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ACTIVE POWER LOSS MINIMIZATION IN ELECTRIC POWER SYSTEMS THROUGH CHAOTIC ARTIFICIAL BEE COLONY ALGORITHM

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Original scientific paper

Reactive power optimization (RPO) is a major field of study to ensure power systems for operating in a secure and economical manner. RPO can be used for decreasing of active power losses, voltage control, and for the optimization of the power coefficients in power systems. The non-linear power loss function is used as an object function that will be minimized. In this study Chaotic Artificial Bee Colony (CABC) algorithm is used to minimize the active power loss of power systems. Chaotic maps such as logistic map and Henon map are used against the random number generator. CABC is applied on the IEEE6-bus and IEEE 30-bus test systems and the results are shown. Accordingly, the results have been evaluated and observed that the stability critical values found by CABC can be used to produce good potential solutions. Simulation results are promising and show the effectiveness of the applied approach.

Keywords: *chaos; Chaotic Artificial Bee Colony; optimization; power systems*

Smanjenje gubitka aktivne snage u elektro-energetskim sustavima primjenom algoritma kaotične umjetne kolonije pčela

Izvorni znanstveni članak

Optimizacija reaktivne snage - Reactive power optimization (RPO) - osnovno je područje istraživanja u svrhu sigurnog i ekonomičnog rada energetskih sustava. RPO se može primijeniti za smanjenje gubitaka aktivne snage, reguliranje napona te za optimizaciju energetskih koeficijenata u energetskim sustavima. Funkcija ne-linearnog gubitka snage koristi se kao funkcija cilja koju treba smanjiti. U ovom se radu algoritam Kaotične umjetne kolonije pčela - Chaotic Artificial Bee Colony (CABC) - primjenjuje za smanjenje gubitka aktivne snage u energetskim sustavima. Rabe se kaotične mape kao što su logistička mapa i Henon mapa. CABS se primjenjuje na provjeravanim sustavima IEEE 6-sabirnice i IEEE 30-sabirnice i daju se rezultati. Provjerom rezultata ustanovilo se da primjena kritičnih vrijednosti stabilnosti dobivenih pomoću CABS može rezultirati dobrim potencijalnim rješenjima. Rezultati simulacije su obećavajući i pokazuju učinkovitost primijenjenog pristupa.

Ključne riječi: *elektroenergetski sustavi; kaos; kaotična umjetna kolonija pčela; optimizacija*

1 Introduction

Reactive power optimization (RPO) has a significant importance for voltage stability, voltage quality, and power losses in power systems. The total active power loss function is the object function of the system. This function is a non-linear function having many variables depending on many constraints [1÷5]. This problem is firstly solved by the classical methods such as linear, non-linear, and quadratic dynamic mathematical algorithms. Subsequently intuitive methods have been used. RPO is realized by Lu and Ma neuro-dynamic programming [1]. Durairaj and Fox have applied evolutionary computation based RPO to 30 and 118 bus systems of IEEE [2]. Hazrai and Sinha have done active and reactive power optimization via particle swarm algorithm [3]. Li. et al. have used adaptive particle swarm algorithm [4]. Wei et al. and Chen et al. have used basic immunity in genetic algorithm (GA) and advance GA methods in RPO respectively [5, 6]. Wang et al. have used cultivation simulation algorithm [7, 8]. Wei et al. have found optimum parameter values by using the method of germ [9]. Zhang et al. have reached the global minimum point by application based search algorithm [10]. Liu et al. have applied a hybrid optimization with taboo search and ordinal optimization methods [11]. Liu et al., Lenin, and Mohan have used ant colony in the solution of RPO problem [12÷14]. Liu et al. have applied adaptive genetic simulation annealing algorithm [15] and then Zhang and Lui have joined the literature by RPO with fuzzy logic controlled particle swarm algorithm [16]. Optimization of power systems has been investigated by many researchers. [17÷20]. One of the intuitive methods, ABC is an algorithm that reaches to global minimum by looking for the solution in the evolutionary way and that is inspired by the movements of the bees during the nectar search. ABC is an algorithm incorporated to the literature by Karaboğa in 2005. This algorithm is used for the optimization of many non-linear problems in a short time slice [21÷30].

