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Enhanced Harmony Search Algorithm for Solving Optimal Reactive Power Problem

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ABSTRACT

This paper projects Enhanced Harmony Search (EHS) algorithm for solving optimal reactive power problem. In this approach Harmony search (HS) algorithm has been hybridized with Differential evolution (DE) method. Harmony Search mimics the procedure of a music player to search for an ideal state of harmony in music playing. Harmony Search can autonomously mull over each component variable in a vector while it generates a new vector. These features augment the flexibility of the Harmony Search algorithm and produce better solutions and overcome the disadvantage of Differential Evolution. Enhanced Harmony Search (EHS) algorithm has two deeds. One is EHS has the flexibility& it can adjust the values lightly in order to get a better global value for optimization. Other one is EHS can greatly boost the population's diversity. Enhanced Harmony Search (EHS) algorithm only uses the DE's strategies to search for global optimal results, but also utilize HS's tricks that generate a new vector by selecting the components of different vectors arbitrarily in the harmony memory and its outside. In order to evaluate the proposed Enhanced Harmony Search (EHS) algorithm, it has been tested in standard IEEE 118 & practical 191 bus test systems. Simulations results reveal the best performance of the proposed algorithm in reducing the real power loss.

Keywords: *Optimal reactive power, Transmission loss, differential evolution, harmony search algorithm.*

INTRODUCTION

Optimal reactive power problem plays most important role in the stability of power system operation and control. In this paper the main aspect is to diminish the real power loss and to keep the voltage variables within the limits. Previously many mathematical techniques like gradient method, Newton method, linear programming [4-7] has been utilized to solve the optimal reactive power dispatch problem and those methods have many difficulties in handling inequality constraints. Voltage stability and voltage collapse play an imperative role in power system planning and operation [8]. Recently Evolutionary algorithms like genetic algorithm have been already utilized to solve the reactive power flow problem [9,10]. This paper projects Enhanced Harmony Search (EHS) algorithm for solving optimal reactive power problem. In this approach Harmony search (HS) algorithm has been hybridized with Differential evolution (DE) method. Harmony Search mimics the procedure of a music player to search for an ideal state of harmony in music playing. Harmony Search can autonomously mull over each component variable in a vector while it generates a new vector. These features augment the flexibility of the Harmony Search algorithm and produce better solutions and overcome the disadvantage of Differential Evolution. Enhanced Harmony Search (EHS) algorithm has two deeds. One is EHS has the flexibility& it can adjust the values lightly in order to get a better global value for optimization. Other one is EHS can greatly boost the population's diversity.

Enhanced Harmony Search (EHS) algorithm only uses the DE's strategies to search for global optimal results, but also utilize HS's tricks that generate a new vector by selecting the components of different vectors arbitrarily in the harmony memory and its outside. Global optimization has received extensive research attention, and a great number of methods have been applied to solve this problem. Evolutionary algorithm is a heuristic approach for minimizing possibly nonlinear and non-differentiable continuous space functions. For many decades, evolutionary algorithms range from the first algorithm Genetic Algorithm (GA) [11] to Evolutionary Strategies (ES) [12], Genetic Programming (GP) [13], Evolutionary

Programming (EP) [14], Differential Evolution (DE) [15], and other methods, such as Simulated Annealing (SA) [16], Particle Swarm Optimizer (PSO) [17, 18], and Neural Networks [19]. All of these have been successfully applied to a wide range of optimization problems, such as, image processing, pattern recognition, scheduling, engineering design, and others [20].

Differential evolution (DE) algorithm as a novel version of GA is a population-based stochastic direct search method for global optimization. Unlike GA that uses binary coding to represent problem parameters, DE uses real valued parameters, which is easily applied to experimental minimization where the cost value is derived from a physical experiment rather than a computer simulation. DE has four advantages: ability to handle non-differentiable, nonlinear and multi-modal cost functions; ability to parallel cope with computation intensive cost functions; ease of use; and good convergence properties. It has been successfully applied to various benchmark and real-world problems, including a travelling salesman problem [21], design centring [22], digital filter design [21, 23], and noisy objection functions [24], and so on. Harmony Search (HS) is a new heuristic algorithm mimics the improvisation of music players, which was proposed by Geem [25]. HS is optimization algorithms that seek a best state (global optimum-minimum cost or maximum benefit or efficiency) determined by objective function assessment. It has been successfully used into various benchmark and real-world problems, includes a travelling salesman problem [26], parameter optimization of river flood model [27], design of pipeline network [28, 29], and design of truss structures [30]. The proposed algorithm is more flexible and greatly enhancements population's diversity, which totally different from Liao [31] proposed method, which use the current Number of Function Evaluations (NFE) to replace the parameter t in improvisation step [32-34]. In order to evaluate the proposed Enhanced Harmony Search (EHS) algorithm, it has been tested in standard IEEE 118 & practical 191 bus test systems. Simulations results reveal the best performance of the proposed algorithm in reducing the real power loss.

