R_1 R_2 + X_1 X_2)},\quad con_2 := \frac{V_\infty}{(R_1 R_2 + X_1 X_2)}$$

$$con_3 := \frac{(C_1 R_1 + C_2 X_2)}{(R_1 R_2 + X_1 X_2)},\quad con_4 := \frac{V_\infty}{(R_1 R_2 + X_1 X_2)}$$

$Z := R + jX$, $Y := G + jB$, $1 + ZY := C_1 + jC_2$

$C_1 := RG - XB$, $C_2 := XG + RB$, $R_1 := R - C_2 x'_d$

$R_2 := R - C_2 x_q$, $X_1 := X + C_1 x_q$, $X_2 := X + C_1 x'_d$

4. Conclusion

This paper deals with power system stabilization problem using optimal foraging theory, which formulates foraging as an optimization problem and via computational or analytical methods can provide an optimal foraging policy that specifies how foraging decisions are made. It is possible that the local environment where a population of bacteria live changes either gradually (e.g., via consumption of nutrients) or suddenly due to some other influence. This objective scrutinizes to possibilities for power system stabilization by utilizing how mobile behaviors in both individual and groups of bacteria implement foraging and optimization.

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[References]

[1] F. P. deMello and C. Concordia, "Concepts of synchronous machine stability as affected by excitation control", *IEEE Trans.* Vol. PAS-88, April 1969, pp. 189-202.

[2] K. M. Passino, "Biomimicry of Bacterial Foraging for Distributed Optimization and Control", *IEEE Control System Magazine*, June 2002, pp. 52-67.