Lots of chaotic maps in the literature possess certainty, ergodicity and the stochastic property. Recently, chaotic sequences have been adopted instead of random sequences and good results have been shown in many applications. They have also been used together with some heuristic optimization algorithms (Alatas, Akin, & Ozer, 2009; Coelho & Mariani, 2008) [31, 32] to express optimization variables. The choice of chaotic sequences is justified theoretically by their unpredictability, i.e., by their spread-spectrum characteristic, non periodic, complex temporal behavior, and ergodic properties. Alatas has proposed ABC algorithms using chaotic maps [33]. In this study Chaotic Artificial Bee Colony algorithm (CABC), is used to minimize the active power loss of power systems.Chaotic maps such as logistic map and Henon map are used against the random number generator.The CABC algorithm for solving RPO has been solved for IEEE 6-bus system and IEEE 30-bus system. The CABC algorithm is compared with clasiccal ABC algorithm. It is shown by the results that active power losses can be decreased by CABC algorithm.

2 Reactive power optimization

The goal of RPO is to minimize the active power losses by changing the generator bus voltages, reactive power value of the capacitors connected to the system, and the level modifier values of the transformers. Active power losses are expressed in equation 1 where P_{loss} is the total active power loss, N_{E} is the number of distribution lines, g_k is the conductance of the line connecting i and j bus, V_i is the voltage of the i^{th} bus, V_j is the voltage of the j^{th} bus, φ_{ij} is the phase angle of the voltage value between i and j [1÷16]:

$$\begin{aligned}\min f_Q &= \sum_{k\in N_{\text{E}}} P_{\text{loss}} \\ \min f_Q &= \sum_{k\in N_{\text{E}}} g_k (V_i^2 + V_j^2 - 2V_i V_j \cos\varphi_{ij}).\end{aligned} \tag{1}$$

Power balance equality constraints known from power flow equations are given in Eqs. (2) and (3) where δ_i and δ_j are the angle of voltage value of the i^{th} and j^{th} bus respectively. N_{B} is the total number of buses, $P_{\text{G}i}$ and $Q_{\text{G}i}$ are the active and reactive power of the generator respectively. $P_{\text{D}i}$ and $G_{\text{D}i}$ are the demanded active and reactive powers. G_{ij} and B_{ij} are the conductance and suceptance value between the i and j buses.

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j \begin{bmatrix} G_{ij} \cos(\delta_i - \delta_j) + \\ B_{ij} \sin(\delta_i - \delta_j) \end{bmatrix} = 0 \tag{2}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} V_j \begin{bmatrix} G_{ij} \sin(\delta_i - \delta_j) + \\ B_{ij} \cos(\delta_i - \delta_j) \end{bmatrix} = 0 \tag{3}$$

The variation interval of the variables is given in Eqs. (4), (5), (6), and (7). Where T_k is the transformer tap changer Q_C is the reactive power compansator:

