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Bio Inspired Mutation based CFPSO to Optimize Size and Location of FACTS Device Under Generator Contingency

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Abstract: Reactive power is associated with voltage parameter. This parameter is a major concern in power systems due to unbalance between power generation and power demand. Due to accumulate in electricity demand, power loss and various factors; modern power system networks are being operated under highly stressed conditions. To meet reactive power requirement and maintaining the bus voltage within acceptable limits, the contribution of Flexible AC Transmission Systems (FACTS) controllers (Static Synchronous COMpensator (STATCOM) are vital. In this research work, the feeble buses under single generator contingency were recognized to uphold the reactive power compensators by executing new index approaches. The location and rating of STATCOM are the significant parameters, affecting network loss reduction and improving network performance. In this article, an investigation is accomplished to fix appropriate location and rating STATCOM to optimize the multi objective function as stated by bio inspired Gaussian mutation based Constriction Factor Particle Swarm Optimization (GM-CFPSO). Matlab/Simulink associated simulations confirmed the effectiveness of the proposed approach on IEEE 14 bus systems. The findings of the simulation revealed that, the optimum placing and sizing of STATCOM improved greatly the voltage stability margin and curtailment in power loss of the network.

Keywords: Mutation; Optimization; Power loss; PSO; STATCOM; Voltage stability.

INTRODUCTION

Electric power is the backbone of a country's economy and its industrial growth. Recently, it is observed that, growing industrialization along with the rapid urbanization of society outcomes dramatic increase in electric power demand. Due to this, few branches had been overloaded or objectionable fall in voltage profile of buses forcing the system towards instability region and possibly even a black out Hence, voltage stability had become one of the most sensitive issues in power systems planning and operation [1]. To meet the high quality of customer service, magnitude of load voltage must be retained within the permissible range. Voltage stability problems are highly associated with the reactive power imbalance [2]. In India, approximately 30% to 35% of generated electric power had been lost while it was transmitted to consumer terminals. Transmission power loss is inter-related with terminal voltage profile. Hence, for a reliable operation of any power system, the voltage deviations and power transmission losses should to be minimized as much as possible [3].

Captivating numerous criteria like environmental and political issues, time consumption to install new plants and transmission lines, investment cost into consideration, a perceptive solution would be the employment the FACTS devices in the existing network[4,5]. These emerging devices primarily to improve the overall voltage profile of entire system. Secondly, the transmission line losses are alleviated. Therefore, it's a reduction in cost of the power generation [6].

The distinct objective of the research work is to curtail the transmission line losses (real and reactive power losses), improve system stability margin, a progress in voltage profile. The stated targets can be

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achieved either by construction of new power plants, electrical power transmission lines or else by employing FACTS devices –STATic Synchronous COMpensator (STATCOM) at appropriate site in the power system network [7-9].

The most common asperities associated with accomplished methods are: non-linearity, non-convexity, convergence depends on initial starting point, algorithmic complexity, high execution time, convergence speed, search process is trapped at local minima and sometimes the solutions obtained by these methods fail to provide the global optima [10-12]. From the pitfalls of classical methods stated above, traditional methods were not favoured to solve the multi objective problems.

Population-based techniques are facilitating to overcome the snag of classical optimization techniques [13-15]. For the research article, Particle Swarm Optimization (PSO) approach and its variants had been addressed to solve multi objective problem. In multi objective problem, three cases: loss minimization; voltage profile improvement; voltage stability augmentation are deemed to gauge the performance of the PSO approaches.

A well known stability indices (VSI) including voltage collapse proximity indicator (VCPI) [16-19] and Contingency Severity Index (CSI)[20-22] have been consolidated to originate a Unification_ Index (U_I) to guess bus voltage deviation of the system for the right appraisal of severity in this study to identify the most suitable locations in the given network for optimal placement of STATCOM. The United Index is gauged during outage of single generator bus. With respect to index value, the ranking of severe lines is made. The appropriate location for placement of STATCOM had been identified among the severest bus to diminish voltage deviation of buses to augment the voltage stability margin in the power system.

Moazzami.M in ref.[23] portrayed the payment of Adaptive PSO (APSO) algorithm to suppress the limitations of a classic PSO. The shunt and series type devices have been incorporated under frequency load shedding. In this regard, the most cost-effective VAR generation by parallel FACTS devices is the foremost objective of using the APSO algorithm in standard IEEE 30 bus systems. Amongst, STATCOM had done exceptional performance.

In this study [24], Esmin urged a Hybrid PSO (HPSOM) algorithm is an amalgamation of PSO with arithmetic mutation for loss minimization. The study had been investigated in two phases. In the first phase, by executing tangent vector technique, the most severe area of the power system had been acknowledged with the voltage instability factor. In the phase two, the PSO approach had been enforced to assess the amount of shunt VAR compensation of each bus.

