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A Novel approach to Optimal Power Flow with Reactive Power Loss Minimization using an Enhanced Music Based Harmony Search

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ABSTRACT: This paper presents a new optimization algorithm, Music Based Harmony Search (MBHS) applied to the Optimal Power flow (OPF) problem with line constraints for minimizing the Fuel costs together with Generator Reactive power losses. The proposed method is compared with other optimization techniques like Simple Genetic Algorithm (SGA), Adaptive Genetic Algorithm (AGA) and Particle Swarm Optimization (PSO) to prove its supremacy. The algorithm is tested on a standard IEEE 30 bus test bed and numerous analyses viz., the effect on taps; shunt reactors etc., with different MBHS parameters are demonstrated. It is found that MBHS offers a computationally faster (75.83 times) and robust solution for OPF problem.

KEYWORDS: Music Based Harmony Search, Bio-mimicked algorithms, Optimal Power Flow, Reactive Power Minimization, Genetic Algorithm, Optimization techniques.

I. INTRODUCTION

Constantly depleting natural energy reserves, increasing demands and soaring prices have stressed the requirement of Energy conservation now. Global warming has led to the inevitable requisite of cleaner energy, reduced emissions and necessity of maintaining minimal losses. Expanding areas of Power System, liberalization, increasing dependency and greater prerequisite of System security and reliability has made the Optimal Power Flow an inevitable part of the power system research.

Reactive Power is a non-usable ingredient of the power and the transmission of lesser reactive power adds to the economy of the Generation and consumers. But, reactive power cannot be completely shunned as it is essential for the formation of magnetic field and for the maintenance of the constant voltage profile in the system. Capacitors and Shunt reactance are placed in the system to maintain the adequate reactive power, and are placed very near to the consumption point. To be in the correct sense, Reactive power is produced by the loads than the generators and reactive power in excess affects the transfer capacity of the power lines and heating of motors whereas and inadequate quantity leads to the higher losses, lower voltage profile and higher risk of outages. Every generator is vowed to supply the minimum amount of reactive power to the system. Here in this paper, a new approach towards optimization off reactive power together with generation cost is discussed sans any violations of obligatory boundaries using a new optimization method; Music Based Harmony Search algorithm.

This paper is organized into six sections. Section II offers a deep view on the works available on Music Based Harmony Search and Reactive Power optimized power flow. Section III describes the principles and modelling of Music Based Harmony Search Algorithm. Section IV narrates the generalized problem formulation. Section V reports the Simulation, Test systems and Implementation issues together with comparison with other techniques like GA, PSO etc. Section VI concludes the paper by analyzing the results.

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II. SURVEY OF LITERATURE

Several researchers have worked on the optimization problems using MBHS and a brief abridgment of all applications can be found in Zong Woo Geem *et al.* [1]. Much recent application of MBHS has been to Civil Engineering, general mathematical problems like Sudoku, hydrologic calibration and ecological conservation. A new improved variant of HS was exposed in [2], where a variable HMCR, PAR, NI were determined from previously used values from Harmony Search applications and objective function evaluation from other algorithms. Later developments include Ensemble Memory Consideration by Gleem *et al.* (2006), where a group of musicians are considered together with the collective relation between the variables. Further works on Harmony search are found on „Ensemble Considering" where a group of musicians are considered together with the collective relation between the variables by same authors.

Dandachi *et al.* (1995) put forward a new reactive power pricing strategy as part of extension of the SC-OPF package of the National Grid Company, which was based on Sequential Linear Programming. A decoupled approached was made by utilizing the tap transformers for Security Constrained OPF for reactive power pricing and a feasibility study was conducted on a 713 bus typical NCC base system. Chebbo *et al.* [3] demonstrated CARD based on Iterative Fully Coupled Active and Reactive dispatch solution for Reactive power OPF which was based on sparse dual revised simplex linear programming method for Maximization of Reactive Power Reserve Margins.