$$V_{i\,\min} \le V_i \le V_{i\,\max}, \tag{4}$$

$$Q_{G_i\,\min} \le Q_{G_i} \le Q_{G_i\,\max}, \tag{5}$$

$$T_{k\,\min} \le T_k \le T_{k\,\max}, \tag{6}$$

$$Q_{C_i\,\min} \le Q_{C_i} \le Q_{C_i\,\max}. \tag{7}$$

3 Artificial Bee Colony (ABC)

ABC algorithm has been inspired by the intelligent behavior of reel bees while they are searching for nectar recources and sharing them with other bees [21÷26]. The artificial bee colony consists of three kinds of bees named as employed, onlooker, and scouts. Each sort of them differs from their role in the optimization process. Employed bees staying over the nectar source hold the neighboring sources in mind. Onlooker bees recieve this information from employed bees and make a resource selection to gather the nectar. The scout bees are also responsible for finding new nectar resources. The algorithm has three steps. The first step is moving the employed bees onto the food resources and calculating their nectar amounts. Secondly, bees make a resource choice in accordance with the information they took from the employed bees and the nectar amount is calculated. In the last step, one of the employed bees is nominated randomly as a scout bee and it is sent to the sources to find new sources [30]. Half of the bees in the colony are appointed as employed and the rest half as onlooker bees in the algorithm [43]. Therefore, number of employed bees is equal to the number of nectar sources [24÷27]. The employed bee becomes a scout when its food source has been exhausted by the bees. The food sources in the algorithm refer to the possible solutions of the problem to be optimized. The nectar amount belonging to a source means the quality value which is said by that source [24]. The flow chart of the ABC algorithm is given in Fig. 1 [28]. In the first step of the algorithm random solutions are produced in the interval of the variables xi (i= 1, ..., S). Secondly, each employed bee discovers new sources whose amounts are equal to the half of the total sources. Eq. (8) is used to find a new source:

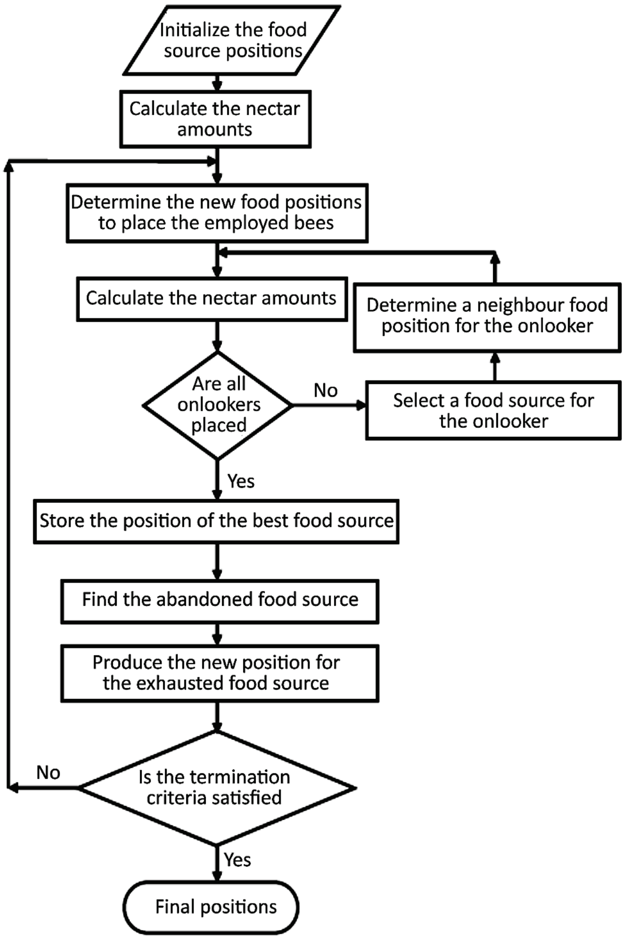

Figure 1 Flowchart of the ABC algorithm

$$v_{ij} = x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}). \tag{8}$$

In Eq. (8) k is given by (int ($rand$ S) + 1) and j = 1, …, D. After vector v_i is generated, it is compared with the solutions of x_i and the best one is selected. In the last step onlooker bees chose a food source with the possibility given in Eq. (9) where P_i is the possibility of onlooker bees choosing a food source and fit_i is the fitness function.

$$P_i = \frac{fit_i}{\sum_{j=1}^{s} fit_j}, \tag{9}$$

$$X_{ij} = x_{i\,\min} + rand * X(x_{j\,\max} - x_{j\,\min}). \quad (10)$$

Scout bees do not use any pre knowledge while they are searching for nectar sources, but they absolutely do their researches randomly [28]. The scout bees are chosen among the employed bees. This selection is done with respect to the limit parameter. If a solution that represents a source is not realized with a certain number of trials, then this source is abandoned. The bee of that source goes to find new source as a scout bee. The number of comings and goings to a source is determined by the 'limit' parameter. Finding a new source of a scout bee is given in Eq. (10).

