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UPGRADED HARMONY SEARCH ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

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ABSTRACT

In this paper, a new-fangled Improved harmony search algorithm (IHS) is projected to solve optimal reactive power dispatch problem. Harmony search (HS) is a derivative-free tangible parameter optimization algorithm. It draws encouragement from the musical improvisation process of searching for a perfect state of harmony. The projected opposition-based HS of the present work employs opposition-based learning for harmony memory initialization and also for generation jumping. The perception of opposite number is employed in IHS to improve the convergence rate of the HS algorithm. The proposed IHS has been tested on standard IEEE 57 bus test systems and simulation results show clearly the better performance of the proposed algorithm in reducing the real power loss.

Keywords: Opposition-based learning, Differential learning, Harmony search, optimal reactive power, Minimization problem, Transmission loss.

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Contribution/ Originality

This study uses new estimation methodology-Opposition based Harmony search algorithm to solve the Reactive power dispatch problem. The main aim is to reduce the Real Power loss and also to maintain the voltage profiles within the specified limits.

1. INTRODUCTION

Reactive power optimization plays a key role in optimal operation of power systems. Many numerical methods [1-7] have been applied to solve the optimal reactive power dispatch problem. The problem of voltage stability plays a strategic role in power system planning and operation

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[8]. So many Evolutionary algorithms have been already proposed to solve the reactive power flow problem [9-11]. In [12, 13], Hybrid differential evolution algorithm and Biogeography Based algorithm has been projected to solve the reactive power dispatch problem. In [14, 15], a fuzzy based technique and improved evolutionary programming has been applied to solve the optimal reactive power dispatch problem. In [16, 17] nonlinear interior point method and pattern based algorithm has been used to solve the reactive power problem. In [18-20], various types of probabilistic algorithms utilized to solve optimal reactive power problem. This paper plans a new-fangled enhanced harmony search algorithm (IHS) to solve reactive power dispatch problem. The harmony search algorithm [21, 22] is one of the newly developed optimization algorithm. Tizhoosh presented the perception of opposition-based learning (OBL) in [23]. This idea has been applied to quicken the reinforcement learning [24, 25] and the back propagation learning [26] in neural networks. In the modern literature, the idea of opposite numbers has been utilized to speed up the convergence rate of an optimization algorithm, e.g., opposition-based differential evolution (ODE) [27, 28]. This information of opposite number has been amalgamated during the harmony memory (HM) initialization and also for generating the New Harmony vectors during the progression of HS. The projected IHS algorithm has been evaluated on IEEE 57 bus test system. The simulation results show that our projected approach outperforms all the entitled reported algorithms in minimization of real power loss.

2. PROBLEM FORMULATION

The Optimal Power Flow problem is well thought-out as a common minimization problem with constraints, and it has been mathematically as follows,

a. Real Power Loss

The main objective of the reactive power dispatch is to minimize the Real power loss in the transmission network, which can be defined as follows:

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

or

$$F = PL = \sum_{i\in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i\neq slack}^{Ng} P_{gi} - P_d \qquad (2)$$

Where g_k : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. P_d: is the total active power demand, P_{gi}: is the generator active power of unit i, and P_{gsalck}: is the generator active power of slack bus.

b. Voltage Profile Improvement

For the minimization of the voltage deviation in PQ buses, the objective function turns out to be:

$$F = PL + \omega_v \times VD \qquad (3)$$

Where ω_v: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \qquad (4)$$

c. Equality Constraint

The equality constraint of the Optimal Reactive Power Dispatch problem is represented by the power balance equation (5). The total power generation is addition of total power demand and the power losses and is given by,

$$P_G = P_D + P_L \qquad (5)$$

d. Inequality Constraints

The inequality constraints are the limits on components in the power system as well as the limits produced to guarantee system security.

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \qquad (6)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \qquad (7)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \qquad (8)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \qquad (9)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \le Q_c \le Q_C^{max}, i \in N_C \qquad (10)$$

Where N is the total number of buses, N_T is the total number of Transformers; N_c is the total number of shunt reactive compensators.

3. HARMONY SEARCH ALGORITHM

Harmony search (HS) is a new-fangled population-based algorithm that imitates the music inventiveness progression where the musicians manage their instruments' pitch by searching for a perfect state of harmony. The resemblance between improvisation and optimization is likely as follows:

1. Every decision variable relates to very musician
2. Decision variable's value range relates to the musical instrument's pitch range.
3. Iteration relates to the Musical harmony at a definite time.
4. Objective function relates to the Spectators aesthetics.

