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# Shrinkage of Active Power Loss by Hybridization of Flower Pollination Algorithm with Chaotic Harmony Search Algorithm

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**Abstract**

In this paper, Hybridization of flower pollination algorithm with chaotic harmony search algorithm (HFPCHS) is proposed to solve optimal reactive power dispatch problem. This method integrates the standard Flower Pollination algorithm (FP) with the chaotic Harmony Search (HS) algorithm to improve the searching accuracy. By using chaotic sequences in Harmony search Algorithm can be helpful to progress the consistency of the global optimality, and they also augment the quality of the results. The proposed HFPCHS has been tested on standard IEEE 57 bus test system and simulation results show clearly the better performance of the proposed algorithm in reducing the real power loss.

**Keywords:** Flower pollination algorithm, Harmony search, chaotic sequences, optimal reactive power, Transmission loss.

## 1. Introduction

Reactive power optimization places an important role in optimal operation of power systems. Various numerical methods like the gradient method [O.Alsac *et al* (1973); Lee K Y *et al* (1985)], Newton method [A.Monticelli *et al* (1987)] and linear programming [Deeb N *et al* (1990); E. Hobson (1980) ; K.Y Lee *et al* (1987); M.K. Mangoli (1993)] have been implemented to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the intricacy in managing inequality constraints. The problem of voltage stability and collapse play a key role in power system planning and operation [C.A. Canizares *et al* (1996)]. Evolutionary algorithms such as genetic algorithm have been already projected to solve the reactive power flow problem [S.R.Paranjothi *et al* (2002); D. Devaraj *et al* (2005); A. Berizzi *et al* (2012)]. Evolutionary algorithm is a heuristic methodology used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [C.-F. Yang *et al* (2012)], Hybrid differential evolution algorithm is projected to increase the voltage stability index. In [P. Roy *et al* (2012)] Biogeography Based algorithm is projected to solve the reactive power dispatch problem. In [B. Venkatesh *et al* (2000)], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [W. Yan *et al* (2004)], an improved evolutionary programming is used to elucidate the optimal reactive power dispatch problem. In [W. Yan *et al* (2006)], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [J. Yu *et al* (2008)], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [F. Capitanescu (2011)] proposes a two-step approach to calculate Reactive power reserves with respect to operating constraints and voltage stability. In [Z. Hu *et al* (2010)], a programming based approach is used to solve the optimal reactive power dispatch problem. In [A. Kargarian et al (2012)] present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper proposes Hybrid of flower pollination algorithm with chaotic harmony search algorithm (HFPCHS) to solve reactive power dispatch problem. Flowering plant (Yang, X. S. et al 2012) has been growing for at least more than millions of million years. The harmony search algorithm (Geem Z, 2006) is one of the newly developed optimization algorithm and it is one the most proficient algorithm in the field of combinatorial optimization. The proposed HFPCHS algorithm has been evaluated on standard IEEE 57, bus test system. The simulation results show that our proposed approach outperforms all the entitled reported algorithms in minimization of real power loss.

## 2.Problem Formulation

The OPF problem is considered as a common minimization problem with constraints, and can be written in the following form:

Minimize f(x, u) (1)

Subject to g(x,u)=0 (2)
and
$h(x,u) \leq 0$ (3)

Where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, .., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T$ (4)

The control variables are the generator bus voltages, the shunt capacitors and the transformers tap-settings:

$u = \left(V_g, T, Q_c\right)^T$ (5)

or

$u = \left(V_{g1}, \dots, V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T$ (6)

Where Ng, Nt and Nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

## 3.Objective Function

### *3.1Active power loss*

The objective of the reactive power dispatch is to minimize the active power loss in the transmission network, which can be mathematically described as follows:

$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j cos\theta_{ij}\right)$ (7)

or

$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d$ (8)

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.

### *3.2Voltage profile improvement*

For minimizing the voltage deviation in PQ buses, the objective function becomes:

$F = PL + \omega_v \times VD$ (9)

Where $\omega_v$: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$VD = \sum_{i=1}^{Npq} |V_i - 1|$ (10)

### *3.3Equality Constraint*

The equality constraint g(x,u) of the ORPD problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$P_G = P_D + P_L$ (11)

### *3.4Inequality Constraints*

The inequality constraints h(x,u) imitate the limits on components in the power system as well as the limits created to ensure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators:

$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max}$ (12)

$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g$ (13)

Upper and lower bounds on the bus voltage magnitudes:

$V_i^{min} \leq V_i \leq V_i^{max}, i \in N$ (14)

Upper and lower bounds on the transformers tap ratios:

$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T$ (15)

Upper and lower bounds on the compensators reactive powers:

$Q_c^{min} \leq Q_c \leq Q_C^{max}, i \in N_C$ (16)

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.