4 Chaotic maps

ABC algorithm has been inspired by the intelligent A chaotic map is a discrete-time dynamical system in the iteration form of:

$$X_{i+1} = F(\boldsymbol{x}_i, Z). \quad (11)$$

where Z is the control parameter, $\boldsymbol{x}$ is a vector and F is a nonlinear transformation [34]. In this study Logistic map and Henon map are used.

4.1 Logistic map

The logistic map is a one-dimensional discrete-time non-linear system exhibiting quadratic non-linearity. The logistic map is given by the function

$$f:[0,1] \rightarrow \Re \text{ defined by } f(x) = \mu x(1-x), \quad (12)$$

which is expressed in state equation form as :

$$x_{i+1} = f(x_i) = \mu x_i(1-x_i),\ i = 0, 1, 2, ..., \quad (13)$$

where $x_i \in (0, 1)$, x_0 is not equal to $\{0,25; 0,5; 0,75\}$ and μ is set to 4 for ergodicity. μ is known as the control parameter or bifurcation parameter.

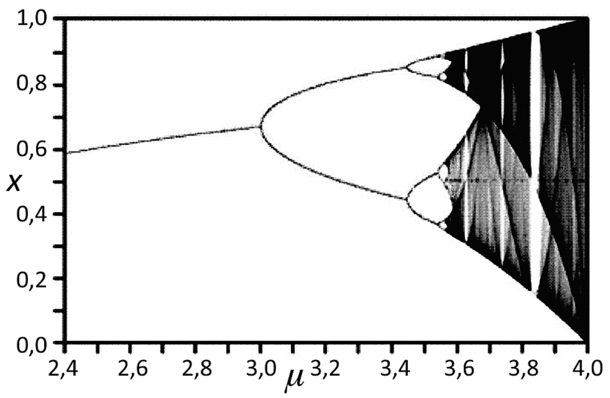

Figure 2 The bifurcation diagram of the logistic map

Here x_i is the state of the system at time i. X_{i+1} denotes the next state and i denotes the discrete time. The logistic map is frequently used by PSO [35÷37]. Repeated iteration of f gives rise to a sequence of points $\{x_i\}$, known as an orbit. The bifurcation diagram of the logistic map is shown in Fig. 2. The chaotic numbers generated by logistic map are shown in Fig. 3.

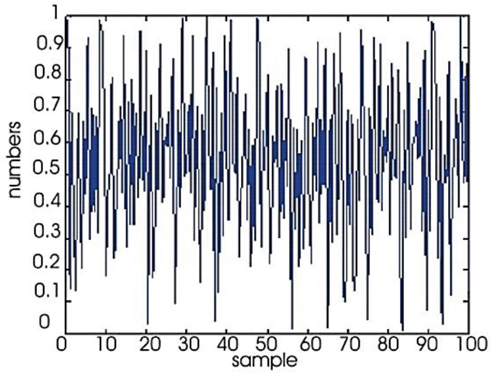

Figure 3 The chaotic numbers generated by logistic map

4.2 Henon map

Henon map is a two dimensional dynamical system, that is the simplified version of the Lorenz system [38]. The Henon equations are given by

