Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 41-50

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Enhancement of Loadability Limit of Deregulated Power System via Adaptive Real-Coded Biogeography-Based Optimization

[1]Ramesh Kumar Arunachalam and [2]Dr. Premalatha Logamani

[1]Assistant Professor, Department of Electrical and Electronics Engineering, SMK Fomra Institute of Technology, Anna University, Chennai-603103, Tamilnadu, India.
[2]Professor, Department of Electrical and Electronics Engineering, Anad Institute of Higher Technology, Anna University, Chennai-603103, Tamilnadu, India.

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form
19 November 2014
Accepted 22 December 2014
Available online 2 January 2015

Keywords:
Total transfer capability; biogeography-based optimization; adaptive Gaussian mutation; Flexible AC Transmission System; deregulated power system.

ABSTRACT

Background: With the growing demand for power in the open market, the augmentation of TTC (total transfer capability) is one solution close at hand. **Objective:** This paper proposes an algorithm, based on adaptive real-coded biogeography-based optimization (ARCBBO), to determine the optimal location and capacity of FACTS devices such as thyristor-controlled series capacitor and static VAR compensator to increase the loadability and boost power transfer capability of the system. This problem has been considered as an optimal power flow (OPF) based enhancement of total transfer capability. Experiments were performed without and with FACTS devices. The proposed technique aims to improve the searching ability, enhance population diversity and maintain smooth convergence characteristics by using adaptive Gaussian mutation. **Results:** The proposed algorithm has been tested on standard 30-bus and IEEE 118-bus systems and outcomes compared with those of existing population-based methods. **Conclusion:** The solution quality of the proposed method is superior over other techniques reported in recent literature. Due to its simple framework, and smooth and quick convergence characteristics, the ARCBBO algorithm is suggested to be ideal to solve the multi-constrained large-scale power systems.

To Cite This Article: Ramesh Kumar A. and Dr. Premalatha L., Enhancement of Loadability Limit of Deregulated Power System via Adaptive Real-Coded Biogeography-Based Optimization. ***Aust. J. Basic & Appl. Sci.,*** *9(1): 41-50, 2015*

INTRODUCTION

Load growth in a power system is increasing faster than the transmission capability. In the past decade, the increase in transmission capability has been almost 50% of the increased generation capability. The transmission system thus faces several challenges. In the extant open-access power system where everybody can sell or buy energy, there is increasing need for improvements in the transmission capacity of the system whereas maintaining system reliability and security (Y.H. Song and X. Wang, 2003).

Due to huge investment for transmission system, determination of loadability limit is an important role for future development of power systems. A loadability limit of power system is related to thermal, voltage stability and security monitoring. It is the margin between the operating point of the system and the maximum loading point. Recently, various techniques are used to determine the maximum loadability limit (G.D. Irisarri *et al.*, 1997), (A. Shunmugalatha and S. Mary Raja Slochanal, 2008), (K. Gnanambal and C.K. Babulal, 2012).

The North American Electrical Reliability Council (NERC) has recognized a structure for formative ATC of interconnected networks (NERC report, 1997). Continuation power flow, repeated power flow based approaches were used by various researchers to determine ATC and TTC (G.C. Ejebe *et al.*, 1998), (V. Ajjarappu and C. Christy, 1992), (Y. Ou and C. Singh, 2002).

During the evaluation of TTC, the system operator needs valuable information regarding the proficiency of an interconnected network to consistently transfer bulk power between two nodes or between different areas of the network without causing threat to system reliability. It has been well demonstrated that the location of the devices and their control parameters significantly affect TTC, which could be overcome with the use of FACTS devices. The capability of the transmission system has improved with FACTS technology (Xiao Ying *et al.*, 2003), (H. Sawhney and B. Jeyasurya 2004), (N.D. Ghawghawe and K.L. Thakre, 2009), (R. Mohan Mathur and Rajiv K. Varma, 2002), (Y. Xiao *et al.*, 2001), (Y. Xiao *et al.*, 2003).

Corresponding Author: Ramesh Kumar A., Assistant Professor, Department of Electrical and Electronics Engineering, SMK Fomra Institute of Technology, Chennai-603103, Tamilnadu, India.
E-mail: a_rameshkumar@live.com

FACTS devices can offer effective TTC enhancement with low operation and maintenance cost. Several evolutionary algorithms have been used to identify the optimal location and size of FACTS devices. For example, a probabilistic based method was employed for complex and large-scale power systems (M.A. Khaburi and M.R. Haghifam, 2010). A hybrid real-coded genetic algorithm (RCGA) is demonstrated in (T. Nireekshana *et al*., 2012), and a hybrid mutation particle swarm optimization is demonstrated in (H. Farahmand *et al*., 2012).