Solution vector is enhanced iteration by iteration just like musical harmony is enhanced time after time.

The HS parameters defined as follows:

1. Harmony Memory Size (HMS)
2. Harmony Memory considering Rate (HMCR), where HMCR ∈ [0, 1];

3. Pitch adjust Rate (PAR), Where PAR ∈ [0, 1];
4. Stopping Criteria (i.e. number of improvisation (NI)).

a. Set Harmony Memory

The harmony memory (HM) is a matrix of solutions with a size of HMS, where every harmony memory vector symbolizes one solution. In this step, the solutions are arbitrarily created and reshuffled in a reversed order to HM, based on their objective function values such as $f(a^1) \leq f(a^2) \, ... \leq f(a^{HMS})$.

$$\mathrm{HM} = \left[\begin{array}{ccc|c} & & & f(a^1) \\ a_1^1 & \cdots & a_N^1 & . \\ \vdots & \ddots & \vdots & . \\ a_1^{HMS} & \cdots & a_N^{HMS} & . \\ & & & f(a^{HMS}) \end{array}\right] \qquad (11)$$

In this step, the HS generates a New Harmony vector, $a' = (a'_{1,} a'_2 \, ... \, a'_N)$. The following equation concise the two steps i.e. memory consideration and arbitrary consideration.

$$a'_i \leftarrow \begin{cases} a'_i \in \left\{\{a_i^1, a_i^2, \ldots \ldots . . a_i^{HMS}\right\} w.p. HMCR \\ \quad a'_i \in \ A_i \qquad w.p. \ (1 - HMCR) \end{cases} \qquad (12)$$

The superfluous exploration for superior solutions in the exploration space is accomplished through tuning each decision variable in the new-fangled harmony vector, $a' = (a'_{1,} a'_2 \, ... \, a'_N)$ inherited from HM using PAR operator. These decision variables (a'_i) are dissected and to be tweaked with the probability of PAR ∈ [0, 1] as in Eq. (13).

$$a'_i \leftarrow \begin{cases} \quad Adjusting\ pitch\ w.p.PAR \\ Doing\ Nothing\ w.p.(1 - PAR) \end{cases} \qquad (13)$$

If a produced arbitrary number rnd ∈ [0, 1] within the probability of PAR then, the new decision variable (a'_i) will be attuned based on the following equation:

$$(a'_i) = (a'_i) \pm \mathrm{rand}() * \mathrm{bw} \qquad (14)$$

Here, bw is an arbitrary distance bandwidth used to perk up the performance of HS and (rand ()) is a function that yields an arbitrary number ∈ [0, 1].

b. Modernize the Harmony Memory

In order to refurbish HM with the new created vector $a' = (a'_1, a'_2, \ldots \ldots a'_N),$, the objective function is calculated for each new-fangled Harmony vector f (a'). If the objective function value for the fresh vector is superior than the deprived harmony vector stockpiled in HM, then the poorest harmony vector is exchanged by the new vector. Else, this new vector is disregarded.

$$a' \in \ HM \wedge a^{worst} \notin \ HM \qquad (15)$$

Lastly, the finest harmony memory vector is selected and is considered to be the best solution to the problem.

c. Variants Based on Parameters Setting

The appropriate selection of HS parameter values is considered as one of the vital task. The projected algorithm comprises dynamic version for both pitch adjustment rate (PAR) and bandwidth (bw) values. The PAR value is linearly augmented in each iteration of HS by using the following equation:

$$\mathrm{PAR(gn)} = \mathrm{PAR_{min}} + \frac{PAR_{max} - PAR_{min}}{NI} \text{ x } gn \qquad (16)$$

Where PAR(gn) is the PAR value for each generation, $\mathrm{PAR_{min}}$ and $\mathrm{PAR_{max}}$ are the minimum pitch adjusting rate and maximum pitch adjusting rate.NI is the maximum number of iterations and gn is the generation number.

The bandwidth (bw) value is exponentially reduced in each iteration of HS by using the following equation:

$$\mathrm{bw(gn)} = \mathrm{bw_{min}} + \frac{bw_{max} - bw_{min}}{NI} \text{ x } gn \qquad (17)$$

where bw(gn) is the bandwidth value for each generation, $\mathrm{bw_{max}}$ is the maximum bandwidth, $\mathrm{bw_{min}}$ is the minimum bandwidth and *gn* is the generation number.