$$x_{i+1} = 1 + y_i - ax_i^2, \quad (14)$$

$$y_{i+1} = bx_i. \quad (15)$$

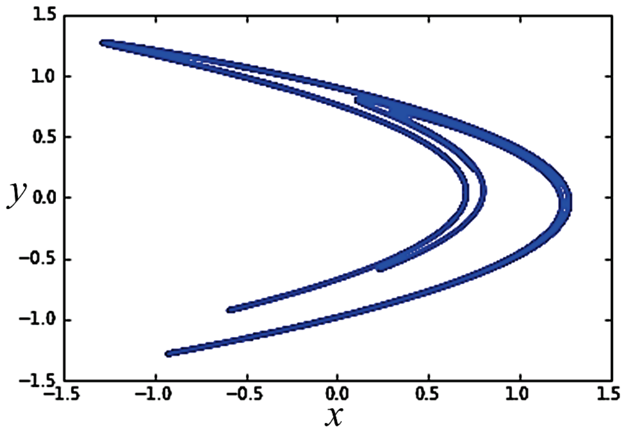

Figure 4 Henon map for a = 1,4 and b = 0,3

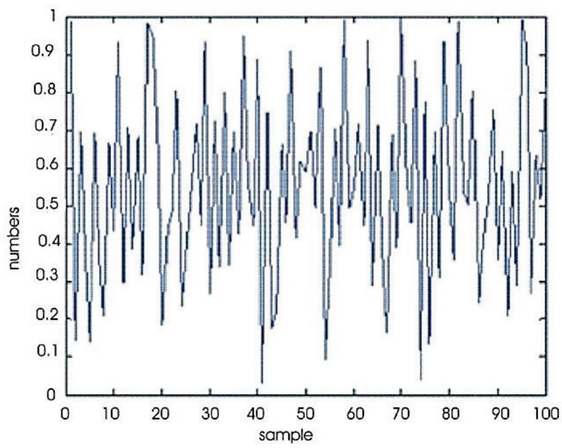

Figure 5 The chaotic numbers generated by Henon map

The Henon map has a strange attractor for a = 1,4 and b = 0,3 values. The Henon map used in this study is shown in Fig. 4. The chaotic numbers generated by logistic map are shown in Fig. 5.

5 Chaotic Artificial Bee Colony

Chaotic behavior refers to one type of complex dynamical behaviour that possesses some very special features such as being extremely sensitive to tiny variations of initial conditions. Chaotic systems exhibit irregular, unpredictable behavior. The boundary between linear and chaotic behavior is often characterized by period doubling, followed by quadrupling, etc., although other routes to chaos are also possible. Typically chaotic motions result when the system operating at a stable periodic orbit undergoes a series of bifurcations leading to the birth of a strange attractor under some parametric variations [42].

In simulating complex phenomena, sampling, numerical analysis, decision making and especially heuristic optimization needs random sequences with a long period and good uniformity (Coelho & Mariani, 2008; Schuster, 1988)[32].

The chaotic map can be helpful to escape from a local minimum [39], and it can also improve the global/local searching capabilities. Randomly initializing of ABC and the limit parameter that is adjusted in initialization step that cannot be changed during new iterations may affect the algorithm performance on convergence speed. The use of chaotic sequences in ABC can be helpful to escape more easily from local minima than can be done through the classical ABC.[43]

Chaos can be applied to CABC in various ways. In this study, the chaotic maps such as logistic map and Henon map are used against the random number generator. Initial artificial colony is generated by iterating the selected chaotic maps until reaching the colony size as shown in Fig. 6. N is the dimension for the problem; i is the colony member; and j is the dimension. $x_{i,j}$ is the j^{th} dimension of the ith colony member [33].

$i = 0$
Do
Randomly initialize the first chaotic variable
$j = 0$
Do
Generate chaotic variable cr_{ij} according to the chaotic maps given.

$X_{ij} = x_{i\,min} + cr_{ij} X (x_{j\,max} - x_{j\,min})$

While $j <$ Number of Employed Bee
$i = i + 1$
While $i \leq$ Colony size

Figure 6 Pseudo-code of CABC change to orginal ABC

6 Simulation and results

The CABC algorithm has been applied first on IEEE-6 and second on IEEE-30 bus systems to minimize the active power loss. The IEEE-6 bus system is shown in Fig. 7.