Objective Function

Active Power Loss

The objective of the reactive power dispatch problem is to minimize the active power loss and can be defined in equations as follows:

$$F = PL = \sum_{k\in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \quad (1)$$

Where g_k : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems.

Voltage Profile Improvement

To minimize the voltage deviation in PQ buses, the objective function can be written as:

$$F = PL + \omega_v \times VD \quad (2)$$

Where ω_v: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \quad (3)$$

Equality Constraint

The equality constraint of the problem is indicated by the power balance equation as follows:

$$P_G = P_D + P_L \quad (4)$$

Where the total power generation PG has to cover the total power demand PD and the power losses PL.

Inequality Constraints

The inequality constraint implies the limits on components in the power system in addition to the limits created to make sure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators are written as follows:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \quad (5)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \text{ , } i \in N_g \quad (6)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max} \text{ , } i \in N \quad (7)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \le T_i \le T_i^{max} \text{ , } i \in N_T \quad (8)$$

Upper and lower bounds on the compensators

$$Q_c^{min} \le Q_c \le Q_C^{max} \text{ , } i \in N_C \quad (9)$$

Where N is the total number of buses, NT is the total number of Transformers; Nc is the total number of shunt reactive compensators.

Differential Evolution Algorithm

The Differential Evolution (DE) algorithm was originally introduced by Price and Storn & at present, there are a number of variants of DE. The particular variant used throughout this investigation is the DE/rand/1/bin scheme, *rand* means randomly chosen population vector, *1* is the number of difference vectors used, *bin* means crossover due to independent binomial experiments. This scheme will be discussed here briefly.

$$P_{x,g} = (x_{i,g}), i = 0,1,..,N_P - 1; g = 0,1,..,G_{max} \quad (10)$$

$$x_{i,g} = (x_{j,i,g}), j = 0,1,..,D - 1 \quad (11)$$

Where N_p denotes the number of population vectors, g defines the generation counter, and D stands for the dimensionality, i.e. the number of parameters. In case a preliminary solution is available, the initial population might be generated by adding normally distributed random deviations to the nominal solution $x_{nom;0}$.

DE generates new parameter vectors by adding the weighted difference between two population vectors to a third vector. Let this operation be called mutation.

$$v_{i,g+1} = x_{r1,g} + F.(x_{r2,g} - x_{r3,g}) \quad (12)$$

Where random indexes r1, r2, *r*3 ϵ1, 2, ..., N_p, cross rate F ∈ [0, 2].

In order to increase the diversity of the perturbed parameter vectors, crossover is operated.

$$u_{ji,g+1} = \begin{cases} v_{ji,g+1} if(rand(j) \leq CR) or j = rand(i) \\ x_{ji,g} if(rand(j) > CR) or j \neq rand(i) \end{cases} \quad (13)$$

where rand(j) is the jth evaluation of a uniform random number generator with outcome ∈ [0, 1], rand(i) is a randomly chosen index ∈ 1, 2, ...,D which endures that $u_{i;g+1}$ gets at least one parameter from $v_{i;g+1}$. CR is the crossover constant ∈ [0, 1]. If the trial vector yields a lower cost function value than the target vector, the trial vector replaces the target vector in the following generation. This last operation is called selection. Each population vector has to serve once as the target vector so that N_p competitions take

Place in one generation. However, due to the limitation of $N_p \cdot (N_p - 1)$ potential perturbation possibilities for base vector, there is a limited possibility to find regions of improvement and hence stagnation can be the price to pay for the low number of N_p. In order to increase the number of potential points to be searched while still maintaining a low number of N_p gives rise to the various strategies for diversity enhancement, of which research on DE's mutation is one method.

HARMONY SEARCH

Harmony Search (HS) algorithm was newly developed in an analogy of music creativeness process where music players manage the pitches of their instruments to obtain better harmony. The Harmony Memory Size (HMS) determines the number of vectors to be stored. Then, through the Harmony Memory Considering Rate (HMCR) choose any one value from the HM, utilize the Pitch Adjusting Rate (PAR) choose an neighbouring value of one value from the HM, and choose totally random value from the possible value range. The steps in the process of HS are as follows:

Step a: Initialize the algorithm parameters and optimization operators. Such as HM, HMS, HMCR, PAR.

