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A PROPOSED VARIANT OF DIFFERENTIAL EVOLUTION FOR OPTIMAL POWER FLOW PROBLEM

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Abstract
This paper presents a proposed variant of differential evolution approach (DEA) for solving the optimal power flow (OPF) problem. The OPF aims to minimize/maximize certain objective functions while maintaining different equality and inequality constraints. The fuel cost minimization, power losses minimization, and voltage stability improvement are considered as the OPF objective functions. The proposed approach employs a proposed variant of DEA (DE/best/1) for solving the OPF. The proposed approach has a high capability of global search exploitation and fast convergence. The effectiveness of the proposed DEA is tested on the standard IEEE 30-bus test system and the West Delta region system (WDN) as a part of the Egyptian Unified network. The obtained numerical results by the proposed DEA are compared with other evolutionary methods to show its potential and capability.

يتناول البحث إقتراح نهجية جديده من خوارزمية التطور التفاضلي لحل مشكلة سريان القدره الأمثل. تهدف هذه المشكلة إلي تحقيق أفضل قيم لدوال هدف معينه دون تجاوز الحدود الصغري والقصوى للقيود الحاكمة. وقد تضمنت دالة الهدف كلا من: تخفيض تكلفة الوقود، ومفاقيد خطوط النقل، وتحسين إتزان الجهد كدوال هدف لمشكلة سريان القدره الأمثل. المنهجية المقترحه لديها قدرة عالية لاستغلال البحث الشامل وسرعة تقارب نحو الحل الأمثل .وقد تم فحص النهج المقترح واختباره من خلال تطبيقه على نظام (IEEE 30-bus) وكذلك علي نظام منطقة غرب الدلتا كجزء من الشبكة الموحدة المصرية، تم مقارنة نتائج الطريقة المقترحة مع نتائج طرق تطوريه متعددة لإظهار فعالية الطريقة المقترحة ومقدرتها على الحل الأمثل لسريان القدره الكهربيه في خطوط النقل.

Keywords : Optimal power flow, differential evolution, fuel cost, power losses, voltage stability.

1. Introduction

Optimal power flow (OPF) had been one of the widely significant operational problems in electric power systems, which has received great interest. The objective of OPF is to minimize selected objective function of a particular power system while maintaining the different equality and inequality constraints. The equality constraints are the load flow equations, while the inequality constraints are the limits of independent and dependent variables. The independent variables are the generator real powers, the generator bus voltages, transformer tap settings and reactive power injection. The dependent variables are slack bus power, load bus voltages, generator reactive powers, and line flows. The main objective of OPF is to minimize the fuel cost. However, due to continuous growth in the demand of electricity with unmatched generation and transmission capacity expansion, voltage instability is emerging as a new challenge for power system planning and operation. At the same time, insufficient reactive power sources of power system produce large transmission loss.

The OPF problem has been traditionally solved using a variety of conventional optimization methods (COMs) such as gradient projection method (GPM) [1], reduced gradient method [2], interior point (IP) method [3], Benders decomposition [4], linear programming (LP) method, quadratic programming (QP) method, and non-linear programming (NLP) method [5]. But they are very weak in handling nonlinear problems and they may converge to a local optimum since they are usually based on some simplifications.

In the last decades, various modern computational intelligence techniques (MCITs) have been utilized to solve the OPF problem such as simulated annealing (SA) [6], tabu search (TS) [7], improved genetic algorithms (IGA) [8], enhanced genetic algorithm (EGA) [9 and 10], adaptive genetic algorithm with adjusting population size (AGAPOP) [11], refined genetic algorithm (RGA) [12], evolutionary algorithm (EA) [13], evolutionary programming (EP) [14], improved evolutionary programming (IEP) [15], particle swarm optimization (PSO) [16 and 17], micro-PSO [18], hybrid PSO and SA [19], fuzzy-based hybrid particle swarm optimization (FPSO) [20], DEA [21 and 22], modified differential evolution algorithm (MDEA) [23], harmony search algorithm (HSA) [24], chaotic self-adaptive differential HSA (CSDHSA) [25], biogeography-based optimization

(BBO) [26], genetic evolving ant direction HDE (EADHDE) [27], evolving ant direction differential evolution (EADDE) [28], black-hole-based optimization (BHBO) [29], imperialist competitive algorithm (ICA) [30], quasi-oppositional teaching learning based optimization (QOTLBO) [31], and krill herd algorithm (KHA) [32].