Lee *et al.* (1997) developed a Contingency Constrained Optimal Reactive Dispatch (ACCORD) algorithm which was based on Voltage/VAr management algorithm of Alsac *et al.*, (1990). E. Lobato *et al.* [4] proposed a Mixed Integer Linear Programming based approach in OPF for minimizing transmission losses and generator reactive outputs. The authors has represented the objective function by a set of tangent cuts, and linearized in each iterations. Pudjianto *et al.* (2002) demonstrated a direct reactive OPF, where the conventional decoupling is replaced by the constrained reactive implicit coupling (CRIC), which is found to improve the optimization, during heavy loading. A linear Programming and Primal dual Interior point based approaches are found there. Another appreciable work on Reactive Power Optimization can be found in [5] by Hazra *et al.* (2007).

III. MUSIC BASED HARMONY SEARCH

Music Based Harmony Search was first projected by Zong Wong Geem *et al.* (2001) and was inspired by the natural music performance and from the Musicians improvisation techniques; where each musician searches for the best harmony of pleasing composition with the notes and constantly improvises it by using various techniques to create a enjoyable melody. The Artificial music harmonization seeks the gradual alteration of pitch, which in turn affects the population, adaptively, for obtaining the perfect harmony of the objective. The terms related to MBHS are briefly described below:

A. Musical Instrument (Variable) and Harmony Matrix:

Variables are the components of the solution vector which analogizes to the keys in a music instrument. The combined string of variables analogizes to chromosome as in Genetic Algorithm. The harmony memory can be represented as

$$HM = \begin{bmatrix} x_1^1 & x_1^2 & \dots\dots\dots\dots & x_1^n \\ x_2^1 & x_2^2 & \dots\dots\dots\dots & x_2^n \\ x_m^1 & x_m^2 & \dots\dots\dots\dots & x_m^n \end{bmatrix}$$

x_m^n

where, is „n"th variable and a „m" size harmony memory and

a probable solution to a variable of objective. The complete [$x_?^1 . x_?^2 \dots\dots\dots\dots x_?^n$] is the solution vector. Harmony Memory Matrix (HMM) comprises of plausible solution matrix, where each row represents a complete solution vector of the size of Harmony solution size.

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B. Aesthetics and Practice:

Aesthetics resembles to the pleasant music, which the musician struggles to achieve by improvisation. Herein, artificial music based harmony search, aesthetics refers to the Objective function, which needs to be optimized. Every Practice (Iteration) session counts to one cycle of improvisation, where each of the Harmony Search operators (HSO) are put into action which ends up in the updating the Experience Memory Matrix (EMM).

IV. HARMONY OPERATORS

Improvisation [6] of the HMM is done using the Memory Consideration, Pitch Adjustment and Random Generation of New Harmony memory matrix.

A. *Random Playing:* This section mimics the musician‟s behavior of playing random notes with octave ratio 1:2 or 2:3, generating harmony in improvisation. Random Pitches increases the search space and gives wider options to explore the solution thus prevent from getting trapped in local minima. Random notes are generated satisfying the boundary range of pitches.

B. *Memory Considering:* In memory considering a value of the variable is selected in between the permissible limits of the variable and the available variable value. The same
process is followed for another other variables in the string.

C. *Harmony Memory Consideration Rate:* HMCR

represents the probability of selecting a variable from the HM matrix. The strings which analogize to "notes" are directly selected in improvisation process from the Harmony Memory depending on the HMCR.[7-9] The (1-HMCR) count of probability is selected from Memory Consideration and remaining from HM depending on HMCR rate.

$$x_1^{NEW} = \begin{cases} \text{From HM for probability of HMCR} \\ \text{Randomly Generated for } (1-HMCR) \text{probabilty} \end{cases}$$

where x_1^{NEW} is the first variable of the Note consisting

$$x_1^{NOTE} = [x_1, x_2, x_3 \dots\dots\dots\dots\dots\dots x_{HMS}]$$

D. *Pitch Range and Pitch Adjusting Rate (PAR):* Pitch Range refers to the value boundaries of each decision variable which need to be bounded for the safe operation. The wider the PR, better the results but on the cost of computation time.[10] PAR refers to the probability that any variable in the HM to undergo changes, which resemble to the mutation process in the conventional Genetic Algorithm, but unlike to GA, the MBHS uses the complete HM to do the mutation instead of using two chromosome for crossover or single chromosome in mutating. Every „note‟ which gets generated from the Memory Considering will get tested for pitch adjustment according the PAR. Its being found that low PAR with a narrow bandwidth slows down the convergence and high PAR with large bandwidth can cause the solution to scatter [11].

$$x_1^{NEW} = \begin{cases} \text{Yes, if PAR tested positive} \\ \text{No, If } (1-PAR) \text{ probable variable} \end{cases}$$

If tested „yes‟, each variable in the Note undergoes, $x_i^y = [x_i' * rand * BW]$, where „r‟ is a random number

generated between (0, 1) and

is the first variable of the

Note consisting of

and

„BW‟ is the difference between the upper and lower boundaries.