Recently, a biogeography-based optimization (BBO) algorithm was proposed for solving optimization problems (D. Simon, 2008). In this approach, islands or habitats were modeled to represent solutions, and immigration and emigration of species between islands denote sharing of features between solutions. For optimization problems of economic load dispatch in power systems, this method has been tested (A. Bhattacharya and P.K. Chattopadhyay, 2010).

Adaptive real coded biogeography based optimization (ARCBBO) is developed by implementation of adaptive Gaussian mutation with BBO algorithm. Adopting the ARCBBO technique, the paper aims to enhance loadability limit and TTC with the use of FACTS controllers like TCSC and SVC. Active and reactive power control as well as adaptive voltage magnitude control can be regulated simultaneously by ARCBBO. So, this problem is considered as optimal power flow problem (OPF). ARCBBO is used to solve OPF problem and it has been tested on standard 30-bus and IEEE 118-bus systems.

2. *Problem Formulation:*

ATC is calculated according to the NERC procedure. It is the difference between total transfer capability (TTC) and the sum total of existing transmission commitment (ETC), transmission reliability margin (TRM) and capacity benefit margin (CBM) (NERC report, 1997). TTC is limited by the system characteristics including thermal, voltage and stability limits. ETC is calculated from base case power flow analysis. TRM is usually a constant (i.e. 10% of the TTC). CBM is calculated from the market values of energy contractors. It can be expressed as

$$ATC = TTC - (TRM + CBM + ETC) \quad (1)$$

$$TTC = Minimum\{Thermal, Voltage, Stability\} \quad (2)$$

The goal of intensification of TTC is a multi-constrained optimization problem whose solution is expected to find the best location and size of FACTS devices. The objective function is to maximize the system loadability limit and hence TTC is improved. Repeated power flow method is used to solve the following power flow equations.

$$Maximize\ f = \sum_{i=1}^{N_{pq}} \lambda_i \quad (3)$$

$$P_{Di} = P_{Di}^0 (1 \pm \lambda_i) \quad (4)$$

$$TTC = \sum_{k \in NL} S_k \quad (5)$$

Subjected to

(i) Power flow constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{Nb} V_i V_j \left[G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)\right] = 0 \quad i = 1,2,..., N_b \quad (6)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{Nb} V_i V_j \left[G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)\right] = 0 \quad i = 1,2,..., N_b \quad (7)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \quad i = 1,2,..., N_g \quad (8)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \quad i = 1,2,..., N_g \quad (9)$$

$$V_i^{min} \le V_i \le V_i^{max} \quad i = 1,2,..., N_{pq} + N_g \quad (10)$$

$$S_k \le S_k^{max} \quad (11)$$

where λ_i is the loadability factor for each load bus, P_{Gi} & Q_{Gi} are the active and reactive power injected at bus i, P_{Di} & Q_{Di} are the active and reactive power demand at bus i, V_i & δ_i are the magnitude and phase angle of voltage at bus i, G_{ij} & B_{ij} are the real and imaginary part of admittance of transmission line, N_b, N_g & N_{pq} are the number of bus, number of generator and number of load bus, respectively. S_k is the thermal limit of the k^{th} transmission line. min and max represents the minimum and the maximum limits of the parameter, respectively.

(ii) FACTS device constraints

Here, SVC is used as a reactive power absorption device, as explained in equation (12).

$$Q_{SCV} = B_{SVC} \times \left(V_{ref}^2\right) \quad (12)$$

$$-100\text{MVAr} \le Q_{SVC} \ge 100\text{MVAr} \tag{13}$$

$$-0.8X_L \le X_{TCSC} \ge 0.2X_L \tag{14}$$

where B_{SVC} is the susceptance added by placing SVC in the bus, X_{TCSC} is the reactance added by placing TCSC, X_L is the reactance of the line where TCSC is connected, and Q_{SVC} is the reactive power injected at the bus by connecting SVC.

Finally, the objective function with all constraints combined for the OPF problem is given by

$$Min\,F = G/\sum P_{Di} + \sum_{i\in N_g}\lambda_{Pg}(P_{Gi} - P_{Gi}^{\lim})^2 + \sum_{i\in Ng}\lambda_{Qg}(Q_{Gi} - Q_{Gi}^{\lim})^2 + \sum_{i\in Npq}\lambda_V(V_{Li} - V_{Li}^{\lim})^2 + \sum_{i\in NL}\lambda_{Pf}(S_i - S_i^{\max})^2 \tag{15}$$

where G is a constant and λ_{Pg} , λ_{Qg} , λ_V and λ_{Pf} are penalty factors.