DEA has been utilized in various applications of power system optimization due to its simplicity, and efficiency [33]. In this paper, a new variant of DEA (DE/best/1) is proposed for solving the OPF problem in order to minimize the total fuel cost, power losses, and to improve voltage stability while the equality and inequality constraints are satisfied. This variant is distinguished with a high capability of global search exploitation and faster convergence.

2. OPF Problem Formulation

2.1 Objective Functions

2.1.1Minimization of fuel cost

Fuel cost for any generator is traditionally modeled as polynomial quadratic function as follows [20-23]:

$$F = \sum_{i=1}^{N_g} a_i {Pg_i}^2 + b_i Pg_i + c_i \qquad (1)$$

Where, F refers to the total fuel costs of generators in \$/hr; Pg_i is the active power output in MW of each generator i; a_i, b_i, and c_i are the corresponding fuel cost coefficients.

2.1.2 Minimization of system power losses

The minimization of system real power losses P_{loss} (MW) can be calculated as follows [20, 22, 24, 29 and 31]:

$$P_{loss} = \sum_{i,j \in N_b} g_{ij}\left(V_i^2 + V_j^2 - V_i V_j \cos\theta_{ij}\right) \qquad (2)$$

Where, N_b is the number of buses; g_{ij} is the conductance of the transmission line between buses i and j; V_i and V_j are the voltages magnitudes at the terminal buses i and j, respectively, and θ_{ij} is the voltage angle difference between the terminal buses i and j.

2.1.3 Voltage stability enhancement

In practice, the voltage stability becomes an essentially requirement. Thus, the minimization of the maximum voltage stability index (L-index) is utilized for enhancing the voltage stability [21]. L-index is in the range of zero (no load case) and one (voltage collapse). L-index for each bus j (L_j) is defined as [21 and 22]:

$$L_j = \left| 1 - \sum_{i=1}^{N_g} F_{ji} \frac{V_i}{V_j} \angle(\theta_{ij} + \delta_i - \delta_j) \right| \qquad (3)$$

$$F_{ji} = -\left[Y_{LL}\right]^{-1}\left[Y_{LG}\right] \qquad (4)$$

Where, δ_i, δ_j are the voltage phase angle of the buses i and j, Y_{LL} and Y_{LG} are sub-matrices of Y-Bus matrix. The L-index should be minimized to improve the voltage stability as follows:

$$\text{Min}(L\text{-index}) = \text{Min}\,(L_j^{max}) \quad j = 1,2,\ldots\ldots N_b \qquad (5)$$

2.2 Equality and Inequality constraints

The equality constraints are usually represented by the load flow balance equations. Furthermore, the power system has to satisfy inequality constraints corresponding to the operational variables as:

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max},\ i = 1, 2, \ldots\ldots N_{pv} \qquad (6)$$

$$V_i^{min} \le V_i \le V_i^{max},\ i = 1, 2, \ldots\ldots N_b \qquad (7)$$

$$T_k^{min} \le T_k \le T_k^{max},\ k = 1, 2, \ldots\ldots N_t \qquad (8)$$

$$\left|S_L\right| \le S_L^{max},\ L = 1, 2, \ldots\ldots N_L \qquad (9)$$

$$0 \le Q_{Ce} \le Q_{Ce}^{max},\ e = 1, 2, \ldots\ldots N_C \qquad (10)$$

$$P_g^{min} \le P_g \le P_g^{max} \qquad (11)$$

Where, Q_{g_i} is the reactive power generated at bus i; N_{pv} refers to the total number of voltage-controlled buses. T_k is the tapping change of a transformer k, and N_t refers to the total number of on-load tap changing transformers. S_L refers to the apparent power flow through transmission line L, and N_L refers to the number of transmission lines in the system. Q_{c_e} is the reactive power output of the VAR source at bus e, N_C refers to the total number of existing VAR sources, and P_g is the active power output at generator.

