Implementation of Modified Chaos Embedded Symbiotic Organisms Search Algorithm to Solve Economic Dispatch Problem

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***Abstract*— With the increase in fossil fuel prices, power system operators were facing a challenge to reduce the operational cost since it is directly related to the consumer electricity price. To counter the issue, the optimal power output of generation units were obtained by solving economic dispatch problem. In past years, various researchers have attempted to solve the problem using different optimization technique. However, several optimization techniques failed to produce a high-quality solution due to the drawbacks of the optimization process. This paper presents a new optimization technique termed as modified chaos embedded symbiotic organisms search technique in the attempt to produce a higher quality solution. The proposed technique was employed to solve economic dispatch problem on a 26-bus IEEE reliability test system (RTS) at several case studies. Comparative studies with respect to PSO, EP and AIS has yielded that the proposed algorithm has proven its superiority over the other optimization technique.**

***Index Terms*—Economic Dispatch, Piecewise Map, Chaotic Local Search, Symbiotic Organisms Search.**

I. Introduction

Over the years, it can be observed that the energy demand has increased. The increase in fossil fuel prices has led the power system operator to face challenges in reducing the operational costs. The operational cost can affect the electricity cost which needs to be paid by the energy consumer. In order to cater the increase in electricity demand, new power generation facility may be required. However, the proposed solution may be hindered by constraints such as unsuitable location and high installation cost. Although a new power plant can be installed, non-optimal power dispatch would cause the operational cost to be high. Therefore, economic dispatch can be implemented to reduce the total generation cost in a power system. Numerous studies have been conducted to solve on economic dispatch. Warsono *et al.* [1] have reviewed the implementation of Genetic Algorithm (GA) variations to solve economic dispatch problem. On the other hand, Vanaja *et al.* [2] have attempted to address ED problems using Artificial Immune System (AIS). Real coding and binary coding representation of AIS were examined and comparative study with GA revealed that real coded AIS yielded the best performance in terms of total generation cost. Implementation of AIS to solve ED problem on a 3-generation unit power system by Rahman *et al.* [2] has supported the results obtained by [3] where adaptive cloning, selective mutation and tournament selection scheme yielded the best performance in terms of solution quality. Sinha *et al*. [4] have conducted a study on the implementation of Evolutionary Programming (EP) variations to solve ED problems resulted in the best performance yielded by Improved Fast (IFEP) technique. Rahimullah *et al.* [5] have attempted to solve ED problems using different variants of EP. A comparative study was conducted with respect to GA resulting in EP performs better as compared to GA. Zamani *et al.* [6] have demonstrated the implementation of classical Particle Swarm Optimization (PSO) to solve multi-area ED problem revealing PSO performed better as compared to EP and AIS. Aside of GA, EP, AIS and PSO, various other optimization techniques have been employed to solve ED problems. Among the highlighted methods are such as Artificial Bee Colony (ABC) [7], Ant Colony Optimization (ACO) [8], Cuckoo Search [9], Harmony Search Algorithm (HSA) [10] and Teaching-Learning-based Optimization (TLBO) algorithm [11].

However, some methods were unable to provide a minimal total generation cost due to the drawbacks of the methodology used by the researchers. Researchers in [12] reported that classical optimization technique such as deterministic optimization method having a tendency to stuck at local extrema point and the possibility of divergence in the optimization process. On the other hand, gradient-based method faced difficulties while dealing with non-smooth and discontinuous function [13]. Studies conducted in [14] reported that although dynamic programming method can solve ED problems, the curse of dimensionality hinders the