3. Review of Biogeography-Based Optimization:

BBO has been proposed by Dan (D. Siman, 2008) as a comprehensive algorithm for solving optimization problems and is based on the study of geographical distribution of species. The BBO approach has two main operators, namely migration operator and mutation operator.

3.1 Migration Operator:

Migration is the process by which each individual in the habitat is probabilistically modified by sharing information with other individual solutions. A geographical area with high habitat suitability index (HSI) is said to be well suitable for biological species. It tends to have a large number of species, high emigration rate, and low immigration rate. Suitability index variables (SIVs) are those that characterize the habitat of the species. Therefore, a habitat with a high HSI tends to be more static in its species distribution. A habitat with a high HSI is analogous to a good solution, and a habitat with a low HSI is analogous to a poor solution. The individuals in a habitat share features based on the migration rate. Immigration rate, λ_k, and emigration rate, μ_k, are functions of the number of species in a habitat. When there are no species in a habitat, its immigration rate is maximum. λ_k can be found by:

$$\lambda_k = I\left(1 - \frac{k}{n}\right) \tag{16}$$

where I is the maximum possible immigration rate, k is the number of species of kth individual, and n is the maximum number of species. μ_k can be found by:

$$\mu_k = E\left(\frac{k}{n}\right) \tag{17}$$

where E is the maximum possible emigration rate.

3.2 Mutation Operator:

Mutation tends to increase the diversity among individuals in a habitat in approaching a better solution. Due to natural events, the HSI of a habitat may change dramatically, resulting in a species count distinct from its equilibrium value. Species count may be associated with a probability value (Pi). If the probability value is very low, an individual's solution is assumed to have been mutated with other solutions. So, mutation rate of individual solution can be calculated using species count probability, given by:

$$M_i = M_{max} * \left(\frac{1 - P_i}{P_{max}}\right) \tag{18}$$

where M_i is the mutation rate, M_{max} is the maximum mutation rate, which is a user-defined parameter, and P_{max} is the maximum probability of species count.

4. Adaptive Real-Coded Biogeography-Based Optimization:

In BBO, Migration operator can improve the performance of BBO. It is used to modify habitat by simply replacing similar kind of habitat that means habitat shares less information from the others. Hence, migration operator is lacking of exploration ability.

In order to share more information in between habitats, BBO is inspired with DE, the migration operator is improved by applying DE mutation strategy. The following operation is used as migration operator in this paper,

$$X_i = X_{best} + F \times \left|(X_{r1} - X_{r2})\right| \tag{19}$$

Where X_i is the i^{th} individual, X_{best} is the best individual, X_{r1} and X_{r2} are the random individuals among the total population and F is the scaling factor.

In BBO, individuals are encoded by a floating point for the continuous optimization problems and random mutation is used which deficient the exploration ability. In RCBBO (Wenyin Gong *et al*., 2010), individuals are

represented by a D-dimensional real parameter vector, and a probabilistically based Gaussian mutation operator is used, which improves the diversity of the population and its searching ability.
The Gaussian mutation characteristic function is given by:

$$X_i' = X_i + N(\mu, \sigma_i^2) \quad (20)$$

where $N(\mu, \sigma_i^2)$ represents the Gaussian random variable with mean μ and variance σ^2. The values of mean and variance are considered 0 and 1, respectively (Wenyin Gong *et al.*, 2010).

Generally, a probability-based mutation operation affects the convergence characteristics. Therefore, adaptive Gaussian mutation is applied in the present work to improve the solution of worst half of individuals in the population. In equation (19), μ = 0, and σ_i is found using the following equation:

$$\sigma_i = \beta * \sum_{i=1}^{n} \left(\frac{F_i}{f_{\min}} \right) * \left(X_i^{\max} - X_i^{\min} \right) \quad (21)$$

where β is the scaling factor or mutation probability, F_i is the fitness value of ith individual, and f_{min} is the minimum fitness value of the habitat in the population.
Adaptive mutation probability is given by

$$\beta = \beta_{\max} - \frac{\beta_{\max} - \beta_{\min}}{T_{\max}} \times T \quad (22)$$

where $\beta_{\max} = 1$, $\beta_{\min} = 0.005$, T_{max} is the maximum iteration, and T is the current iteration.