3. Proposed Differential Evolution Variant

DEA is a population-based stochastic search approach. The major stages of DEA can be described as follows:

3.1 Initialization

The DE control variables are initialized to construct a population P of size NP, by randomizing individuals within their feasible numerical range. At initial generation (G=0), the j^{th} variable of the i^{th} population member (X) could be initialized as:

$$X_{i,j}(0) = X_j^{min} + \text{rand}(0,1).(X_j^{max} - X_j^{min}) \qquad (12)$$

$$i = 1, \ldots.., NP \quad \text{and} \quad j = 1, \ldots.\ldots, D$$

where, the superscripts min and max are lower and upper bounds of the j^{th} variable, rand (0,1) is a random number between 0 and 1, and D is the number of variables of each individual i.

3.2 Mutation

After that, the mutation process generates mutant vectors (V_i) at every generation G. The proposed mutation strategy selects the best individual and perturbs it with the difference of two other randomly selected vectors as:

$$V_{i,j}(G+1) = X_{best,j}(G) + F.\,(X_{r1,j}(G) - X_{r2,j}(G)) \qquad (13)$$

Where, r1, and r2 are randomly integers chosen from the range [1, NP], and they are different from the individual i. X_{best} is the individual with best fitness of the current generation. F is the scale factor which is usually in the range of [0.4–1]. This proposed variant of mutation is DE/best/1, where DE refers to differential evolution, ("/best/") refers to a best chosen base vector $x_{r1,j}$ that is mutated by the addition of a single ("/1/") scaled and randomly chosen difference vector F. $(x_{r2,j} - x_{r3,j})$ [33].

3.3 Crossover

The crossover operation creates trial vectors (U_i) by exchanging the components of the mutant vectors (V_i) and the target vectors (X_i) as:

$$U_{i,j}(G+1) = \begin{cases} V_{i,j}(G+1) & \text{if} \quad \text{rand}(0,1) < C_r \\ X_{i,j}(G) & \text{else} \end{cases} \tag{14}$$

Where, C_r is the crossover probability, which is usually selected within the range [0, 1].

3.4 Selection

The selection process is carried out in the last stage to compare the fitness of the trial vector and the corresponding target vector and select the parent will survive in the next generation which provides the best solution as follows:

$$X_{i,j}(G+1) = \begin{cases} U_{i,j}(G+1) & \text{if} \quad f(U_{i,j}(G+1)) \leq f(X_{i,j}(G)) \\ X_{i,j}(G) & \text{else} \end{cases} \tag{15}$$

Where, f (.) is the function to be minimized. Then, these stages are repeated across generations and stopped whenever maximum number of generations is reached or other stopping criterion is satisfied.

In this paper, random re-initialization is used to replace the exceeded control variable by a randomly chosen value from within the feasible range following (Eq. 12). For the other constraints of dependent variables, the fitness of the individual, which violates, is set to a very high value. So, the infeasible solutions have a little chance to be transferred to the next generation.

4. Simulation Results

In order to evaluate the effectiveness of the proposed approach, two power systems have been considered which are IEEE 30-bus and the WDN systems. Three objectives are considered, which are fuel cost, losses, and L-index.

4.1 IEEE 30-bus power system

The first system consists of 30 buses, 41 branches, 6 generators, 4 on-load tap changing transformers and 9 shunt capacitive sources [1 and 21]. In this system, 24 control variables are optimized for minimizing three objective functions considering one objective at a time. The simulation runs are performed using the proposed DEA with NP = 50, F = 0.6, Cr= 0.9 at maximum of 300 iterations.

4.1.1 Case 1: Fuel costs minimization

The proposed DE variant has been run for Case 1 and the optimal control variables are shown in Table 1. It is clear that the proposed approach reduces the total fuel cost from 901.96 \$/hr to 799.0827 \$/hr compared with the initial case. This reduction is equivalent to 11.41 %. Using the same conditions, the obtained results using the DEA (in Case 1) are compared to other approaches reported by many researches as shown in Table 2. This comparison demonstrates that the proposed DE variant outperforms over many techniques that used to solve the OPF problem in minimizing the total fuel cost.

Also, the convergence of this objective over iterations is shown in Fig. 1. It is shown that the proposed DEA has excellent convergence characteristics since it reaches the minimum fuel costs very fast at iteration No. 80.