4. OPPOSITION-BASED LEARNING

Evolutionary optimizations procedures normally start with some key solutions and directed to optimal solution. The progress of searching terminates when some predefined criteria is fulfilled. Is it is not possible or unavailable then we, generally, start with arbitrary forecasts. We progress our chance of starting with a closer solution by concurrently examination of the opposite solution. By exploit this; the fitter one can be selected as a primary solution. In fact, bestowing to the theory of possibility, 50% of the time a presumption is adjuvant from the solution than its opposite presumption. Hence, beginning with the nearer of the two presumptions has the potential to hurry the convergence. The identical technique may be smeared not only to preliminary solutions but also constantly to each solution in the existing population.

a. Definition of Opposite Number

Let $x \in [lb, ub]$ be a real number. The opposite number is defined as in (18).

$$\breve{x} = lb + ub - x \qquad (18)$$

b. Explanation of Opposite Point

Let $X = (x_1, x_2, .., x_n)$ be a point in n-dimensional space, where $(x_1, x_2, .., x_n) \in R$ and$x_i \in [ub_i, lb_i] \forall_i \in \{1,2, .., n\}$. The opposite point $\breve{x} = (\breve{x_1}, \breve{x_2}, ., \breve{x_n})$ is completely defined by its components as in (19).

$$\breve{x}_\iota = lb_i + ub_i - x_i \qquad (19)$$

c. Opposition-Based Optimization

Let $X = (x_1, x_2, .., x_n)$ be a point in n-dimensional space, Assume $f = (\cdot)$ is a fitness function which is used to measure the entrant's fitness. The opposite point $\breve{x} = (\breve{x_1}, \breve{x_2}, ., \breve{x_n})$ is opposite of $= (x_1, x_2, .., x_n)$.

Now, if $f(\breve{x}) \leq f(X)$ then point X can be swapped with $\breve{x}$; Otherwise, we endure with X. Hence, the point and its opposite point are valued concurrently in order to continue with the righter one.

5. IHS ALGORITHM FOR SOLVING REACTIVE POWER PROBLEM

Analogous to all population-based optimization algorithms, two key steps are obvious for HS algorithm. These are HM initialization and creating new HM by espousing the principle of HS. In the present work, the stratagem of Opposition-based learning (OBL) is amalgamated in two steps. The original HS is selected as the parent algorithm and opposition-based ideas are implanted in it with an objective to divulge augmented convergence outline.

```
1. Fix the elements HMS, HMCR, PAR^min, PAR^max, BW^min, BW^max, and NI.
2. Fix the HM with X_0ij .
3. Opposition-based HM preparing.
        $for\ (i = 0; i < HMS; i++)$
    $for\ (j = 0; j < n; j++) OX_{oij} = para_j^{min} // OX_o;\ opposite\ of initial X_0 + para_j^{max} - X_{oij}$
    end for
end for
    Finishing point of opposition-based HM initialization.
    Select HMS fittest individuals from set of $\{X_{oij}, OX_{oij}\}$ as primary HM.
    HM being the matrix of fittest X vectors
4. Extemporise a New Harmony X^new as follows: Modernize PAR(gn) and BW(gn)
        $for\ (i = 0; i < HMS; i++)$
            $for\ (j = 0; j < n; j++)$
                $if\ (r_1 < HMCR) then$
                    $x_{ij}^{new} = x_{ij}^{a}$    $// a \in (1,2,..,HMS)$
                    $if\ (r_2 < PAR(gn)) then$
                        $x_{ij}^{new} = x_{ij}^{new} \pm r_3 \times BW(gn)$    $// r_1, r_2, r_3 \in [0,1]$
                    end if
                else
                    $x_{ij}^{new} = para_{ij}^{min} + r \times (para_{ij}^{max} - para_{ij}^{min}) // r \in [0,1]$
                end if
            end for
        end for
```

```
5. Modernize the HM as $X^{worst} = X^{new}\ if\ f(X^{new}) < f(X^{worst})$
6. Opposition-based generation hopping
            $if\ (rand_2 < h_r)//rand_2 \in [0,1], h_r - hopping\ rate$
                $for\ (i = 0; i < HMS; i++)$
                    $for\ (j = 0; j < n; j++)$
                        $OX_{ij} = min_j^{gn} + max_j^{gn} - X_{i,j}$
    $//min_j^{gn}$: minimum value of the jth variable in the existing generation (gn)
    $//max_j^{gn}$: maximum value of the jth variable in the existing generation (gn)
end for
end for
end if
    Pick HMS fittest HM from the set of $\{X_{ij}, OX_{oij}\}$ as existing HM.
7. If NI is concluded, return the best harmony vector $X^{best}$ in the HM; or else go back to Step 4.
```