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$$x_1^{NEW}$$

$$x_1^{NOTE} = [x_1, x_2, x_3 \dots\dots\dots\dots\dots\dots\dots x_{HMS}]$$

V. ALGORITHM

STEP 1: Initialize the Parameters, Acquire the system data **STEP 2**: Initialize Harmony Memory Size (HMS), Harmony Memory Considering Rate (HMCR), Pitch Adjusting Rate (PAR) and Number of Improvisations (NI).

STEP 3: Generate the Harmony Memory randomly in uniform distribution

$$X_i^j = L_{x_i} + r * (U_{x_i} - L_{x_i})$$

where j = 1, 2, 3 to Memory Size and „r" is a random number in between 0 and 1.

STEP 4: New Memory improvisation is made using the MBH operators.
STEP 5: If R (0, 1) < HMCR, then go for Memory consideration, else if tested positive for PAR, go for Pitch Adjustment, Else go for random generation.
STEP 6: Evaluate the fitness and select if it is better than the worse solution of HM, accept, else go for Step 4.
STEP 7: Evaluate the Aesthetics.
STEP 8: The stopping criterion is checked by convergence of maximum allowable improvisations.

VI. OPTIMAL POWER FLOW PROBLEM

A. Conventional Generation cost minimization function

The conventional fuel cost minimization objective can be represented as below. Here the main constraint is the minimization of the generation cost by allocating the generator capacities in the finest economic mode, collectively satisfying the power flow, security constraints, thermal and stability constraints of the system.

$$F(x) = F_T = \sum_{i=1}^{n} F_i(P_i) \quad \dots\dots\dots\dots\dots\dots (1)$$

where

FT = Total cost of generation ($/hr) n = Number of generators
Pi = Real power generation of i^{th} generator
Fi = Fuel cost function of i^{th} generator
Respecting,

$$G(x,u) = 0 \{\text{Equality constraints}\}$$

$$H(x,u) \leq 0 \{\text{Inequality constraints}\}$$

where „u" is the set of controllable quantities, which can be adjusted by the operator like Generator Active Power output, Generator voltage, Transformer settings and Capacitor settings. „x" is the set of state quantities like voltage magnitude at load bus and Slack bus power and reactive power at each generator & Line Flows. The Fuel cost minimization with cost coefficients can be represented as,

$$F_i(P_i) = \sum_{n-1}^{Ng} (A_i + B_i P_{gi} + C_i {P_{gi}}^2) \ \$/\text{Hr} \quad \dots\dots\dots\dots. (2)$$

where *Ng* is the number of generators including the slack bus. *Pgi* is the generated active power at bus *i*. A*i*, B*i* and C*i*

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are the

quadratic constants for i^{th} generator, which is obtained from the fuel cost curves of the generator, normally obtained by curve fitting techniques.

A. Reactive Power Optimization Problem

Reactive Power Optimization is meanderingly the minimization of total losses for the complete system, subject to the operational and security conditions of the system [7]

$$F_{RP}(x,u) = Min \sum_{i=1}^{n} Losses_i$$

$$Min \sum_{i=1}^{NB}\sum_{j=1}^{NB} G_{ij}(V_i^2 + V_j^2 - 2V_iV_jCos(\delta_i - \delta_j)) \quad \text{...... (3)}$$

where „n" is the number of branches, „x" is the continuous variables and „u" is the discontinuous variables. „NB" is the

number of buses, „NL" is the number of Lines, „ $G_{ij}^{\prime}$ is the conductance between the bus „i" and „j", V_i & V_j are voltage magnitudes at bus „i" and „j", δ_i & δ_j are the voltage angles at bus „i" and „j".