Table 1 Results for IEEE 30-bus system

Vari-ables	Min	Max	Initial	Case 1	Case 2	Case 3
Pg_1	50	200	99.24	177.04	52.87	82.6038
Pg_2	20	80	80	48.769	78.5535	52.9573
Pg_5	15	50	50	21.3	50	48.3272
Pg_8	10	35	20	21.0986	34.9999	34.4142
Pg_{11}	10	30	20	11.8199	30	28.8822
Pg_{13}	12	40	20	12	39.8458	39.8153
Vg_1	0.95	1.1	1.05	1.1	1.1	1.0999
Vg_2	0.95	1.1	1.04	1.0877	1.0976	1.0985
Vg_5	0.95	1.1	1.01	1.0614	1.08	1.0999
Vg_8	0.95	1.1	1.01	1.0692	1.0869	1.0999
Vg_{11}	0.95	1.1	1.05	1.1	1.1	1.0992
Vg_{13}	0.95	1.1	1.05	1.1	1.1	1.1
T_{6-9}	0.9	1.1	1.078	1.0563	1.0672	1.0085
T_{6-10}	0.9	1.1	1.069	0.9	0.9001	0.9033
T_{4-12}	0.9	1.1	1.032	0.9907	0.987	0.9737
T_{28-27}	0.9	1.1	1.068	0.9668	0.9737	0.9634
Qc_{10}	0	5	0	5	4.9874	3.7225
Qc_{12}	0	5	0	5	4.9986	1.921
Qc_{15}	0	5	0	4.9996	4.0976	0.6966
Qc_{17}	0	5	0	5	4.9996	3.5034
Qc_{20}	0	5	0	4.4014	4.1611	2.9601
Qc_{21}	0	5	0	4.9999	4.9993	4.919
Qc_{23}	0	5	0	2.7988	3.1345	0.092
Qc_{27}	0	5	0	5	4.992	0.8226
Qc_{29}	0	5	0	2.4976	2.256	1.1737
Fuel cost (\$/hr)	-	-	901.96	**799.0827**	963.6169	915.2172
P_{losses} (MW)	-	-	5.596	8.63	**2.866**	3.626
L_{max}	-	-	0.172	0.1277	0.126	**0.1243**

Table 2 A comparison between different techniques of Case 1 for IEEE 30-bus system

Method	Minimum Fuel cost (\$/hr)
Proposed DEA variant	**799.0827**
BBO [26]	799.1116
DEA [21]	799.2891
SA [6]	799.45
AGAPOP [11]	799.8441
BHBO [29]	799.9217
EADHDE [27]	800.1579
EADDE [28]	800.2041
PSO [16]	800.41
DEA [22]	800.56
FPSO [20]	800.72
IGA [8]	800.805
CDHSA [25]	801.5888
ICA [30]	801.843
CDHSA [25]	802.0230
EGA [9]	802.06
TS [7]	802.29
DHSA [25]	802.2966
MDEA [23]	802.376
IEP [15]	802.465
EP [14]	802.62
RGA [12]	804.02
GPM [1]	804.853

4.1.2 Case 2: Power losses minimization

In the second case, the considered objective is to minimize power losses (Eq. 2). Table 1 shows the optimal settings of the control variables and its corresponding results of the proposed DEA for Case 2. From this table, the power losses are reduced from 5.596 MW to 2.866 MW compared with the initial case. The acquired results using the DEA variant for Case 2 are compared to other reported approaches in Table 3. This demonstrates that the proposed DEA variant outperforms over many techniques used to minimize the power losses. Also, the convergence of this objective is shown in Fig. 2 which makes sure that the proposed DEA has excellent convergence characteristics to obtain the minimum real losses in minimum time.

4.1.3 Case 3: Minimization of L-max

In this case, the voltage stability enhancement is considered as an objective function by minimizing L-max (Eq. 3). Table 1 shows the optimal control variables and the corresponding results of the proposed approach for Case 3. The convergence of this objective is shown in Fig. 3. From both, L-max using the DEA is reduced from 0.172 to 0.1246 compared with the initial case so the voltage stability is improved.