Step b: Improvise a new harmony from HM. A New Harmony vector is generated from HM, based on memory considerations, pitch adjustments, and randomization. The HMCR is the probability of choosing one value from the historic values stored in the HM, and (1-HMCR) is the probability of randomly choosing one feasible value not limited to those stored in the HM.

$$x_{i,g+1} = \begin{cases} x_{ji,g} if(rand(0,1) \leq HMCR, \\ l_i + rand(0,1)(u_i - l_i) with probability (1 - HMCR) \end{cases} \quad (14)$$

$$x_{i,g+1} = \begin{cases} x_{i,g+1} - rand(0,1) * BAND if(rand(0,1) \leq 0.5, \\ x_{i,g+1} + rand(0,1) * BAND if(rand(0,1) > 0,5. \end{cases} \quad (15)$$

Step c: Update HM. If a New Harmony vector is better than the worst harmony in HM, judged in terms of the objective function value, the New Harmony is included in HM and the existing worst harmony is excluded from HM.

Step d: Repeat Steps b and c until the terminating criterion is satisfied.

ENHANCED HARMONY SEARCH (EHS) ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER PROBLEM

In this approach Harmony search (HS) algorithm has been hybridized with Differential evolution (DE) method. Harmony Search mimics the procedure of a music player to search for an ideal state of harmony in music playing. Harmony Search can autonomously mull over each component variable in a vector while it generates a new vector. These features augment the flexibility of the Harmony Search algorithm and produce better solutions and overcome the disadvantage of Differential Evolution. Enhanced Harmony Search (EHS) algorithm has two deeds. One is EHS has the flexibility& it can adjust the values lightly in order to get a better global value for optimization. Other one is EHS can greatly boost the population's diversity. The complete algorithm of EHS is as follows.

Initialization

In order to unite DE and HS successfully, we assume the DE's general method DE/rand/1/bin strategy to generate a point X, if some dimension values of the point are located beyond the constraint of the variables, i.e. we use the following rules to adjust it:

$$x_i = \begin{cases} l_i + U_i(0,1)(u_i - l_i) if x_i < l_i \\ u_i - U_i(0,1)(u_i - l_i) if x_i > u_i \end{cases} \quad (16)$$

Where $U_i(0, 1)$ is the uniform random variable from [0, 1] in each dimension *i*, and $1 \le i \le N$, which is also suit for initializing HS's harmony memory. The improvement includes four steps as follows,

Improve the Generation

Step a: produce the initial population randomly and compute the fitness of each individual;

Input: algorithm parameters: CR, F, HMCR, PAR;

Initialization: Generate the initial population of N_p as HM with vectors satisfying lower and

upper bounds;

fort∈1, ...,G_{max} do

repeat

The halting criterion is not satisfied

fori∈1, ...,Np do

//r0! = r1! = r2! = i

r0 = floor(rand(0, 1) ∗N_p); while(r0==i);

r1 = floor(rand(0, 1) ∗N_p); while(r1==r0 or r1==i);

r2 = floor(rand(0, 1) ∗N_p); while(r2==r1 or r2==r0 or r2==i);

jrand= floor(D ∗rand(0, 1));

end for

for j ∈1, ...,D do

if rand(0, 1) ≤ CR or j==j rand) then

$u_j = x_{j;r0} + F*(x_{j;r1} - x_{j;r2})$;

else

$u_j = x_{j;i}$;

end if

end for

//Improvise a new harmony

For j ∈1, ...,D do

// Harmony memory considering: arbitrarily select any variable-i pitch in HM

if(rand(0, 1) ≤ HMCR then

if(round(0, 1) ≤ PAR then

//Pitch adjusting: randomly adjust u_j within a small bandwidth,

±rand(0, 1) ∗BAND

if(round(0, 1) ≤ 0.5 then

$v_j = u_j +$ rand(0, 1) ∗BAND

else

$v_j = u_j -$ rand(0, 1) ∗BAND

end if

end if

else

//Random playing: arbitrarily select any pitch within upper u_j and lower bounds l_j

$v_j = l_j +$ rand(0, 1) $*(u_j - l_j)$

end if

end for

if v_j is better than the worst harmony in HM, x_{worst}, then

Replace x_{worst} with v_j in HM, then sort HM

end if

until |f(best) − f(worst)| < ε

end for

Step b: discover the best and the worst individuals in the existing population in HM;

Step c: manage a new harmony: first, generated a new vector by DE's operation; secondly, adjust the vector through HS;

Step d: revise harmony memory, which is same to selection. If the fitness which is measured by the objective function of the generated harmony vector (trail vector) $u_{i;g}$ is better than or equal to the worst harmony vector(target vector) $x_{i;j}$, it replaces the worst harmony vector in the next generation; otherwise, the target retains its place in the population for at least one more generation.

$$x_{i,g+1} = \begin{cases} u_{i,g} if \left(u_{i,g} \le f(x_{i,g})\right), \\ x_{i,g} otherwise. \end{cases} \quad (17)$$

Step e: confirm the stopping criterion: $|f(best) - f(worst)| < \varepsilon = 1 \times 10^{-16}$. This halting criterion is used to make the algorithm stop earlier when the results satisfy the precision of the optimal reactive power problem.