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technique from providing an optimal solution. In [15], ABC is reported to suffer from poor exploitation and slow convergence. PSO is also known to suffer premature convergence problems despite its known advantages [16]. Other related work was the one conducted in [17]. In this study, bacterial foraging algorithm (BFA) offers faster convergence speed. However, non-optimal selection of BFA parameters can affect the convergence of the optimization process, which may lead to divergence. Symbiotic Organisms Search (SOS) is one of the recent optimization technique which can solve the unsolvable problem. SOS was developed by Min-Yuan Cheng and Doddy Prayogo in 2014 [18]. It simulates the symbiosis relationship of organisms in an ecosystem. SOS-based optimization techniques have proven its capability to produce a high-quality solution by solving various optimization problems such as cantilever beam design, task scheduling [17], optimal power flow [18] and economic dispatch [19]. To further improve the searching capability of SOS algorithm, various researchers have proposed several modifications to the novel SOS algorithm. In [20], task scheduling problem has been solved by using a modified SOS algorithm where the chaos component is embedded in the mutualism and commensalism phase of the algorithm. Secui *et al.* [23] have altered the novel SOS algorithm to solve economic dispatch problem by introducing selection factor and chaotic variable on the mutualism and commensalism relationship while eliminating parasitism relationship to reduce the time needed for computation process. However, this approach may not simulate the real symbiotic relationship since one of the components of symbiotic relationship has been eliminated. In [21], a different modification has been conducted on SOS algorithm where the symbiosis relationship of SOS algorithm was maintained as in the novel algorithm while introducing Chaotic Local Search (CLS) method after the symbiosis relationship phase in the attempt to solve optimal distributed generation allocation problem. Hence, naming the optimization technique as Chaos Embedded Symbiotic Organisms Search (CSOS).

Therefore, this paper presents the implementation of modified Chaos embedded Symbiotic Organisms Search (mCSOS) technique to solve economic dispatch problems. The optimization algorithm used in this research is the modified SOS algorithm which is proposed by authors in [21]. In this study, instead of using the same chaos mapping as implemented in [21], the authors have implemented different chaos mapping with the different value of chaotic local search parameter. The optimization technique is then tested on 26-bus IEEE test system, and several case studies will be subjected to the optimization problem to observe its robustness. A comparative study between mCSOS with other optimization technique such as PSO, EP and AIS in terms of solution quality are also conducted in this study.

II. Problem Formulation

Economic dispatch is defined as the combination of power generated by the generation units in a power system which would yield the minimum total generation cost [6]. In economic dispatch, the main objective of the optimization scheme is to minimize the total generation cost, which can be expressed as:

$$F = min(C_{gT}) \tag{1}$$

$$C_{gT} = \sum_{k=1}^{N_g} C_g^{(k)} \tag{2}$$

where F is the objective function of minimization of total generation cost in a power system C_{gT}. $C_g^{(k)}$ is defined as the generation cost for k^{th} generation unit, and N_g is the number of generators operating in a power system.

The generation cost of a generation unit is dependent on the power output of a generation unit, and it can be expressed as a quadratic function of the power generated in a generation unit. It can be mathematically expressed as:

$$C_g^{(k)} = \alpha_k + \beta_k P_{G,k} + \gamma_j P_{G,k}^2 \tag{3}$$

where $P_{G,k}$ is the active power generated by k^{th} generation unit and α_k, β_k, and γ_k are the cost coefficient of k^{th} generation unit in a power system.

In order to simulate realism to the optimization problem, constraints are imposed to the optimization. One of the constraints subjected to the optimization process is power balance constraint. Power balance constraint states that the total power generated by the generation units in a power system should cater real power losses and all the loads in the power system. The constraint can be expressed as:

$$\sum_{j=1}^{N_g} P_{G,k} = \sum_{n=1}^{N_{bus}} P_{D,n} + P_{loss} \tag{4}$$

where $P_{D,n}$ is the active power demand at n^{th} bus of the power system, P_{loss} and N_{bus} is the total active power loss and the total number of bus in the power system respectively.

Next, the power output of k^{th} generation unit is bounded between minimum and maximum limitation since operation below the minimum limit can cause the generation unit to become unstable, and operation beyond maximum limit can cause overload on the units. This limitation can be identified as output power boundary constraints, and it can be expressed as:

$$P_{G,k}^{min} < P_{G,k} < P_{G,k}^{max} \tag{5}$$

where $P_{G,k}^{min}$ and $P_{G,k}^{max}$ are the minimum power output and maximum power output of k^{th} generation unit respectively.