4.2 West Delta region system

The second system is the West Delta region (WDN), which is a part of the Unified Egyptian network. This network is composed of 52 buses and 8 generators connected by 108 lines [34 and 35]. Initially, there are four violated bus voltages at buses 18, 20-22. In this system, the number of iterations is reduced to 200. Similar results are obtained by the proposed DEA variant for minimizing the three single objective functions where the simulation results and optimal settings of the control variables are shown in Table 4.

In Case 1, the proposed DEA reduced the total fuel cost from 25099 \$/hr to 22954 \$/hr compared with the initial case. Added to that, it minimized the power losses in Case 2 to 7.3409 MW compared to 19.015 MW at the initial case. Moreover, the proposed DE variant reduced L-max in Case 3 from 0.173 to 0.1494 compared with the initial case. The convergence characteristics are shown in Figs. 4, 5, and 6 for Cases 1, 2, and 3, respectively. These figures elucidates that the proposed DEA reaches to the minimum objective value at the 70th generation for Case 1, and 90th generation for Case 2, which illustrates the high exploitation characteristics to find the best solution. However the proposed approach gets stuck at the 20th generation for Case 3, this is due to the lack of reactive power sources in this system.

5. Conclusions

In this paper, a DEA variant, which is called DE/best/1, has been proposed to solve the optimal power flow (OPF) problem. The OPF problem has been formulated as a constrained optimization problem to minimize the total fuel cost, power losses, and enhancement of voltage stability. The proposed DEA variant has been successfully implemented and tested on the IEEE 30-bus system and the West Delta region system as a part of the Egyptian Unified network. Not only the proposed DEA variant is able to obtain the least objective values, but also it has faster convergence characteristics which confirms to its high capability to explore the global minimum. Also, the simulation results obtained by the proposed DEA variant (DE/best/1) are compared with various evolutionary methods. This demonstrates the effectiveness and the superiority of the proposed DEA variant to solve the OPF problem over the heuristic techniques in terms of solution quality with fast convergence characteristics.

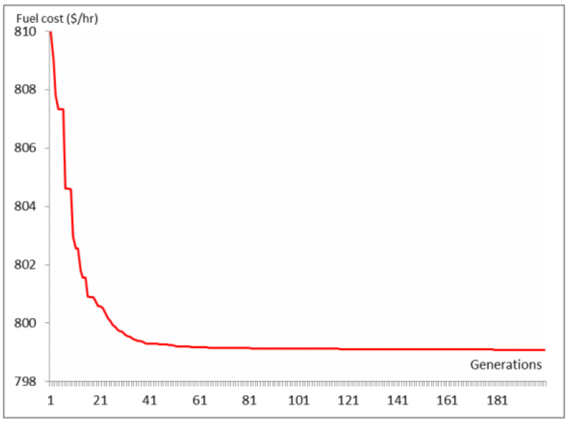

Figure 1 Convergence characteristics of fuel cost function for IEEE 30-bus system

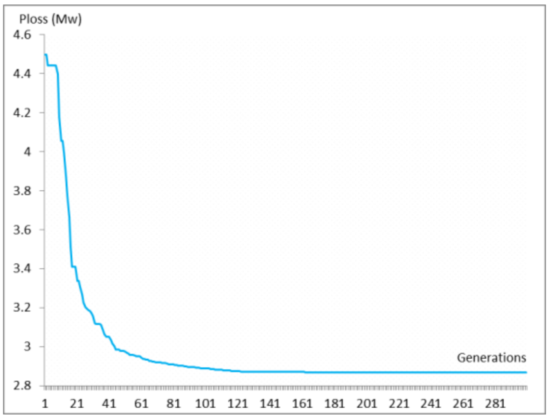

Figure 2 Convergence characteristics of power losses function for IEEE 30-bus system

Table 3 Comparison of the simulation results in Case 2 for IEEE 30-bus system

Method	Power losses (MW)
Proposed DEA variant	**2.866**
QOTLBO [31]	2.8834
TLBO [31]	2.9343
HAS [24]	2.9678
EGA [10]	3.2008
DEA [22]	3.24
BHBO [29]	3.5035