**4.Nature-Inspired Flower Pollination Algorithm**

The flower reproduction is eventually through pollination. Flower pollination is linked with the transfer of pollen, and such transfer of pollen is associated with pollinators such as insects, birds, animals etc. Bees and Birds may perform as Levy flight behaviour, with jump or fly distance steps obeying a Levy allotment. The biological evolution point of view, the objective of the flower pollination is the survival of the fittest and the optimal reproduction of plants in terms of numbers as well as the largely fittest. Flower reliability can be represented mathematically as

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - g_*) \qquad (17)$$

Where $x_i^t$ is the pollen *i* or solution vector $x_i$ at iteration *t*, and $g_*$ is the current best solution found among all solutions at the current generation/iteration. Here γ is a scaling factor to control the step size. *L*(λ) is the parameter that corresponds to the strength of the pollination, which essentially is also the step size. Since insects may move over a long distance with various distance steps, we can use a Levy flight to mimic this characteristic efficiently. We draw *L* > 0 from a Levy distribution,

$$L \sim \frac{\lambda\Gamma(\lambda sin(\Pi\lambda/2))}{\Pi}\frac{1}{s^{1+\lambda}}, (s \gg s_0 > 0) \qquad (18)$$

Here, Γ(λ) is the standard gamma function, and this distribution is valid for large steps *s* > 0.
Then, to model the local pollination,

$$x_i^{t+1} = x_i^t + \in \left(x_j^t - x_k^t\right) \qquad (19)$$

Where $x_j^t$ and $x_k^t$ are pollen from different flowers of the same plant species. This essentially mimics the flower reliability in a limited neighbourhood. Mathematically, if $x_j^t$ and $x_k^t$ comes from the same species or selected from the same population, this equivalently becomes a local random walk if we draw ∈ from a uniform distribution in [0,1].

**5.Harmony search algorithm**

Harmony search (HS) is a new-fangled population-based metaheuristic optimization algorithm that imitates the music inventiveness process where the musicians manage their instruments' pitch by searching for an ideal state of harmony.

The parameters of the HS are:
1. Harmony Memory Size (HMS)
2. Harmony Memory considering Rate (HMCR), where HMCR ∈ [0, 1];
3. Pitch adjust Rate (PAR), Where PAR ∈ [0, 1];

The harmony memory (HM) is a matrix of solutions with a size of HMS, where every harmony memory vector represents one solution. In this step, the solutions are arbitrarily constructed and rearranged in a reversed order to HM, based on their objective function values such as

$$f(a^1) \le f(a^2) \; \ldots\ldots \le f(a^{HMS}) \; .$$

$$HM = \left[\begin{matrix} a_1^1 & \cdots & a_N^1 \\ \vdots & \ddots & \vdots \\ a_1^{HMS} & \cdots & a_N^{HMS} \end{matrix}\left|\begin{matrix} f(a^1) \\ . \\ . \\ . \\ f(a^{HMS}) \end{matrix}\right.\right] \qquad (20)$$

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

$$a'_i \leftarrow \begin{cases} a'_i \in \left\{\{a_i^1, a_i^2, \ldots\ldots\ldots a_i^{HMS}\right\} w.p.HMCR \\ \quad a'_i \in \; A_i \qquad w.p. \; (1 - HMCR) \end{cases} \qquad (21)$$

The additional search for high-quality solutions in the search space is achieved through tuning each decision variable in the new-fangled harmony vector, $a' = (a'_{1,} a'_2 \ldots\ldots a'_N)$ inherited from HM using PAR operator. These decision variables ($a'_i$) are examined and to be tuned with the probability of PAR ∈ [0, 1] as in Eq. (22).

$$a'_i \leftarrow \begin{cases} \quad Adjusting\ pitch\ w.p.PAR \\ Doing\ Nothing\ w.p.(1 - PAR) \end{cases} \qquad (22)$$

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

$$(a'_i) = (a'_i) \pm \text{rand}\,() * \text{bw} \qquad (23)$$

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

In order to renovate HM with the new produced vector $a' = (a'_1, a'_2, \ldots \ldots a'_N)$, , the objective function is computed for each new-fangled Harmony vector f $(a')$. If the objective function value for the fresh vector is better than the worst harmony vector stored in HM, then the worst harmony vector is replaced by the new vector. Else, this new vector is disregarded.