III. Modified Chaos Embedded Symbiotic Organisms Search for Economic Dispatch Problem

In order to solve economic dispatch problem, the modified Chaos Embedded Symbiotic Organisms Search (mCSOS) is introduced to determine the optimal combination of output power of the generation units in a power system which yields the minimal total generation cost. The proposed mCSOS algorithm is an optimization algorithm; modified from CSOS algorithm developed in [21], which simulated the relationship of organisms in an ecosystem. Then, a search is conducted around the best organism in the ecosystem in the attempt to further improve the search capability of the algorithm. In this paper, the organisms of mCSOS are defined as the power generated at each generation unit in a power system excluding the slack generator while the fitness value is defined as the total generation cost of all generation units in the system. The detailed information regarding the steps of CSOS algorithm can be referred to reference [21], and brief explanation of the optimization process using mCSOS is stated as follow:

1) Initialization

At this stage, output power of the generation units in a power system which excludes the slack generator (generation unit on the slack bus) was generated using random number bounded by the minimum and maximum limit of the individual generation units. The generated output power, known as organism will be accepted to be included in the pool of organisms known as ecosystem if the organism yields lower total generation cost compared to the pre-optimized total generation cost.

$$X_i = \left\{X_i^{(1)}, X_i^{(k)}, \dots, X_i^{(Nd)}\right\} \tag{6}$$

for $i = 1, 2, \dots, N_{org}$

where X_i is the i^{th} organism in the ecosystem, $X_i^{(k)}$ is the k^{th} generation unit of the i^{th} organism, N_d is the number of generation units excluding the slack generator in a power system, and N_{org} is the number of organisms in an ecosystem. After the ecosystem has been generated, one organism will be initialized to be the best organism in which that the organism possesses the best fitness value among the other organisms. Then, chaotic search radius, r is initialized as expressed by:

$$r_j = \frac{P_{G,j}^{max} - P_{G,j}^{min}}{2} \tag{7}$$

$$r = \left\{r_1, r_j, \dots, r_{N_d}\right\} \tag{8}$$

2) Mutualism

During this phase, the organisms will be modified through mutualism relationship of organisms in an ecosystem. The process started by choosing i^{th} set of generation units output, X_i from the ecosystem. Next, j^{th} set of generation units output, X_j was randomly selected from the ecosystem in which X_j should not be the same organism as X_i. Then, a mutual vector, *MV* was computed for every generation units in power system. Mutual vector in the mutualism relationship can be expressed as:

$$MV = \frac{X_i + X_j}{2} \tag{9}$$

After the mutual vector has been computed, X_i and X_j are subjected to mutualism relationship, hence producing new sets of generation units output for i^{th} and j^{th} organism which are known as $X_{i,new}$ and $X_{j,new}$ respectively. The mutualistic symbiosis of X_i and X_j can be mathematically expressed as:

$$X_{i,new} = X_i + \delta_{m,i} \times \left(X_{best} - (MV \times BF1)\right) \tag{10}$$

$$X_{j,new} = X_j + \delta_{m,j} \times \left(X_{best} - (MV \times BF2)\right) \tag{11}$$

where X_{best} is the best organism in the ecosystem, $\delta_{m,i}$ and $\delta_{m,j}$ are random number ranged between *0* to *1*. *BF1* and *BF2* are random integer number with value either *1* or *2*.

The fitness value of $X_{i,new}$ and $X_{j,new}$ is then evaluated and will be compared with the fitness value of X_i and X_j respectively. If the newly produced organism is fitter than the original, then the new organism will replace the older one. Otherwise, the original organism will retain its place in the ecosystem.

3) Commensalism

In this phase, the organisms will be modified based on commensalism relationship in an ecosystem. Firstly, the j^{th} set of generation units output, X_j is randomly selected from the ecosystem in which that i^{th} set of generation units output X_i and X_j is different. Then, a new set of generation units output $X_{i,new}$ is produced through commensal symbiosis between X_i and X_j, which can be represented as:

$$X_{i,new} = X_i + \delta_{c,i} \times \left(X_{best} - X_j\right) \tag{12}$$

where $\delta_{c,i}$ is a random number ranged between *-1* to *1*. The fitness value of $X_{i,new}$ is then computed and if it is fitter compared to fitness value of X_i, then $X_{i,new}$ will replace X_i. Otherwise, X_i will remain in the ecosystem.