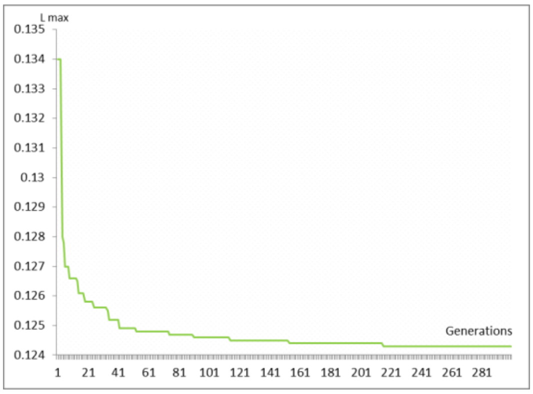

Figure 3 Convergence characteristics of L-max function for IEEE 30-bus system

Table 4 Results for West delta region system

Variable	Min	Max	Initial	Case 1	Case 2	Case 3
Pg_1	0	250	85.69	152.12	56.0257	48.47
Pg_2	0	250	157.4	10	52.2641	150.584
Pg_3	0	250	139.31	214.64	181.429	81.4863
Pg_4	0	250	113.69	180.40	134.731	54.6849
Pg_5	0	375	166.48	10	116.702	247.489
Pg_6	0	250	31.71	234.15	99.5582	119.530
Pg_7	0	250	92	56.305	161.599	134.497
Pg_8	0	250	122.49	32.125	87.4394	86.1596
Vg_1	0.94	1.06	1	1.06	1.0571	0.9664
Vg_2	0.94	1.06	1	1.06	1.0587	1.0027
Vg_3	0.94	1.06	1	1.06	1.0598	1.06
Vg_4	0.94	1.06	1	1.06	1.06	1.0416
Vg_5	0.94	1.06	1	1.0591	1.0496	1.004
Vg_6	0.94	1.06	1	1.06	1.0476	0.9685
Vg_7	0.94	1.06	1	1.0455	1.0479	0.9508
Vg_8	0.94	1.06	1	1.0515	1.0458	0.9967
Fuel cost ($/hr)	-	-	25099	**22954**	24751	27688
P_{losses} (MW)	-	-	19.015	37.433	**7.3409**	28.1976
L_{max}	-	-	0.173	0.1494	0.1495	**0.1494**

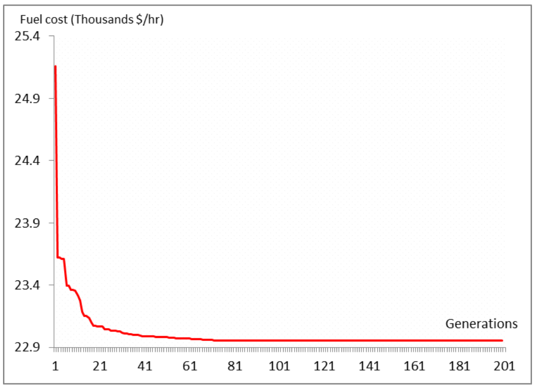

Figure 4 Convergence characteristics of fuel cost function for West delta region system

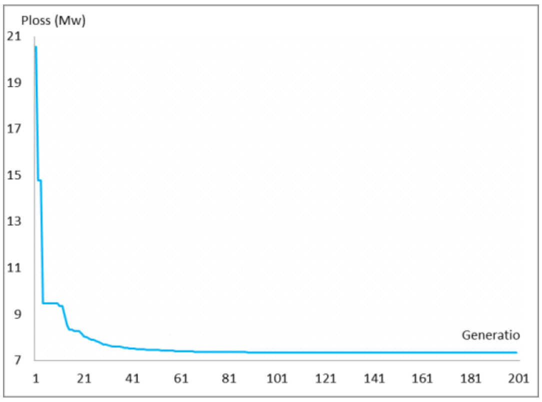

Figure 5 Convergence characteristics of power losses function for West delta region system