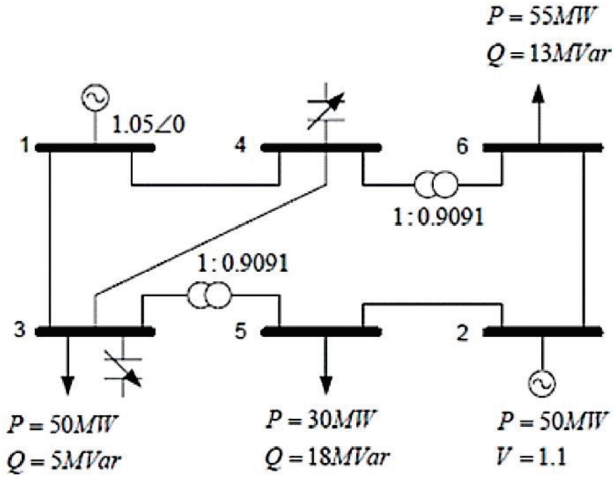

Figure7 IEEE6-Bus System

The line information of the system is shown in Tab. 1. The bounds of the variables are given in Tab. 2. The first bus is the oscillation bus, the second bus is the generator bus and the others are the charge buses.

Table 1 Line Information of the IEEE-6-BUS Test System (100 MVA Considered as base)

Bus Number		Impedance (pu)		
from	to	*R*	*X*	tap setting
1	3	0,123	0,518	
1	4	0,080	0,370	
4	3	0,097	0,407	
3	5	0,000	0,003	0,9756
5	2	0,282	0,640	
2	6	0,723	1,050	
4	6	0,000	0,133	0,9091

The objective function for the Active power loss problem is given by Eq. (1). The Active and reactive power balances of the variables denoting the constraints are shown in Eqs. (2) and (3). Additonally Tab. 2 constitutes the constraints of the variables. The values of the CABC algorithm are as follows: Colony Dimension=20, Maximum number of cycles=500, Number of variables=5, Limit parameter=3000.

Table 2 Rpo Varıable Bounds

	Tap		Voltage(pu)	Reactive Power Supply(MVAR)	
			Generator	Capacitor	
	T35	T46	V2	Q3	Q4
min	0,91	0,91	1,10	0	0
max	1,11	1,11	1,15	5	5,5

Variables given in Tab. 2 refer to the nectar position and the active power losses refer to nectar amount. Fig. 8 illustrates the changes in active power loss based on Cycles for the IEEE-6 bus system obtained by classical ABC [40] whereas Figs. 9 and 10 illustrate the changes obtained by CABC algorithm using Henon and Logistic map respectively. Tab. 3 shows the result minimal active power loss values of IEEE-6 bus system for the ABC, CABC-Henon and CABC-Logistic.

Tab. 3 shows the result minimal active power loss values of IEEE-6 bus system for the ABC, CABC-Henon and CABC-Logistic. The best solution is 8,4891 (MW) which is found with CABC algorithm using Henon map.