Simulation Results

At first Enhanced Harmony Search (EHS) algorithm has been tested in standard IEEE 118-bus test system [35].The system has 54 generator buses, 64 load buses, 186 branches and 9 of them are with the tap setting transformers. The limits of voltage on generator buses are 0.95 -1.1 per-unit., and on load buses are 0.95 -1.05 per-unit. The limit of transformer rate is 0.9 -1.1, with the changes step of 0.025. The limitations of reactive power source are listed in Table 1, with the change in step of 0.01.

Table1. *Limitation of reactive power sources*

BUS	5	34	37	44	45	46	48
QCMAX	0	14	0	10	10	10	15
QCMIN	-40	0	-25	0	0	0	0
BUS	74	79	82	83	105	107	110
QCMAX	12	20	20	10	20	6	6
QCMIN	0	0	0	0	0	0	0

The statistical comparison results have been listed in Table 2 and the results clearly show the better performance of proposed Enhanced Harmony Search (EHS) algorithm.

Table2. *Comparison results*

Active power loss (p.u)	BBO[36]	ILSBBO/ strategy1[36]	ILSBBO/strategy1[36]	Proposed EHS
Min	128.77	126.98	124.78	112.32
Max	132.64	137.34	132.39	119.26
Average	130.21	130.37	129.22	114.84

Then the Enhanced Harmony Search (EHS) algorithm has been tested in practical 191 test system and the following results have been obtained. In Practical 191 test bus system – Number of Generators = 20, Number of lines = 200, Number of buses = 191 Number of transmission lines = 55. Table 3 shows the optimal control values of practical 191 test system obtained by EHS method. And table 4 shows the results about the value of the real power loss by obtained by Enhanced Harmony Search (EHS) algorithm.

Table3. *Optimal Control values of Practical 191 utility (Indian) system by EHS method*

VG1	1.100	VG 11	0.900
VG 2	0.700	VG 12	1.000
VG 3	1.010	VG 13	1.000
VG 4	1.010	VG 14	0.900
VG 5	1.100	VG 15	1.000
VG 6	1.100	VG 16	1.000
VG 7	1.100	VG 17	0.900
VG 8	1.010	VG 18	1.000
VG 9	1.100	VG 19	1.100
VG 10	1.010	VG 20	1.100

T1	1.000	T21	0.900	T41	0.900
T2	1.000	T22	0.900	T42	0.900
T3	1.000	T23	0.900	T43	0.910
T4	1.100	T24	0.900	T44	0.910
T5	1.000	T25	0.900	T45	0.910
T6	1.000	T26	1.000	T46	0.900
T7	1.000	T27	0.900	T47	0.910
T8	1.010	T28	0.900	T48	1.000
T9	1.000	T29	1.010	T49	0.900
T10	1.000	T30	0.900	T50	0.900
T11	0.900	T31	0.900	T51	0.900
T12	1.000	T32	0.900	T52	0.900
T13	1.010	T33	1.010	T53	1.000
T14	1.010	T34	0.900	T54	0.900
T15	1.010	T35	0.900	T55	0.900
T19	1.020	T39	0.900		
T20	1.010	T40	0.900		

Table4. *Optimum real power loss values obtained for practical 191 utility (Indian) system by EHS method.*

Real power Loss (MW)	EHS
Min	140.048
Max	144.246
Average	142.012

CONCLUSION

In this paper Enhanced Harmony Search (EHS) algorithm susccessfully solved optimal reactive power problem. Enhanced Harmony Search (EHS) algorithm has two deeds. One is EHS has the flexibility& it can adjust the values lightly in order to get a better global value for optimization. Other one is EHS can greatly boost the population's diversity. Enhanced Harmony Search (EHS) algorithm only uses the DE's strategies to search for global optimal results, but also utilize HS's tricks that generate a new vector by selecting the components of different vectors arbitrarily in the harmony memory and its outside. In order to evaluate the proposed Enhanced Harmony Search (EHS) algorithm, it has been tested in standard IEEE 118 & practical 191 bus test systems. Simulations results reveal the best performance of the proposed algorithm in reducing the real power loss.

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