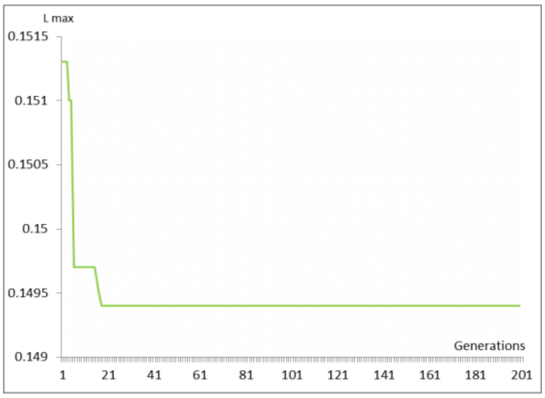

Figure 6 Convergence characteristics of L-max function for West delta region system

6. References

[1]K. Lee, Y. Park, and J. Ortiz, "A united approach to optimal real and reactive power dispatch", IEEE Transactions on Power Apparatus and Systems, Vol. 104, No. 5, pp. 1147-1153, 1985.

[2]E. Carvalho, A. Junior, and T. Ma, "Reduced gradient method combined with augmented Lagrangian and barrier for the optimal power flow problem", Applied Mathematics and Computation, Vol. 200, Issue 2, pp. 529-536, 2008.

[3]F. Capitanescua, and L. Wehenkel, "Experiments with the interior-point method for solving large scale optimal power flow problems", Electric Power Systems Research, Vol. 95, pp. 276-283, February 2013.

[4]N. Amjady, and M. R. Ansari, "Non-convex security constrained optimal power flow by a new solution method composed of Benders decomposition and special ordered sets", International Transactions on Electrical Energy Systems, Vol. 24, Issue 6, pp. 842–857, June 2014.

[5]J. Momoh, M. El-Hawary, and R. Adapa, "A Review of Selected Optimal Power Flow Literature to 1993, Parts I and II", IEEE Transactions on Power Systems, Vol. 14, No. 1, pp. 96–111, 1999.

[6]C. A. Roa-Sepulveda, and B. J. Pavez-Lazo, "A solution to the optimal power flow using simulated annealing", International Journal on Electrical Power and Energy Systems, Vol. 25, No. 1, pp. 47-57, 2003.

[7]M. A. Abido, "Optimal power flow using Tabu search algorithm", Electric Power Components and Systems, Vol. 30, pp. 469-483, 2002.

[8]L. L. Lai, J. T. Ma, R. Yokoyama, and M. Zhao, "Improved genetic algorithms for optimal power flow under both normal and contingent operation states", International Journal on Electrical Power and Energy Systems, Vol. 19, No. 5, pp. 287-292, 1997.

[9]A. G. Bakirtzis, P. N. Biskas, C. E. Zoumas, and V. Petridis, "Optimal power flow by enhanced genetic algorithm", IEEE Transactions on Power Systems, Vol. 17, No. 2, pp. 229-236, 2002.

[10]M. S. Kumari, and S. Maheswarapu, "Enhanced genetic algorithm based computation technique for multi-objective optimal power flow solution", International Journal on Electrical Power and Energy Systems, Vol. 32, pp. 736-742, 2010.

[11]A. F. Attia, Y. A. Al-Turki, and A. M. Abusorrah, "Optimal power flow using adapted genetic algorithm with adjusting population size", Electric Power Components and Systems, Vol. 40, No. 11, 2012.

[12]S. R. Paranjothi, and K. Anburaja, "Optimal power flow using refined genetic algorithm", Electric Power Components and Systems, Vol. 30, 2002.

[13]L. Hongxin, L. Yinhong, and C. Jinfu, "Adaptive multiple evolutionary algorithms search for multi-objective optimal reactive power dispatch", International Transactions on Electrical Energy Systems, Vol. 24, Issue 6, pp. 780-795, June 2014.

[14]J. Yuryevich, and K. P. Wong, "Evolutionary programming based optimal power flow algorithm" IEEE Transactions on Power Systems, Vol. 14, No. 4, pp. 1245-1250, 1999.

[15]W. Ongsakul, and T. Tantimaporn, "Optimal power flow by improved evolutionary programming", Electric Power Components and Systems, Vol. 34, No. 1, pp. 79-95, 2006.

[16]M. A. Abido, "Optimal power flow using particle swarm optimization" International Journal on Electrical Power and Energy Systems, Vol. 24, No. 7, pp. 563-571, 2002.

[17]J. Hazra, and A. K. Sinha, "A multi-objective optimal power flow using particle swarm optimization", European Transactions on Electrical Power, Vol. 21, No. 1, pp. 1028-1045, 2011.