A. Equality Constraints

Frugality of the power system cannot be at the cost of crucial charges like, power generated should be able to supply the maximum load and the various losses in transmitting. These constraints are together termed as equality constraints and typically the power flow equation needs to be satisfied,

$$0 = P_{Gi} - P_{Loadi} - V_i \sum_{j=1}^{n} V_j (G_{ij}\cos\partial_{ij} + B_{ij}\sin\partial_{ij}) \quad \text{..... (4)}$$

$$0 = Q_{Gi} - Q_{Loadi} - V_i \sum_{j=1}^{n} V_j (G_{ij}\sin\partial_{ij} - B_{ij}\cos\partial_{ij}) \quad \text{.... (5)}$$

where, i =1 to n, and „n" is the number of buses in the system.

PGi and QGi are active and reactive power generations at bus-i,

Ploadi and Qloadi are corresponding active and reactive load demands.

B. Inequality Constraints

The inequality constraints selected are: Generator bus upper voltage limits and lower voltage limits ($Vi^{min} \leq Vi \leq Vi^{max}$) at every bus. Active power limits at generator buses ($Pgi^{min} \leq Pgi \leq P^{gimax}$), Reactive Power limits at generator buses, Bus injections ($Qgi^{min} \leq Qgi \leq Qgi^{max}$) limits, Tap changing limits,

Maximum loadability and size of capacitors are considered under Inequality constraints.

VII. IMPLEMENTATION AND RESULTS

The proposed algorithm; Music Based Harmony Search algorithm is implemented in C2D 2.1 GHz system on Matlab platform. It is tested for its healthiness on a standard IEEE 30 test bed consisting of 6 Generators, 42 branches, 2 shunt reactors, 12 control variables, 6 discrete variables, 4 tap-changing transformers together with a total load of 283.4 MW. The parameters used for the simulation is as follows: HMS = 60, HMCR = 0.90, PAR = 0.50, NI = 1000. The cost coefficients are included in the Table 1.

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TABLE I
COST COEFFICIENTS OF THE IEEE 30 BUS SYSTEM

Generator	**Cost Coefficients**			**Real Power**	
	α	**β**	**γ**	**Min**	**Max**
1	0	2.00	37.5	50	200
2	0	1.75	175	20	80
5	0	1.00	625	15	50
8	0	3.25	83	10	35
11	0	3.00	250	10	30
13	0	3.00	250	12	40

TABLE II
COMPARISON OF DE WITH OTHER ALGORITHMS

Control Variables	**Base Case**	**ALGORITHM**			
		SGA	**AGA**	**PSO**	**MBHS**
Slack Bus	-	175.99	175.8	176.5	173.72
PG2 (MW)	80.0	49.34	48.96	48.83	47.04
PG5	50.0	21.93	22.01	21.13	23.40
PG8	20.0	22.96	21.35	20.27	25.34
PG11	20.0	12.78	10.96	12.37	10.67
PG13	20.0	12.10	12.0	12.80	12.36

VG_1(pu)	1.0	1.05	1.05	1.05	1.05
VG_2	1.0	1.01	1.06	1.044	0.96
VG_5	1.0	1.09	0.99	1.043	1.055
VG_8	1.0	1.04	0.972	1.0	1.01
VG_{11}	1.0	1.08	1.02	1.02	0.98
VG_{13}	1.0	1.02	1.01	1.01	1.05
$Tap_{6,9}$(pu)	1.0	0.96	1.02	0.9	0.9
$Tap_{6,10}$	1.0	1.05	0.92	1.1	1.04
$Tap_{4,12}$	1.0	1.012	0.95	1.0	1.05
$Tap_{27,28}$	1.0	1.02	1.03	1.025	1.03
$Shunt_{10}$(pu)	0.00	0.02	0.04	0.02	0.03
$Shunt_{12}$	0.00	0.03	0.02	0.03	0.05
$Shunt_{15}$	0.00	0.02	0.05	0.05	0.02
$Shunt_{17}$	0.00	0.01	0.05	0.03	0.03
$Shunt_{20}$	0.00	0.02	0.02	0.04	0.04
$Shunt_{21}$	0.00	0.04	0.01	0.04	0.05
$Shunt_{23}$	0.00	0.02	0.05	0.03	0.6
$Shunt_{24}$	0.00	0.05	0.05	0.02	0.6
$Shunt_{29}$	0.00	0.04	0.04	0.01	0.04