The method of adaptive mutation has the ability to prevent premature convergence and hence to produce a smooth convergence. This method of mutation can be easily used with real-coded variables, which have been widely used in evolutionary programming (EP), and hence to carry out local as well as global searches.
The pseudo code of an ARCBBO algorithm is given below:
Initialize the ARCBBO parameters
Generate the individuals (SIV) randomly within their feasible region
$X_k = X_k^{\min} + rand(0,1) \times (X_k^{\max} - X_k^{\min})$
Calculate the fitness (HSI) value for each habitat in the population
While halting criteria is not satisfied **do**
Sort the SIVs from best to worst according the fitness value
Map the HSI values to the number of species
Compute immigrate rate and emigration rate for each individual
For i=1 to NP
Select X_i according to immigration rate λ_i
For j=1 to NP
Generate two integer randomly r1≠r2
Select Xj according to emigration rate μ_j
If $rand(0,1) < \mu_j$
$X_i = X_j$
Else
$X_i = X(HSI_{best}) + F \times |(X_{r1} - X_{r2})|$
End If
End For
End For
// Adaptive Gaussian Mutation (Mutate only the worst half of population)
For i = (NP/2) +1 to NP
For j=1 to N_{var}
$\sigma_{ij} = \beta \frac{F_i}{F_{\min}} \times (X_i(j) - X_i(j))$
$X_{ij}' = X_{ji} + Normrnd(0, \sigma_{ij})$
End For
End For
Compute HSI for new habitats
Sort SIV from best to worst

Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 41-50

End While:

Generators active power, system loadability factor for each load bus, FACTS devices location and ratings are the individuals (SIV) of the habitat. Fitness value (HSI) is calculated from objective function, equation (15).

RESULTS AND DISCUSSION

The proposed ARCBBO algorithm is applied to improve the loadabilty limit and enhance the total transfer capability of system under consideration of with and without FACTS devices. Loadability limit and TTC are calculated under intact case and contingency condition. It has been implemented on the MATPOWER 30-bus and IEEE 118-bus systems and the results are presented here. Power flow calculations by Newton–Raphson method were performed using MATPOWER 4.1 (R.D. Zimmerman *et al*., 2011).

The optimal control parameters for the algorithm are chosen from number of simulation results. They are: habitat size = 50, habitat modification probability = 1, immigration probability = 1, step size for numerical integration = 1, maximum immigration and emigration rate = 1, mutation probability= 0.005 and maximum number of iterations = 100. The results show the corresponding objective functions for 50 independent trails.

5.1 IEEE 30-bus System:

The system consists of 6 generator buses and 24 load buses. Bus 1 is taken as slack bus. The system load is 189.2 MW and 107.2 MVAR. The details of bus data and line data are taken from MATPOWER package (R.D. Zimmerman *et al*., 2011). Convergence characteristic of proposed method for 30 bus system is depicted in Fig. 1, which indicates smooth convergence of ARCBBO. For intact case, loadability limits of each load buses are presented in Table 1. Maximum loadability limit obtained for this system by proposed method is compared with different optimization techniques, is presented in Table 2. Loadability limit obtained by the proposed method is 319.3081MW which is better than result reported in (A. Shunmugalatha and S. Mary Raja Slochanal, 2008), (K. Gnanambal and C.K. Babulal, 2012). TTC is calculated by the proposed method with FACTS and without FACTS devices under intact case and contingency condition, results are presented in Table 3.

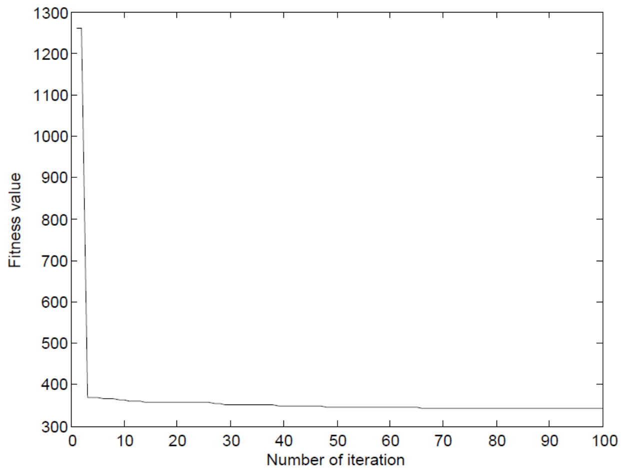

Fig. 1: Convergence characteristics of ARCBBO for 30 bus system.

Table 1: Active power demand at each load buses for 30 bus system.