$a' \in \ HM \wedge a^{worst} \notin \ HM$ (24)

HS algorithm includes dynamic adaptation for both pitch adjustment rate (PAR) and bandwidth (bw) values. The PAR value is linearly increased in each iteration of HS by using the following equation:

$PAR(gn)=PAR_{min} + \frac{PAR_{max}-PAR_{min}}{NI} \text{ x } gn$ (25)

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

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

$bw(gn) = bw_{min} + \frac{bw_{max}-bw_{min}}{NI} \text{ x } gn$ (26)

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

**6.Chaos Theory**

Chaos is a deterministic, random-like process found in a nonlinear, dynamical system, which is non-period, non-converging and non-bounded. Newly chaos has been prolonged to various optimization areas because it can more easily escape from local minima and progress global convergence in comparison with other stochastic optimization algorithms (Abdel-Raouf et al 2014,Gong et al 2009,Coelho et al 2009) . By using chaotic sequences in Harmony search Algorithm can be helpful to progress the consistency of the global optimality, and they also augment the quality of the results. The variance $\sigma^2$ demonstrates the converge degree of all particles.

$\sigma^2 = \sum_{i=1}^{N}\left[\left(f_i - f_{avg}\right)/f\right]^2$ (27)

$f = max\left\{1, max\left\{\left|f_i - f_{avg}\right|\right\}\right\}$ (28)

Where $f_i$ is the fittness of the *i*th particle; $f_{avg}$ is the average fitness value; $f$ is the factor of fitness value. The bigger $\sigma^2$ is the broader *i*th particles will spread. Otherwise, they will almost converge.

Complex behaviour can arise from a simple dynamic system without any stochastic disturbance. And the equation is written as follows ,

$y_{id}(t+1) = \mu y_{id}(t)\left(1 - y_{id}(t)\right)$ (29)

Where $y_{id}(t) \in (0,1), i = 1,..,N, d = 1,..,D. \mu$ is usually set to 4 obtain ergodicity of $y_{id}(t+1)\ within\ (0,1)$. When the initial value $y_{id}(0) \in \{0.20.0.5.0.70\}$ using equation (29) we can obtain chaotic sequences. In order to increase the population diversity and prevent premature convergence, we add adaptively chaotic disturbance $P_c$ at the time of stagnation. Thus, $P_c\ is\ modified\ \ as\ P'_c$ .

$p'_{cd}(t+1) = p_{cd}(t) + R_{id}\left(2_{yid}(t) - 1\right)$ (30)

$R_{id} = \beta|p_{cd}(t) - p_{id}(t)|$ (31)

Where $\beta$ is the region scale factor. Because$y_{id} \in (0,1)$, the second part of Equation (30) is in the range of $(-|R_{id}|, |R_{id}|)$ that would confine the searching area around $p_c$. In addition, the searching range can be adaptively accustomed by the distance between $p_i$ and $p_c$. If $p_c$ is surrounded with the previous best positions *pi*, it means that a good region may have been found, and it is reasonable to search elaborately in a small area. On the contrary, if $p_i$ is far from $p_c$, then it suggests that a good area has not yet been found. For reaching a better solution, searching region should be enlarged (Lin et al 2007).

**HFPCHS algorithm for solving optimal reactive power dispatch problem.**

Describe objective function f(x), $x=(x_1,x_2, \ldots,x_d)^T$
Describe the HS algorithm parameters.
Produce Harmony Memory by iterating the selected
Chaotic maps until reaching to the HMS.
while ( t<max number of iterations )
while ( i<=number of variables)

 

if (rand<HMCR), Choose a value from HM for the variable i
if (rand<PAR), Adjust the value by adding certain amount
end if
else Choose a arbitrary value
end if
end while
Accept the new harmony (solution) if better
end while
Find the current best solution
end
The best solution found by Harmony Search is regarded as initial for Flower Pollination algorithm
Define a switch probability p ∈ [0, 1]
while (t <MaxGeneration)
for i = 1 : n (all n flowers in the population)
if rand < p,
Draw a (d-dimensional) step vector L which comply with a Levy distribution
Global pollination through $x_i^{t+1} = x_i^t + L(B - x_i^t)$
else
Draw U from a uniform distribution in [0,1]
Do local pollination through $x_i^{t+1} = x_i^t + U\left(x_j^t - x_i^t\right)$
end if
Evaluate new solutions
If new solutions are better, update them in the population
end for
Find the current best solution
end while
End