4) Parasitism

In this phase, i^{th} set of generation units output X_i is chosen from the ecosystem. Later, j^{th} set of generation units output X_j was also selected using the same manner as in mutualism and commensalism phase. Then, a parasite vector *PV* is produced by replicating X_i. Randomly selected dimensions of *PV* are consequently modified using randomly generated number which is bounded by the maximum and minimum limit of the particular generation unit. The fitness value of *PV* is then evaluated and compared with the fitness value of X_j. If *PV* is fitter than X_j, then X_j is replaced by *PV*. Otherwise, X_j will be retained and *PV* will be eliminated.

5) Best Organism Identification

After mutualism, commensalism and parasitism phase have been executed, the set of generation units output with the best fitness value will be assumed to be the new best organism, $X_{best,new}$. The fitness of $X_{best,new}$ is then compared with the older best value, X_{best}. If $X_{best,new}$ is fitter as compared to X_{best}, then $X_{best,new}$ will be taken to be the best organism in which $X_{best,new}$ will replace X_{best}. Otherwise, X_{best} will be maintained as the best organism. Later, if all organisms have undergone mutualism, commensalism and parasitism phase, the optimization process will continue to step 6. Otherwise, the organism number counter i will be increased by *1* and proceed to step 2.

6) Chaotic Local Search

The search started by initializing the *chaotic local search* (CLS) iteration counter, t and the chaotic variable cv_t. Chaotic variable cv_t value is generated using random number in the range of 0 to 1 and the number of dimension of cv_t is equal to the number of dimension of X_{best}. CLS iteration started by computing the updated value of chaotic variable cv_{t+1}. In this paper, the type of chaotic map used for chaotic local search is the piecewise map and can be expressed as:

$$cv_t = rand(0,1) \tag{13}$$

$$cv_{t+1} = \begin{cases} \dfrac{cv_t}{p} & 0 \le cv_t < p \\ \dfrac{cv_t - p}{0.5 - p} & p \le cv_t < 0.5 \\ \dfrac{1 - p - cv_t}{0.5 - p} & 0.5 \le cv_t < 1 - p \\ \dfrac{1 - cv_t}{p} & 1 - p \le cv_t < 1 \end{cases} \tag{14}$$

Consequently, the chaotic variable is used to produce a new possible solution by mapping the chaotic variable to the best organism. The fitness value of the new possible solution is then evaluated. The variable mapping can be expressed as:

$$v_{t+1} = X_{best} + \left(r \times (2cv_{t+1} - 1)\right) \tag{15}$$

After the fitness value of v_{t+1} has been evaluated, it is then compared to the fitness value of X_{best}. If the fitness value of v_{t+1} is less fitter compared to the fitness value of X_{best}, then CLS will continue by updating the CLS iteration counter and proceed to update new chaotic variable value. Otherwise, X_{best} will be replaced by v_{t+1}, CLS is halted, the chaotic search space radius is then reduced, and the optimization process continues to the next phase. Chaotic search space reduction can be expressed as:

$$r = r \times rand(0,1) \tag{16}$$

7) Convergence Test

In the convergence test, the algorithm will update the iteration counter. Then, the algorithm will test whether the optimization process has reached its maximum iteration limit or vice versa. In the event the optimization has not reached its maximum iteration limit, the optimization process will be continued at mutualism phase and the ith organism counter, i is initialized to 1. Otherwise, the optimization process will halt.

IV. Results and Discussions

In order to test the capability of the proposed mCSOS algorithm, the optimization algorithm was implemented to solve economic dispatch problem in the attempt to produce optimal combination of generation unit output in a power system which would yield the minimal total generation cost. The test system used in the economic dispatch problem was IEEE 26-bus Reliability Test System (RTS) which consists of 6 power generation units and 17 load demand centre. The parameters set during the optimization process are tabulated in Table I. The cost coefficients, as well as the maximum and minimum power generation limit, are listed as in Table II.

TABLE I
Parameters of CSOS Technique

Parameter	Value
Number of organisms, N_{org}	20
Maximum optimization iteration, *max_iter*	100
CLS control parameter, *p*	0.2
Maximum CLS iteration, *cls_max_iter*	100

TABLE II
Cost Coefficient and Power Output Limits of the Generators

Generation unit at bus no.	P_G^{min}	P_G^{max}	α	β	γ
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
26	50	120	190	12.0	0.0075

Before the optimization process is conducted, pre-optimized total generation cost will be computed. In this paper, pre-optimized total generation cost is considered to be the total generation cost of the power system before economic dispatch is conducted. Then, optimization algorithms will be implemented to solve economic dispatch problem by obtaining the total generation cost of the power system. The total generation cost of the power system after economic dispatch has been conducted was considered to be the post-optimized total generation cost.