Bus No.	Without FACTS	With FACTS	Bus No.	Without FACTS	With FACTS
3	16.9486	16.0738	16	14.5522	7.6851
4	25.9129	32.1941	17	4.8770	0.2915
5	21.1438	22.8444	18	10.1016	0
6	22.2846	26.0667	19	2.4932	2.5400
7	6.0826	3.5292	20	11.6741	3.7730
8	18.9991	21.3314	21	0	4.6822
9	11.9278	26.0000	24	24.9703	19.3836
10	0.3365	18.5126	25	4.0056	2.4209
11	7.8250	11.1130	26	3.8875	6.3852
12	23.1213	21.1893	28	32.1709	13.9862
14	1.4763	4.4651	29	17.3830	13.3354
15	6.1937	10.1522	30	6.0409	13.2127

Table 2: Comparison of maximum loadability in MW.

System	ARCBBO(with FACTS)	ARCBBO(without FACTS)	DEPSO (K. Gnanambal and C.K. Babulal, 2012)	DE (K. Gnanambal and C.K. Babulal, 2012)	MAHPSO (A. Shunmugalatha and S. Mary Raja Slochanal, 2008)
30 bus	326.0674	319.3081	269.74	267.09	260.808
118 bus	7892.3	7855.9	5701.56	5654.3	5645

Table 3: Enhancement of TTC for 30 bus system.

Case	Loadability (MW)	TTC (MVA)	SVC		TCSC		Limiting point
			Bus location	Capacity (MVAR)	Line location	Level of compensation	
Intact without FACTS	319.3081	621.4888	-	-	-	-	Line flow at line 29
Intact with FACTS	326.0674	632.5870	11	23.0337	28	0.2285	Line flow at line 29
Contingency without FACTS	302.8279	577.6207	-	-	-	-	Line flow at line 30
Contingency with FACTS	307.1221	633.2993	9	48.7606	15	0.0294	Line flow at line 30

Under intact case, network TTC are being 621.4888 MVA and 632.5870 MVA without and with FACTS devices respectively. So network TTC is improved by 11 MVA, connecting SVC at bus 11 and TCSC at line 28. Enhancement of TTC is limited by the system thermal limit, at line 29.

Under contingency condition (line no. 2 is outage); network TTC is 577.6207MVA which is lesser than TTC in intact case. TTC is improved to 633.2993MVA, by connecting SVC at bus 9 and TCSC at line 15. TTC is limited by the system thermal limit, at line 29. Power flow constraints of generator active power, reactive power, bus voltages and line flows are within the limits which are shown in Fig. 2 to 5 respectively.

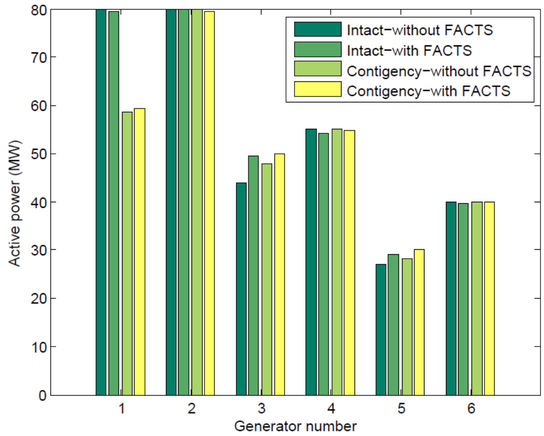

Fig. 2: Generator active power output for 30 bus system.

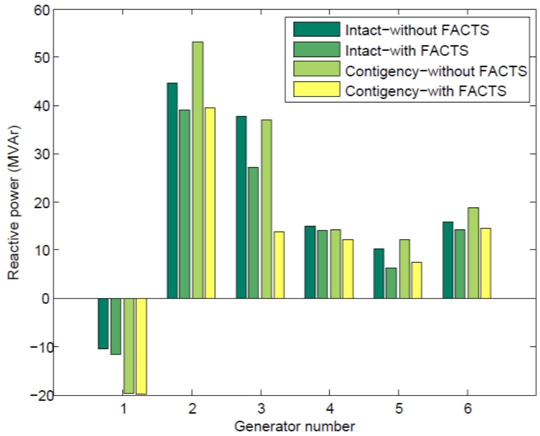

Fig. 3: Generator reactive power output for 30 bus system.