6. SIMULATION RESULTS

The projected hybrid IHS algorithm for solving Optimal Reactive Power Dispatch problem is verified in standard IEEE-57 bus power system. The IEEE 57-bus system data entails of 80 branches, seven generator-buses and 17 branches under load tap setting transformer branches. The probable reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is designated as slack-bus. In this situation, the exploration space has 27 dimensions, i.e., the seven generator voltages, 17 transformer taps, and three capacitor banks. The system variable limits are given in Table I. The initial conditions for the IEEE-57 bus system are given as follows:

$$P_{load} = 12.422 \text{ p.u. } Q_{load} = 3.332 \text{ p.u.}$$

The aggregate preliminary generations and power losses are acquired as follows:

$$\sum P_G = 12.7721 \text{ p.u. } \sum Q_G = 3.4552 \text{ p.u.}$$

$$P_{loss} = 0.27443 \text{ p.u. } Q_{loss} = -1.2246 \text{ p.u.}$$

Table II shows the various system control variables i.e. generator bus voltages, shunt capacitances and transformer tap settings attained after IHS based optimization which are within their tolerable limits. In Table III, comparison of optimum results obtained from projected IHS with other optimization methods for optimal reactive power dispatch (ORPD) problem is given. These results entitle the strength of projected IHS methodology by providing enhanced optimal solution in case of IEEE-57 bus system.

Table-1. Variables Limits

REACTIVE POWER GENERATION LIMITS							
BUS NO	**1**	**2**	**3**	**6**	**8**	**9**	**12**
Q_{GMIN}	-1.1	-.010	-.01	-0.01	-1.1	-0.02	-0.2
Q_{GMAX}	1	0.1	0.1	0.23	1	0.01	1.50

VOLTAGE AND TAP SETTING LIMITS					
V_{GMIN}	V_{GMAX}	V_{PQMIN}	V_{PQMAX}	T_{KMIN}	T_{KMAX}
0.5	1.0	0.91	1.01	0.5	1.0

SHUNT CAPACITOR LIMITS			
BUS NO	18	25	53
Q_{CMIN}	0	0	0
Q_{CMAX}	10	5.2	6.3

Table-2. Control Variables Obtained After Optimization by IHS Method

Control Variables	IHS
V1	1.1
V2	1.062
V3	1.053
V6	1.041
V8	1.062
V9	1.032
V12	1.043
Qc18	0.0841
Qc25	0.332
Qc53	0.0624
T4-18	1.013
T21-20	1.051
T24-25	0.962
T24-26	0.934
T7-29	1.075
T34-32	0.934
T11-41	1.012
T15-45	1.052
T14-46	0.926
T10-51	1.030
T13-49	1.051
T11-43	0.913
T40-56	0.902
T39-57	0.960
T9-55	0.971

Table-3. Comparative Optimization Results

S.No.	Optimization Algorithm	Best Solution	Worst Solution	Average Solution
1	NLP [29]	0.25902	0.30854	0.27858
2	CGA [29]	0.25244	0.27507	0.26293
3	AGA [29]	0.24564	0.26671	0.25127
4	PSO-w [29]	0.24270	0.26152	0.24725
5	PSO-cf [29]	0.24280	0.26032	0.24698
6	CLPSO [29]	0.24515	0.24780	0.24673
7	SPSO-07 [29]	0.24430	0.25457	0.24752
8	L-DE [29]	0.27812	0.41909	0.33177
				Continue

9	L-SACP-DE [29]	0.27915	0.36978	0.31032
10	L-SaDE [29]	0.24267	0.24391	0.24311
11	SOA [29]	0.24265	0.24280	0.24270
12	LM [30]	0.2484	0.2922	0.2641
13	MBEP1 [30]	0.2474	0.2848	0.2643
14	MBEP2 [30]	0.2482	0.283	0.2592
15	BES100 [30]	0.2438	0.263	0.2541
16	BES200 [30]	0.3417	0.2486	0.2443
17	Proposed IHS	0.22345	0.23462	0.23113

7. CONCLUSION

In this paper, the IHS has been efficaciously engaged to solve optimal reactive power problem. The key benefits of the IHS to the problem are optimization of objective function by handling nonlinear constraints. The optimal setting of control variables are attained is within the limits. The proposed algorithm has been tested on the IEEE 57 -bus system. The results are compared with the other heuristic methods and the proposed algorithm established its efficiency and heftiness in minimization of real power loss.

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