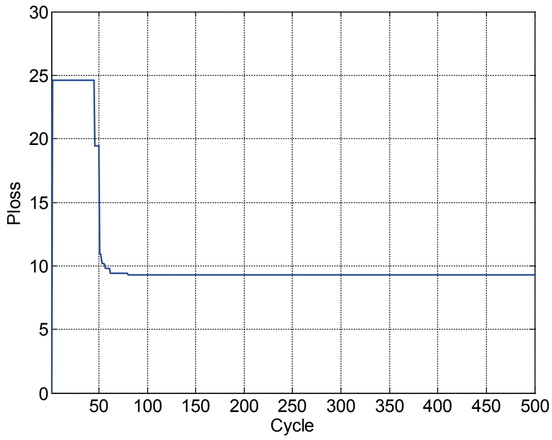

Figure 8 Active Power Loss Values with ABC Algorithm for IEEE-6 Bus System

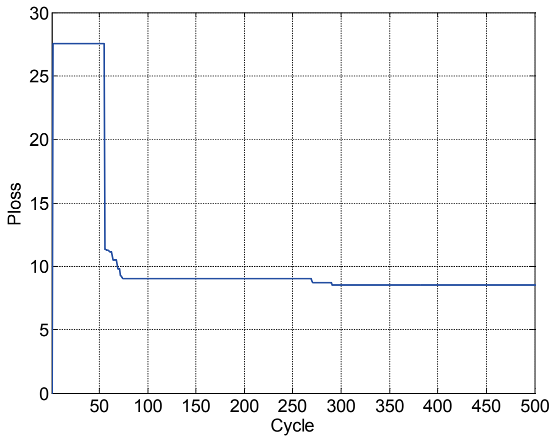

Figure 9 Active Power Loss Values with CABC Algorithm using Henon Map for IEEE-6 Bus System

To prove the effectiveness and robustness of the CABC algorithm it has been applied on the IEEE-30 bus system shown in Fig. 11. It consists of six generator buses, twenty four load buses, and forty one transmission lines of which four branches. Details are given in table VI. Fig. 12 illustrates the changes in active power loss based on Cycles for the IEEE-30 bus system obtained by classical ABC [33] and Figs. 13 and 14 illustrate the changes in active power loss based on Cycles for the IEEE-30 bus system obtained by CABC algorithm using Henon and Logistic map respectively.

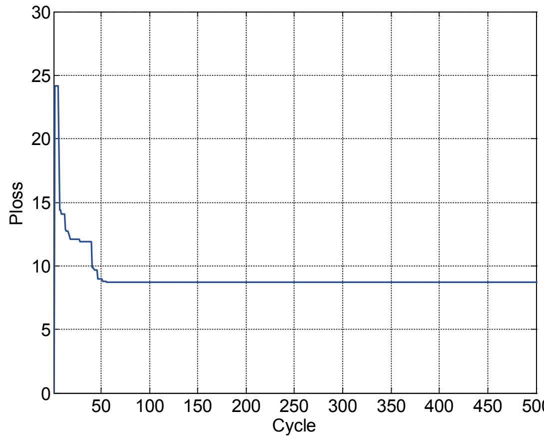

Figure 10 Active Power Loss Values with CABC Algorithm using Logistic Map for IEEE-6 Bus System

Table 3 Result Minimal Active Power Loss Values of IEEE-6 Bus System for the ABC, CABC-Henon and CABC-Logistic

IEEE-6 BUS SYSTEM ACTIVE POWER LOSS VALUES (MW)		
ABC	CABC Henon	CABC Logistic
8,6203	8,4891	8,5046

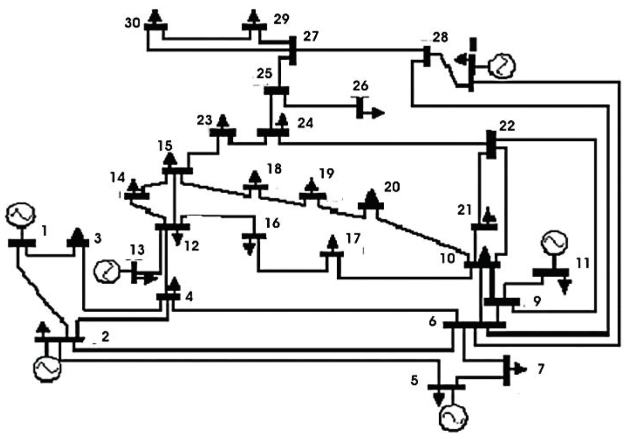

Figure 11 IEEE 30-Bus System

Tab. 5 shows the result minimal active power loss values of IEEE-30 bus system for the ABC, CABC-Henon and CABC-Logistic. The best solution is 4,4325 (MW) which is found with CABC algorithm using Logistic map.

