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Optimal Synergetic Control for Wind Turbine System

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ABSTRACT
In this paper, a optimal synergetic control using the BAT algorithm is established.
The synergetic approach is presented. Then the BAT algorithm is presented and used to provide optimization of the synergetic parameter in order to obtain an optimal synergetic controller. The effectiveness of the proposed optimal synergetic control is verified using a numerical example.
KEYWORDS *- Synergetic theory, BAT optimization algorithm, , pitch system.*

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I INTRODUCTION

The system control issue has attracted significant research attention and various strategies have been developed [1].

In this work, a new method of state and fault estimation is developed based on the synergetic theory. The synergetic approach is initialized by Kolesnikov and Coworkers [2]. The synergetic control consists of two step which is the design of the manifold according to the desired performance and the design of the controller that is constructed by solving a first order differential equation [3,4]. The synergetic control has been applied to many industrial processes, including the area of power electronics systems [5,6].

The appropriate selection of T and λ provides good performance for the synergetic controller. So, an optimization algorithm is required here to search optimal convergence parameters. In the literature, many optimization techniques have been proposed such as Genetic Algorithm (GA) [7]. However, this algorithm requires a very long run time depending on the size of the studied system. Besides, it pains form tunings of algorithm parameters and repeating the revising of the same suboptimal solutions. A Particle Swarm Optimization (PSO) is developed by Eberhart, Kennedy, and Shi [8]. The PSO algorithm suffers from the partial optimism that leads to less accurate at regulation of its speed and the direction. To overcome the mentioned problem, a novel meta-heuristic algorithm known as BAT algorithm is proposed [9].

In this work, we will use the BAT algorithm to obtain an optimal synergetic. The remainder of this paper is presented as follows. It begins with an introduction of the synergetic theory in section 1. The BAT algorithm is presented in section 2. The performance of the proposed optimal is then verified on the pitch system in section 3. Finally, some conclusions are presented in section 4.

II THE SYNERGETIC CONTROL THEORY

The procedure of the design of synergetic control can be itemized as follows:
Consider the linear system described by:

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) \qquad (1)$$

where $x \in \mathbb{R}^n$ is the state vector, $u \in \mathbb{R}^m$ is the control input vector.
To design a synergetic controller, we start by the definition of the manifold that can be a linear function of the state variables [15]:

$$s(x) = Sx, \; S \in \mathbb{R}^{m \times n} \qquad (2)$$

With $S = [\lambda \quad 1]$ has to be selected so that (SB) is invertible.

The control will force the system to operate on the manifold s(x) = 0. The designer can select the manifold according to the desired performances. The number of the manifold is the same as the number of control channels.
For the synergetic approach, the control law is obtained by solving the following equation

$$T\dot{s}(x) + s(x) = 0 \qquad (3)$$

With T>0 is a design parameter specifying the convergence speed toward the manifold. The synergetic parameter T is a positive scalar.
The derivative of the manifold is given by

$$\dot{s}(x) = \frac{ds(x)}{dx}\dot{x} = S(Ax(t) + Bu(t)) \qquad (4)$$

Thus, (3) can be expressed as follows:

$$TS(Ax(t) + Bu(t)) + s(x) = 0 \qquad (5)$$

After solving (5) we obtain the following control law

$$u_{syn}(t) = -(TSB)^{-1}(TSAx(t) + s(x)) \qquad (6)$$

Note that each manifold imposes a new constraint on the state space domain and reduces the order of the system, in the purpose of global stability.
In the next section the concept of algorithm BAT is presented.

III BAT ALGORITHM CONCEPT

In order to find optimal parameters of the synergetic controller T and λ, BAT search optimization algorithm is utilized in this work. BAT search algorithm is an optimization algorithm introduced by Xin-She-Yang [11]. It is fairly meta-heuristic approach for global optimization. It is inspired by the echolocation behaviour of natural bats. Each bat in the initial population uses similar ways by performing echolocation manner for updating its position. Bats use a type of sonar the so-called echolocation, to detect prey and avoid obstacles. They emit a series of loud ultrasound waves and listen to the echo that returned with delay from the surrounding objects which qualify bats to discover the prey. Some rules are idealized to extend the structure of BAT algorithm [11]:

- All bat use the echolocation characteristics to distinguish between prey and barrier
- Each bat flies randomly with velocity υ_i at position x_i emitting a signal with fixed frequency f_{min}, varying wavelength ω and loudness L_0 to search for prey. They can adjust the frequency of their emitted pulses and regulate the rate of pulse emission r in the range of [0, 1], depending on the proximity of their target.
- Loudness, frequency and pulse emitted rate are varied.
- The loudness varies from a large value L_0 to a minimum constant value L_{min}.

Firstly, for each bat, the position and the velocity should be initialized. For each step time t, the position and the velocity are updated using the following equations [11]:

$$\begin{aligned} f_i &= f_{min} + (f_{max} - f_{min})\gamma \\ \upsilon_i(t) &= \upsilon_i(t-1) + (x_i^t - x^*) f_i \\ x_i^t &= x_i^{t-1} + \upsilon_i^t \end{aligned} \qquad (7)$$

Where γ is a random vector drawn form a uniform distribution in the interval [0,1]. x_i^t is the value of decision variable j for bat i at time step t. x^* denotes the current global best solution, that is obtained after comparing all the locations among all the n bats. As the product $\omega_i f_i$ is the velocity increment, we can consider either f_i (or ω_i) to regulate the velocity change while fixing the other factor f_i (or ω_i). In the implementation, each bat is randomly assigned a frequency which is drawn uniformly from $[f_{min}, f_{max}]$.To improve the variability of the possible locations, Yang [11] has proposed to use random walks. For the local search, one solution is chosen among the current best solution and then the random walk is applied to generate a new solution for each bat.

$$x_{new} = x_{old} + \varepsilon L^t \qquad (8)$$

Where L^t is the average loudness of all the bats at instant t and $\varepsilon \in [-1,1]$ is a random number. For bat algorithm, in each iteration the loudness L_i and the rate r_i of pulse emission are updated as follows:

$$L_i(t+1) = \tau L_i(t)$$
$$r_i(t+1) = r_i(0)\left[1 - e^{-\gamma}\right] \qquad (9)$$

Where τ and γ are constants. In the initial step, the loudness and the emission rate are often randomly chosen. The emission rates and the loudness will be updated only if the new solutions are improved, which means that the bats are moving towards the optimal solution.