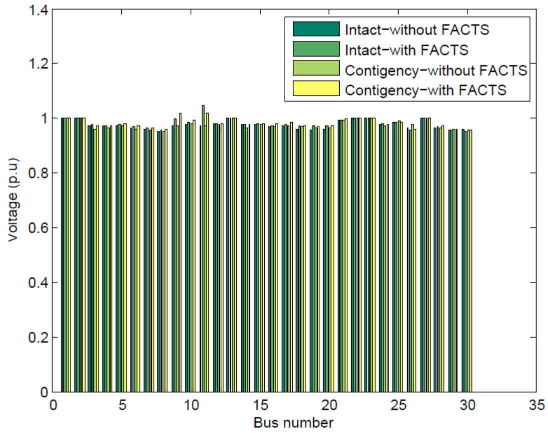

Fig. 4: Bus voltages for 30 bus system.

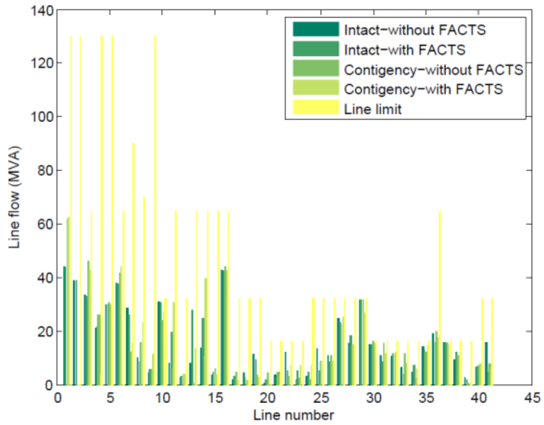

Fig. 5: Line flow for 30 bus system.

5.2 IEEE 118-bus System:

The system consists of 54 generators, 64 load buses, and 186 transmission lines. The system load is 4242 MW and 1438 MVAR. Bus 69 is taken as slack bus. Details of bus data and line data are available in MATPOWER (R.D. Zimmerman *et al*., 2011). Convergence characteristic of proposed method for IEEE 118-bus system is depicted in Fig. 4. For intact case, loadability limits of each load buses are presented in Table 4. Maximum loadability limit obtained for this system by proposed method is compared with different optimization techniques, is presented in Table 2. Loadability limit obtained by the proposed method is 7855.9MW which is better than result reported in (A. Shunmugalatha and S. Mary Raja Slochanal, 2008), (K. Gnanambal and C.K. Babulal, 2012).

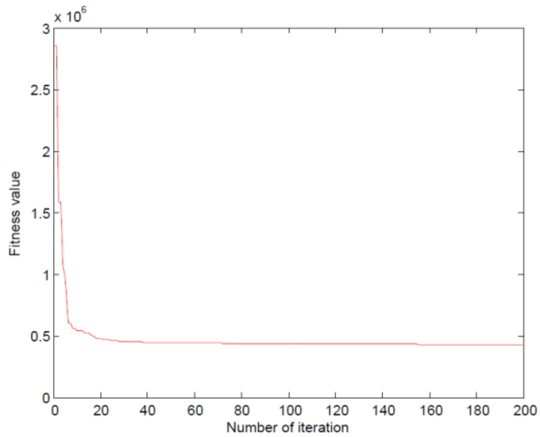

Fig. 6: Convergence characteristics of RCBBO for 118 bus system.

Table 4: Active power demand at each load buses for 118 bus system.

Bus No.	Without FACTS	With FACTS	Bus No.	Without FACTS	With FACTS
2	23.0586	79.9044	57	81.3289	45.4217
3	98.1735	96.9886	58	79.2579	43.4419
5	96.3530	86.8049	60	100.0000	96.6523
7	100.0000	99.9005	63	100.0000	95.9065
9	83.5788	78.0128	64	100.0000	94.3537
11	80.3167	85.8058	67	99.1669	100.0000
13	53.9803	75.3256	68	82.9532	89.0645
14	33.6117	89.5740	71	99.2755	98.6430
16	72.7967	48.3855	75	99.6552	98.0307
17	98.9483	95.0239	78	99.1639	73.1352
20	33.0375	63.0651	79	96.5270	100.0000
21	21.1931	4.7420	81	60.5157	93.8465
22	43.2734	15.5592	82	99.1433	84.7319
23	98.6558	80.9256	83	51.0489	77.0457
28	99.2395	99.3429	84	84.7483	64.9145
29	93.3293	97.0154	86	73.2564	97.0659
30	100.0000	98.2078	88	85.5662	86.3975
33	65.1049	89.8368	93	39.2316	96.5508
35	99.9795	95.6184	94	67.8757	91.8598
37	87.5565	97.0489	95	71.3100	96.1851
38	100.0000	83.4558	96	90.8709	85.2284
39	83.1275	99.8287	97	99.6233	99.7388
41	100.0000	85.3500	98	91.0107	99.2103
43	43.8970	62.4266	101	84.5546	78.3387
44	70.3243	63.4835	102	81.6207	80.5135
45	100.0000	59.1034	106	82.6082	96.7077
47	91.1520	98.1230	108	98.1115	66.3685
48	99.3886	100.0000	109	71.6877	95.4820
50	100.0000	50.2750	114	90.3965	97.6445
51	16.8021	16.4511	115	98.9341	99.5025
52	37.2497	28.5217	117	66.5761	3.3476
53	17.5923	34.2051	118	79.1353	99.6629