In order to simulate different operating condition of the test system, 3 case studies were considered in this study. These case studies will determine the capability of the optimization technique to solve the optimization problem in different conditions. The case studies considered in this paper are:

Case 1: Base case condition
Case 2: Contingency condition
Case 3: Load increment condition

The optimization process for each case study was executed multiple times to observe the variation of results produced by the optimization algorithm. Optimization results produced by the proposed algorithm will be compared with other optimization techniques which are AIS, PSO and EP to show the effectiveness of the proposed optimization algorithm in solving economic dispatch problem.

1) Base Case Condition

During base case condition, the power system was not subjected to any changes. The proposed optimization algorithm is then used to solve the economic dispatch problem. Comparative studies are then conducted on the same case study with respect to PSO, EP and AIS. In order to observe the variation of results yielded by the optimization techniques, the optimization process was executed for 20 times. The results of the optimization process are tabulated in Table III.

TABLE III
OPTIMIZATION RESULTS DURING BASE CASE CONDITION

Parameter	mCSOS	PSO	EP	AIS
Pre-optimized total generation cost	16760.73	16760.73	16760.73	16760.73
Best post-optimized total generation cost	15446.74	15446.76	15453.77	15450.10
Worst post-optimized total generation cost	15446.74	15446.87	15462.71	15453.75
Average post-optimized total generation cost	15446.74	15446.80	15454.22	15453.57

From Table III, it can be observed that the proposed optimization algorithm has successfully solved economic dispatch problem indicating a lower total generation cost when compared to the pre-optimized total generation cost by 7.84%. Other optimization techniques used in this paper were also capable of solving economic dispatch problem. A comparative study conducted in this condition has proven that the proposed algorithm was superior compared to PSO, EP and AIS by providing better results in terms of best post-optimized, worst post-optimized and average post-optimized total generation cost.

2) Contingency Condition

To simulate contingency condition, the generation unit located at bus 2 of the test system was shut down. Hence, reduction of the number of generation unit in the test system forced other generation units to compensate the total power generated to cater the load demand in the test system. The proposed optimization algorithm is then implemented to solve economic dispatch problem. Comparative studies with respect to PSO, EP and AIS was conducted to observe the effectiveness of mCSOS algorithm. The optimization process was executed for 20 times for each optimization technique to observe the variation of results produced by the optimization algorithms and the results of the optimization process are tabulated in Table IV.

TABLE IV
OPTIMIZATION RESULTS DURING CONTINGENCY CONDITION

Parameter	mCSOS	PSO	EP	AIS
Pre-optimized total generation cost	15712.68	15712.68	15712.68	15712.68
Best post-optimized total generation cost	14495.04	14495.04	14498.17	14497.58
Worst post-optimized total generation cost	14495.04	14495.05	14498.55	14498.19
Average post-optimized total generation cost	14495.04	14495.04	14498.19	14498.16

The results obtained from the optimization process have shown that the proposed optimization algorithm has successfully reduced the total generation cost compared to pre-optimized total generation cost, hence proving that economic dispatch problem can be solved. The proposed algorithm has yielded reduction by 7.75% of the total generation cost in the test system. A comparative study was conducted for this case study. It can be seen that PSO is capable of yielding the same best post-optimized total generation cost and average post-optimized total generation cost as the proposed optimization algorithm, PSO has provided higher worst post-optimized total generation cost as compared to the proposed algorithm. The post-optimized total generation cost produced by EP and AIS are higher as compared to the post-optimized total generation cost produced by the proposed algorithm. Hence, the superiority of the optimization algorithm has been justified.