To guarantee the convergence of the pitch angle to the reference value with minimal energy the parameters of the synergetic T and λ control may be picked to minimize the following objective function:

$$J = \int_0^{t_f} \left(x_1(t) - x_{1_{ref}} \right)^2 dt \qquad (10)$$

where t_f is the time range of the simulation. The performance index is designed to minimize the steady state error, and to minimize the consumed energy by the pitch system control. Thus the optimization problem based on this objective function consist of minimize J subjected to

$$T_{\min} \le T \le T_{\max} \qquad (11)$$

$$\lambda_{\min} \le \lambda \le \lambda_{\max} \qquad (12)$$

The typical interval values of the optimized parameters are [0.0001, 100] and [2,200] . We aim to minimize the objective function using the BAT algorithm in order to drive the system closed loop to operate on the reference. All those theoretical results will be verified then in the simulation section.

I. NUMERICAL EXAMPLE

In this section, the wind turbine pitch system is used to prove the analytical results shown above. The pitch system parameter are given below

- $\omega_0 = 0.6\, rad/s,\ \xi_0 = 11.11\, rad/s.$
- $\omega_f = 3.42\, rad/s,\ \xi_f = 0.9\, rad/s.$

Some noises modeled by a zero mean white Gaussian noise is applied to the pitch system.

The objective of this paper in faulty-free condition is to design an optimal synergetic controller that drives the pitch angle to converge to the desired angle x_{1ref} . Under actuator fault, we aim to estimate the fault indicator value.

The following figures show the pitch system dynamics using the BAT synergetic controller. To prove the effectiveness of BAT optimization algorithm, a comparative study between the proposed algorithm and the Genetic algorithm is shown through the simulation results. Fig.1 shows the dynamics of the objective function using the mentioned algorithms. Fig.2 shows the pitch angle evolution, Fig.3 illustrates the shape of the optimal synergetic controller.

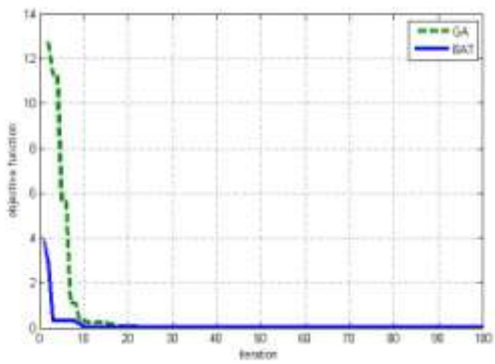

Fig. 1: The objective function

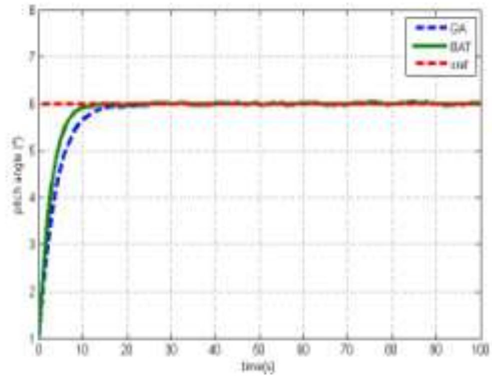

Fig. 2: The pitch angle evolution using optimal synergetic controller (using BAT and Genetic algorithm)

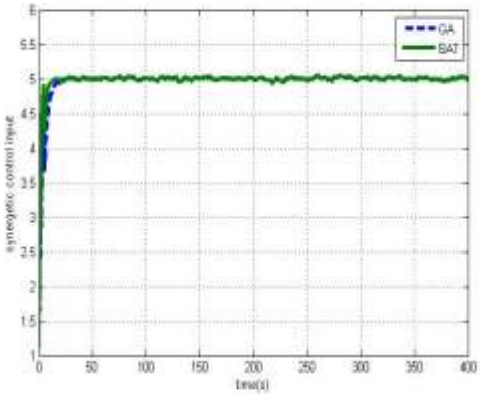

Fig. 3: The optimal synergetic controller using BAT and Genetic algorithm

It is shown in this figure, that the BAT synergetic controller drives the pitch angle to get the reference value a minimum energy.

Those figures proves also the superiority of the BAT algorithm in designing of the parameter convergence compared to GA, where the objective function converge at a faster rate using BAT algorithm compared with the other algorithm.

The parameters of BAT synergetic (SYN BAT) and genetic optimization synergetic (SYN GA) algorithms are shown in Table 1.

Table 1: Optimal design parameters

Synergetic parameter	SYN BAT	SYN GA
T	2.5	3.75
λ	7	6.5

IV CONCLUSION

In this work, an optimal synergetic control is developed to control the wind turbine pitch system. The synergetic control is characterized by two parameters: T and λ that is optimized using the BAT algorithm in order to minimize the rate of convergence to the steady state and the consumption of energy. Simulations results prove the performance of the proposed BAT synergetic controller.

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