TTC is calculated by the proposed method with FACTS and without FACTS devices under intact case and contingency condition, results are presented in Table 5. Network TTC are 12947 MVA (without FACTS) and 13051 MVA (with FACTS) under intact case where TTC is limited by system voltage limit at bus 108 and 109 respectively. TTC is improved by connecting SVCs at buses 49 & 77 and TCSCs at lines 174 & 184.

Under contingency condition (transformer connected in line 5-8 is outage), network TTC is 12710 MVA (without FACTS) and 13335 MVA (with FACTS). TTC is improved by 5%, connecting SVCs at buses 45 & 51 and TCSC at lines 145 & 184. Power flow constraints of generator active power, reactive power and bus voltages are within the limits which are shown in Fig. 7 to 9 respectively.

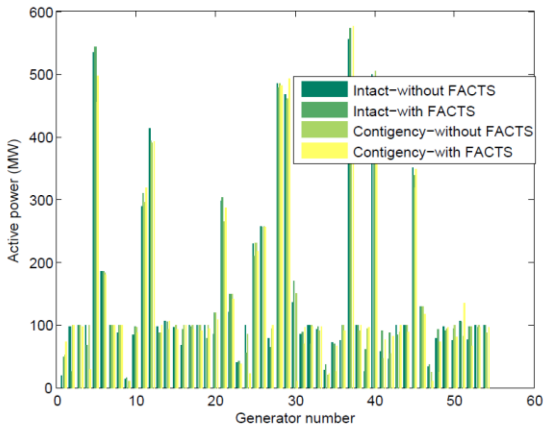

Fig. 7: Generator active power output for 118 bus system.

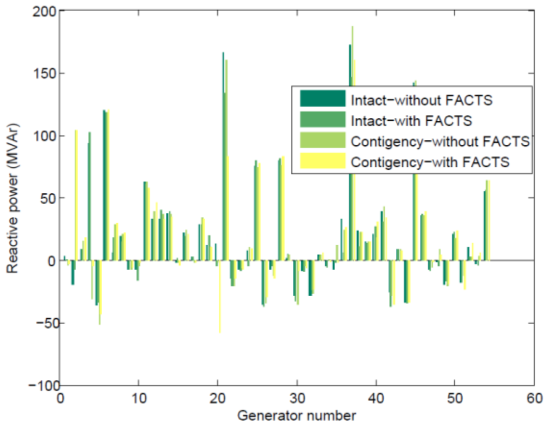

Fig. 8: Generator reactive power output for 118 bus system.

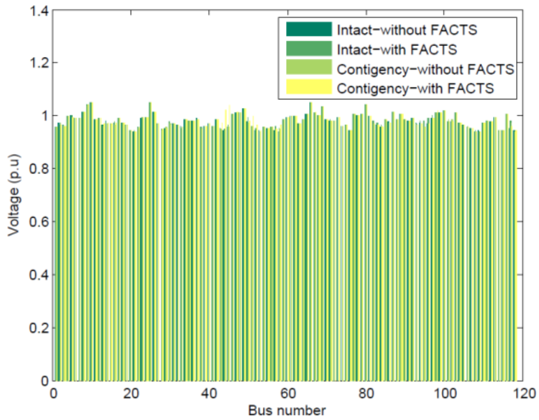

Fig. 9: Bus voltages for 118 bus system.

Table 5: Enhancement of TTC for 118 bus system.