TABLE III
CASE: 1. OPTIMIZATION OF FUEL COST

	SGA	PSO	AGA	MBHS
Average Time (s)	0.910	0.431	0.530	0.012
Losses (MW)	9.60	9.59	9.44	9.15
Fuel Cost (S/MW)	802.88	802.6	802.76	802.85

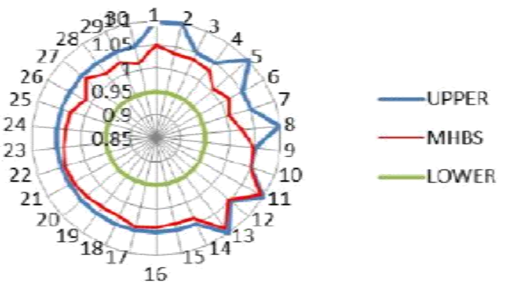

Fig. 2 Voltage Profile of IEEE 30 system

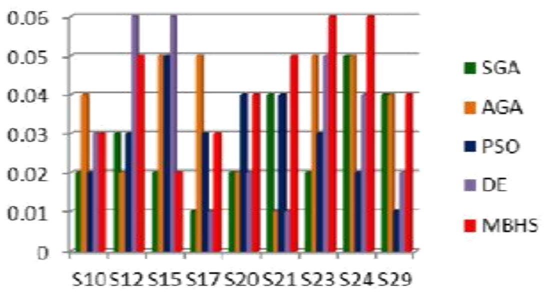

Fig. 3 Comparison of shunt values using diverse algorithms

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TABLE IV
CASE: 2. OPTIMIZATION OF REACTIVE POWER LOSSES

	SGA	PSO	AGA	MBHS
Average Time (s)	1.260	1.640	1.520	0.023
Losses (MW)	6.58	6.83	6.67	6.77
Fuel Cost ($/MW)	973.49	967.2	967.97	955.22

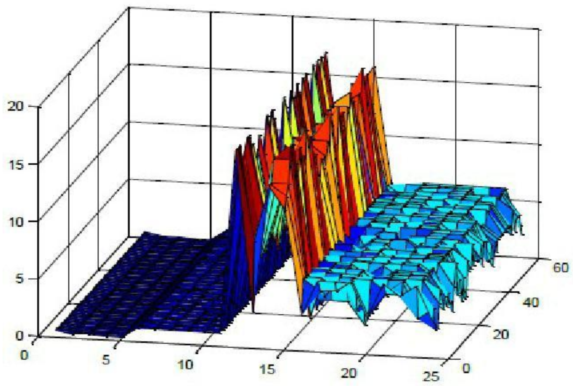

Fig. 1 Surface of the Harmony Memory and variables

It"s found from the above results that the Music Based Harmony Search offers a better, robust and faster solution (99.31%, 75.83 times) to the Optimal Power Flow problem and offers higher savings when compared to classical methods like PSO and GA. Table 1 gives the details of Cost Coefficients used in the problem, Table II reports and compares the variables of the problem with different algorithms and gives information, Table III and IV compares the MBHS for generation cost minimization and reactive power losses optimization. Fig. 1 illustrates the typical harmony memory surface of MBHS, Fig. 2 exemplifies the voltage profile and Fig. 3 demonstrates the shunt values using all the algorithms which are used for the comparison. It"s found that Music Based Harmony Search is a highly encouraging solution for Optimal Power Flow Problem.

VIII. CONCLUSION

This paper has put forward a new approach to Optimal Power Flow problem using a new bio-mimicked algorithm - Music Based Harmony Search. The Proposed technique has been compared with conventional algorithms like Simple Genetic Algorithm (SGA), Adaptive Genetic Algorithm, Particle Swarm Optimization (PSO) etc. The projected algorithm is found to be robust and more efficient and offers computationally faster solution almost double on assessment. Two test cases of Generation cost minimization and Reactive power losses optimizations are demonstrated in this paper and the results are found to be much futuristic.

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