Table 4 IEEE 30Bus System Variable Bounds

	Limit Values of Generator Voltages (pu)						Regulation Limit Values of Tap Setting Transformers				Reactive Power Limit Values of Compensators (pu)			
	V1	V2	V5	V8	V11	V13	T4-12	T6-9	T6-10	T27-28	QC10	QC15	QC19	QC24
min	1	1	1	1	1	1	0,9	0,9	0,9	0,9	0	0	0	0
max	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	0,05	0,05	0,05	0,05

Table 5 Result Minimal Active Power Loss Values of IEEE-30 Bus System for the ABC, CABC-Henon and CABC-Logistic

IEEE-30 BUS SYSTEM ACTIVE POWER LOSS VALUES (MW)		
ABC	CABC Henon	CABC Logistic
4,8368	4,4325	4,4323

It can be seen from Tabs. 4 and 5 that CABC algorithm using chaotic maps can produce better solutions than that of classical ABC algorithm method.

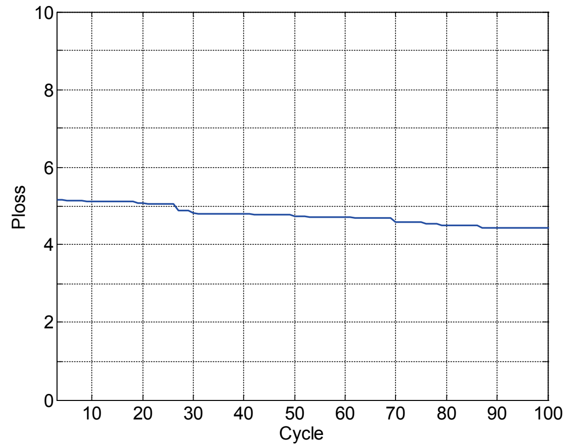

Figure 12 Active Power LossValues with ABC Algorithm for IEEE-30 Bus System

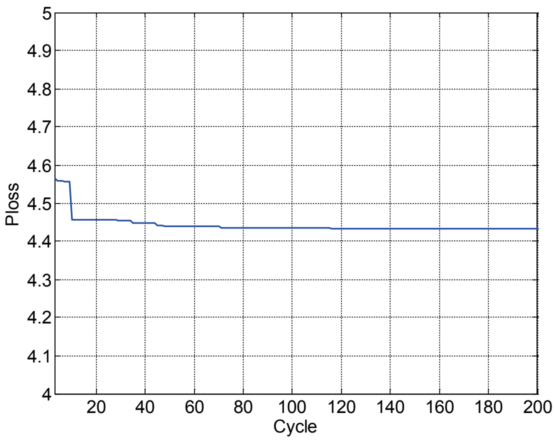

Figure 13 Active Power Loss Values with CABC Algorithm using Henon Map for IEEE-30 Bus System

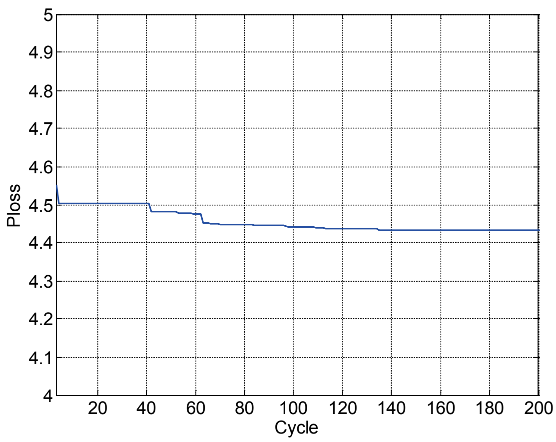

Figure 14 Active Power LossValues with CABC Algorithm using Logistic Map for IEEE-30 Bus System

7 Conclusion

In this study, a new approach to RPO is presented by using CABC algorithm. CABC algorithm based on using chaotic number generators such as Logistic map and Henon map, has been successfully applied to IEEE-6 bus and IEEE-30 bus power systems to minimize the active power loss. The results compared with the classical ABC show that CABC algorithm also reaches the active power loss limits and improves markedly the quality of results. Simulation results are encouraging and show the succes of the applied approach.

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