## 7.Simulation Results

The proposed hybrid HFPCHS algorithm for solving ORPD problem is tested for standard IEEE-57 bus power system. The IEEE 57-bus system data consists of 80 branches, 7 generator-buses and 17 branches under load tap setting transformer branches. The possible reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is selected as slack-bus. In this case, the search 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 1. The preliminary conditions for the IEEE-57 bus power system are given as follows:
$P_{load}$ = 12.425 p.u. $Q_{load}$ = 3.336 p.u.
The total initial generations and power losses are obtained as follows:
$\sum P_G$ = 12.7725 p.u. $\sum Q_G$ = 3.4556 p.u.
$P_{loss}$ = 0.27442 p.u. $Q_{loss}$ = -1.2245 p.u.
Table 2 shows the various system control variables i.e. generator bus voltages, shunt capacitances and transformer tap settings obtained after HFPCHS based optimization which are within their acceptable limits. In Table 3, a comparison of optimum results obtained from proposed HFPCHS with other optimization techniques for optimal reactive power dispatch (ORPD) problem mentioned in literature for IEEE-57 bus power system is given. These results indicate the robustness of proposed HFPCHS approach for providing better 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 | 5.1 | 6.2 | | | | |

Table 2. control variables obtained after optimization by HFPCHS method

| Control Variables | HFPCHS |
|---|---|
| V1 | 1.3 |
| V2 | 1.066 |
| V3 | 1.058 |
| V6 | 1.049 |
| V8 | 1.065 |
| V9 | 1.036 |
| V12 | 1.045 |
| Qc18 | 0.0846 |
| Qc25 | 0.337 |
| Qc53 | 0.0626 |
| T4-18 | 1.015 |
| T21-20 | 1.058 |
| T24-25 | 0.966 |
| T24-26 | 0.938 |
| T7-29 | 1.078 |
| T34-32 | 0.936 |
| T11-41 | 1.014 |
| T15-45 | 1.058 |
| T14-46 | 0.928 |
| T10-51 | 1.037 |
| T13-49 | 1.058 |
| T11-43 | 0.916 |
| T40-56 | 0.908 |
| T39-57 | 0.961 |
| T9-55 | 0.973 |

Table 3. comparative optimization results

| S.No. | Optimization Algorithm | Best Solution | Worst Solution | Average Solution |
|---|---|---|---|---|
| 1 | NLP (Chaohua Dai et al 2009) | 0.25902 | 0.30854 | 0.27858 |
| 2 | CGA(Chaohua Dai et al 2009) | 0.25244 | 0.27507 | 0.26293 |
| 3 | AGA (Chaohua Dai et al 2009) | 0.24564 | 0.26671 | 0.25127 |
| 4 | PSO-w (Chaohua Dai et al 2009) | 0.24270 | 0.26152 | 0.24725 |
| 5 | PSO-cf (Chaohua Dai et al 2009) | 0.24280 | 0.26032 | 0.24698 |
| 6 | CLPSO (Chaohua Dai et al 2009) | 0.24515 | 0.24780 | 0.24673 |
| 7 | SPSO-07 (Chaohua Dai et al 2009) | 0.24430 | 0.25457 | 0.24752 |
| 8 | L-DE (Chaohua Dai et al 2009) | 0.27812 | 0.41909 | 0.33177 |
| 9 | L-SACP-DE(Chaohua Dai et al 2009) | 0.27915 | 0.36978 | 0.31032 |
| 10 | L-SaDE(Chaohua Dai et al 2009) | 0.24267 | 0.24391 | 0.24311 |
| 11 | SOA (Chaohua Dai et al 2009) | 0.24265 | 0.24280 | 0.24270 |
| 12 | LM (Gomes et al 2009) | 0.2484 | 0.2922 | 0.2641 |
| 13 | MBEP1 (Gomes et al 2009) | 0.2474 | 0.2848 | 0.2643 |
| 14 | MBEP2 (Gomes et al 2009) | 0.2482 | 0.283 | 0.2592 |
| 15 | BES100 (Gomes et al 2009) | 0.2438 | 0.263 | 0.2541 |
| 16 | BES200 (Gomes et al 2009) | 0.3417 | 0.2486 | 0.2443 |
| 17 | Proposed HFPCHS | 0.22346 | 0.23468 | 0.23116 |

## 8.Conclusion

In this paper, the HFPCHS has been effectively applied to solve Optimal Reactive Power Dispatch problem. The proposed algorithm has been tested on the standard IEEE 57 -bus system. The results are compared with other heuristic methods and the proposed algorithm demonstrated its effectiveness and robustness in minimization of real power loss and various system control variables are well within the acceptable limits .

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