Case	Loadability (MW)	TTC (MVA)	SVC		TCSC		Limiting point
			Bus location	Capacity (MVAR)	Line location	Level of compensation	
Intact without FACTS	7855.9	12947	-	-	-	-	Voltage at bus 108
Intact with FACTS	7892.3	13051	95,96	54.5651, 38.8503	141, 169	0.6,0.6	Voltage at bus 109
Contingency without FACTS	7644.7	12710	-	-	-	-	Voltage at bus 57
Contingency with FACTS	7674.7	13335	51,45	98.9971, 95.6895	145, 184	0.6,0.065	Voltage at bus 21

6. Conclusion:

In this paper, ARCBBO algorithm was successfully applied to OPF based enhancement of loadability limit and TTC of the power system. This algorithm is tested to be efficient in identifying the optimal location and size of FACTS devices for improvement of TTC in standard 30-bus and IEEE 118-bus systems under intact and contingency conditions. The solution quality of the proposed method is superior over other techniques reported in recent literature. This solution is very useful to independent system operator (ISO) in deregulated power system, because enhancement of total transfer capability may be used for future transaction in transmission system, against the investment of new transmission lines. Due to its simple framework, and smooth and quick convergence characteristics, the ARCBBO algorithm is suggested to be ideal to solve the multi-constrained large-scale power systems.

REFERENCES

Ajjarappu, V. and C. Christy, 1992. The continuation power flow: A tool for steady state voltage stability analysis, IEEE Transaction on Power System, 7(1): 416-423.

Bhattacharya, A. and P.K. Chattopadhyay, 2010. Biogeography-based optimization for different economic load dispatch problems, IEEE Transaction on Power System, 25: 1064-1077.

Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 41-50

Ejebe, G.C., J. Tong, J.G. Waight, J.G. Frame and X. Wang, 1998. Available transfer capability calculations, IEEE Transaction on Power System, 13(4): 1521-1527.

Farahmand, H., M. Rashidinejad, A. Mousavi, A.A. Gharaveisi, M.R. Irving and G.A. Taylor, 2012. Hybrid mutation particle swarm optimization method for available transfer capability enhancement, International Journal of Electrical Power and Energy Systems, 42: 240-249.

Ghawghawe, N.D. and K.L. Thakre, 2009. Computation of TCSC reactance and suggesting criterion of its location for ATC improvement, International Journal of Electrical Power and Energy Systems, 31: 86-93.

Gnanambal, K. and C.K. Babulal, 2012. "Maximum loadability limit of power system using hybrid differential evolution with particle swarm optimization," International Journal of Electrical Power and Energy Systems, 43: 150-155.

Irisarri, G.D., X. Wang, J. Tong and S. Mokhtari, 1997. Maximum loadability of power systems using interior point non-linear optimization methods, IEEE Transaction on Power Systems, 12(1): 162-172.

Khaburi, M.A. and M.R. Haghifam, 2010. A probabilistic modeling based approach for total transfer capability enhancement using FACTS devices, International Journal of Electrical Power and Energy Systems, 32: 12-16.

Nireekshana, T., G. Kesava Rao and S. Siva Naga Raju, 2012. Enhancement of ATC with FACTS devices using real-code genetic algorithm, International Journal of Electrical Power and Energy Systems, 43: 1276-1284.

North American Electric Reliability Council (NERC), 1997. Available transfer capability definitions and determination. NERC report.

Mohan Mathur, R. and Rajiv K. Varma, 2002. Thyristor –Based FACTS Controllers for Electrical Transmission Systems, John Wiley & Sons.

Ou, Y. and C. Singh, 2002. Assessment of available transfer capability and margins, IEEE Transaction on Power Systems, 17(2): 463-468.

Sawhney, H. and B. Jeyasurya, 2004. Application of unified power flow controller for available transfer capability enhancement, Electric Power Systems Research, 69: 155-160.

Shunmugalatha, A. and S. Mary Raja Slochanal, 2008. Maximum loadability of a power system using multi agent-based hybrid particle swarm optimization, Electric Power Components and Systems, 36: 575-586.

Simon, D., 2008. Biogeography-based optimization, IEEE Transaction on Evolutionary Computation, 12: 702-713.

Song, Y.H. and X. Wang, 2003. Operation of Restructured Power Systems. Operation of Market-Oriented Power System, Springer Verlag, 1: 1-12.

Wenyin Gong, Zhihua Cai, X. Charles and Ling Hui Li, 2010. A real-coded biogeography-based optimization with mutation, Applied Mathematics and Computations, 216: 2749-2758.

Xiao, Y., Y.H. Song and Y.Z. Sun, 2001. Application of unified power flow controller to available transfer capability enhancement, IEEE Power Engineering Review, 72: 66-68.

Xiao Ying, Y.H. Song, Liu Chen-Ching and Y.Z. Sun, 2003. Available transfer capability enhancement using FACTS devices, IEEE Transaction on Power Systems, 18(1): 305-312.

Zimmerman, R.D., C.E. Murillo-Sanchez and R.J. Thomas, 2011. MATPOWER: steady-state operations, planning and analysis tools for power systems research and education, IEEE Transaction on Power Systems, 26(1): 12-19.