3) Load Increment Condition

During load increment condition, the active power load at bus 25 of the test system increased uniformly from 0MW up to 160MW by the increment of 20MW. The increment of load will simulate the real-life situation in which the load demand in a power system which keeps increasing from time to time. The load increment was bounded up to 160MW since further increase of load will violate the total maximum power output limit of the generation units in the test system. The similar condition was subjected to PSO, EP and AIS for solving economic dispatch problem. At each loading condition, the optimization process was executed for 5 times to observe the results variation. The results of the optimization process were tabulated in Table V, Table VI and Table VII.

TABLE V
BEST POST-OPTIMIZED RESULTS DURING LOAD INCREMENT CONDITION

Active load at bus 25 (MW)	Pre-optimized cost ($)	Post-optimized cost ($)			
		mCSOS	PSO	EP	AIS
0	16271.79	15062.79	15062.83	15078.04	15069.01
20	16618.54	15335.83	15335.86	15344.24	15344.01
40	16977.92	15614.98	15615.02	15620.81	15620.83
60	17350.73	15900.64	15900.68	15907.69	15907.34
80	17737.87	16193.25	16193.27	16195.36	16200.77
100	18140.41	16493.38	16493.39	16496.14	16498.01
120	18559.64	16801.70	16801.71	16804.87	16805.91
140	18997.09	17119.26	17119.28	17120.60	17124.57
160	19454.69	17447.34	17447.34	17449.52	17449.53

TABLE VI
WORST POST-OPTIMIZED RESULTS DURING LOAD INCREMENT CONDITION

Active load at bus 25 (MW)	Pre-optimized cost ($)	Post-optimized cost ($)			
		mCSOS	PSO	EP	AIS
0	16271.79	15062.79	15062.88	15078.16	15069.01
20	16618.54	15335.83	15335.93	15344.24	15344.01
40	16977.92	15614.98	15615.05	15620.81	15620.83
60	17350.73	15900.64	15900.75	15907.69	15907.34
80	17737.87	16193.25	16193.37	16195.36	16200.77
100	18140.41	16493.38	16493.49	16496.14	16498.01
120	18559.64	16801.70	16801.74	16804.87	16805.91
140	18997.09	17119.26	17119.29	17120.60	17124.57
160	19454.69	17447.34	17447.35	17449.52	17449.53

TABLE VII
AVERAGE POST-OPTIMIZED RESULTS DURING LOAD INCREMENT CONDITION

Active load at bus 25 (MW)	Pre-optimized cost ($)	Post-optimized cost ($)			
		mCSOS	PSO	EP	AIS
0	16271.79	15062.79	15062.85	15078.06	15069.01
20	16618.54	15335.83	15335.89	15344.24	15344.01
40	16977.92	15614.98	15615.03	15620.81	15620.83
60	17350.73	15900.64	15900.70	15907.69	15907.34
80	17737.87	16193.25	16193.30	16195.36	16200.77
100	18140.41	16493.38	16493.43	16496.14	16498.01
120	18559.64	16801.70	16801.72	16804.87	16805.91
140	18997.09	17119.26	17119.28	17120.60	17124.57
160	19454.69	17447.34	17447.34	17449.52	17449.53

From Table V, Table VI and Table VII, it can be concluded that the proposed optimization algorithm has successfully solved economic dispatch problem when the system was subjected to load increment. It can be observed that the proposed algorithm has successfully produced the lowest post-optimized total generation cost at all loading conditions. While PSO and the proposed algorithm had yielded the same post-optimized results when bus 25 of the test system was subjected to load of 160MW, the proposed algorithm has managed to provide a lower worst post-optimized total cost generation compared to PSO during the load condition. A comparative study with respect to AIS and EP has also proven that the proposed algorithm was superior as compared to other optimization techniques.

V. CONCLUSION

This study has presented the implementation of modified chaos embedded symbiotic organisms search to solve economic dispatch problem. It is discovered that the proposed optimization algorithm has successfully solved economic dispatch problem by providing lower post-optimized total generation cost compared to the pre-optimized total generation cost through implementation on IEEE 26-bus RTS. Comparative studies conducted in this study has revealed that the proposed algorithm is superior compared to PSO, EP and AIS in terms of giving the lowest post-optimized total generation cost. It is suggested that the effect of CLS parameter is studied in future so that the optimal CLS parameter can be determined and applied, hence improving the capability of the proposed optimization algorithm.

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