[18]D. Wu, D. Gan, and J. N. Jiang, "An improved micro-particle swarm optimization algorithm and its application in transient stability constrained optimal power flow", International Transactions on Electrical Energy Systems, Vol. 24, Issue 3, pp. 395-411, March 2014.

[19]T. Niknam, M. Narimani, and M. Jabbari, "Dynamic optimal power flow using hybrid particle swarm optimization and simulated annealing. International Transactions on Electrical Energy Systems, Vol. 23, Issue 7, pp. 975-1001, 2013.

[20]R. H. Liang, S. R. Tsai, Y. T. Chen, and T. Wan-Tsun, "Optimal power flow by a fuzzy based hybrid particle swarm optimization approach", Electric power system research, Vol. 81, No. 7, 2011.

[21]A. A. Abou El Ela, M. A. Abido, and S. R. Spea, "Optimal power flow using differential evolution algorithm", Electric Power System Research, Vol. 80, No. 7, pp. 878-885, 2010.

[22]M. A. Abido, and N. A. Al-Ali, "Multi-objective optimal power flow using differential evolution", Arabian Journal for Science and Engineering, Vol. 37, No. 4, pp. 991-1005, 2012.

[23]S. Sayah, and K. Zehar, "Modified differential evolution algorithm for optimal power flow with non-smooth cost functions", Energy Conversion and Management, Vol. 49, No. 11, pp. 3036-3042, 2008.

[24]S. Sivasubramani, and K. S. Swarup, "Multi-objective harmony search algorithm for optimal power flow problem", International Journal on Electrical Power and Energy Systems, Vol. 33, No. 3, pp. 745-752, 2011.

[25]R. Arul, G. Ravi, and S. Velusami, "Solving optimal power flow problems using chaotic self-adaptive differential harmony search algorithm", Electric Power Components and Systems, Vol.41, No. 8, pp. 782-805, 2013.

[26]A. Bhattacharya, and P. K. Chattopadhyay, "Application of biogeography-based optimisation to solve different optimal power flow problems", IET Generation, Transmission & Distribution, Vol. 5, No. 1, pp. 70-80, 2011.

[27]K. Vaisakh, and L. R. Srinivas, "Genetic evolving ant direction HDE for OPF with non-smooth cost functions and statistical analysis" Expert Systems with Applications, Vol. 38, pp. 2046-2062, 2011.

[28]K. Vaisakh, and L. R. Srinivas, "Evolving ant direction differential evolution for OPF with non-smooth cost functions" Engineering Applications of Artificial Intelligence, Vol. 24, pp. 426-436, 2011.

[29]H. R. E. H. Bouchekara, "Optimal power flow using black-hole-based optimization approach", Applied Soft Computing, Vol. 24, pp. 879-888, 2014.

[30]A. J. Ghanizadeh, G. Mokhtari1, M. Abedi, and G. B. Gharehpetian, "Optimal power flow based on imperialist competitive algorithm", International Review of Electrical Engineering, Vol. 6, No. 4, Part B, 2011.

[31]B. Mandal, and P. K. Roy, "Multi-objective optimal power flow using quasi-oppositional teaching learning based optimization", Applied Soft Computing, Vol. 21, pp. 590-606, 2014.

[32]P. K. Roy, and C. Paul, "Optimal power flow using krill herd algorithm" International Transactions on Electrical Energy Systems, 2014.

[33]U. K. Chakraborty, "Advances in differential evolution", Studies in Computational Intelligence, Springer-Verlag Berlin Heidelberg, 2008.

[34]A. A. Abou El Ela, R. El Sehiemy, and A. M. Shaheen, "Multi-objective fuzzy-based procedure for enhancing reactive power management", IET Generation, Transmission & Distribution, Vol. 7, Issue 12, pp. 1453-1460, December 2013.

[35]R. El Sehiemy, A. A. Abou El Ela, and A. M. Shaheen, "A Multi-Objective Fuzzy-based Procedure for Reactive Power-based Preventive Emergency Strategy", International Journal of Engineering Research in Africa Vol. 13, pp. 91-102, 2015. Available: http://www.scientific.net/