In the paper published by Sarathkumar et al. [25], Gravitational Search Algorithm (GSA) was addressed to place FACTS devices optimally such as -TCSC, SVC and UPFC. The locality of these devices favoured with respect to security indexes (voltage stability, line power flow, dropping of power losses and the device cost). The potency of this methodology was tested on IEEE 30 and 57 bus systems.

Anwar A.Siddiqui et al [26], portrayed a perception of Improved GSA (IGSA) to curtail the computational complexity of traditional GSA algorithm by revising velocity and position of the particles. This scheme is employed to pinpoint apt location and rating of UPFC to enhance power transfer capacity of IEEE-57 bus system. The simulation outcomes were enumerated with GSA to authenticate its superior performance.

The settings of FACTS devices were achieved through Constriction Factor based PSO (CFPSO) scheme. To augment the performance of the CFPSO approach a mutation has incorporated - called Cauchy Mutation based CFPSO (CM-CFPSO) and Gaussian Mutation based CFPSO (GM-CFPSO). In these proposed schemes, a new-fangled position equation of the particle had been framed.

To authenticate the implication of proposed approach such as CFPSO and CFPSO with mutations, IEEE 14 bus system was chosen to assess the potency of the propound method using MATLAB working podium under the interruption of single generator bus during the phase of absence and existence of the FACTS device. The consequence of weight coefficient, C_1 and C_2 and the phenomenon of population size on the concrete of this research are also scrutinized. Appraisals were made in provisions of eminence solution and stable convergence behaviour. The proposed approach delivered promising result and encouraging in terms of reduction in real power loss and significant improvement in voltage stability (drop in UI) and voltage profile of the system after employing the FACTS devices.

The remaining part of the research article is structured as follows: Section 2 describes about formulation of index (Unification_Index); Section 2 addresses the works related to problem formulation and constraints are introduced. In Section 4, the description of the proposed approach is presented in detail. In Section 5, simulation results were discussed and analyzed and finally a brief conclusion is drawn in Section 6.

FORMULATION OF INDEX – UNIFICATION_INDEX (U_I)

After finding the VCPI[16-19] and CSI[20-22] values of all the transmission for a particular line outage, the UI is evaluated as given in equations (1) and (2).

$$U\_I_{cd} = M_1 * CSI_{cd} + M_2 * VCPI_{cd} \quad (1)$$

$$U\_I_{Gross} = \sum_{\substack{c=1 \\ c=PQbus}}^{c=N_{PQ}} \left(UI_{cd} \right) \quad (2)$$

$$M_1 + M_2 = 1 \quad (3)$$

Where, M_1 & M_2 are the weighting factors of the two indices for line c-d.

PROBLEM STATEMENT

The augmentation of voltage stability periphery is one of the most crucial and demanding quandary in power system environment.

The concept of cultivating the voltage stability and minimization of line losses by erecting FACTS devices using PSO & proposed approaches were addressed here. In the research work, STATCOM is inspected to encounter the above objectives. The source code was developed in MATLAB software package for power/load flow analysis using (N-R) method. The parameters of STATCOM were incorporated into power/load flow equation.

The multi objective problems accords with the research study are: curtailment in sum of voltage deviation; Voltage stability augmentation (Reduction in sum of U_I); deterioration of active and reactive power losses.

Power balance constraints are treated as equality constraints. Inequality constraints, such as active power output of generating units, generator reactive power, voltages of all generator buses(PV bus) and load bus (PQ bus); power flows between transmission lines and finally, susceptance rating of STATCOM. The objective value found from the proposed technologies must satisfy all the constraints.

Minimization sum of Voltage Deviation Index (F_1)

To persist voltage deviations at the load side within ±5%, the first objective is to diminish the sum of voltage deviation index of the load buses (PQ bus). It is denoted by equations (4) and (5).

$$VV_g = \begin{cases} \text{Zero(0) if } 0.95 \le V_h \le 1.05 \\ \left(1 - V_h\right)^2 * P \text{ if } 0.9 \le V_b \le 0.95 \text{ or } 1.05 \le V_h \le 1.1 \end{cases} \quad (4)$$

$$VD\_I = \sum_{h=1}^{h=N_{PQ}} \left(VV_g \right) \quad (5)$$

Where,

V_h = Voltage magnitude at load bus h; P = a small positive constant; N_{PQ}= Total number of load buses; VD_I = Sum of voltage deviation index.

Minimization of sum of U_I (F_2)

Stability of voltage parameter is a paramount concern in electrical utilities. U_I is an effective quantitative measurement to predicate contemporary circumstances of the system with respect to voltage collapse point.

Minimization of the total (U_IGross) is the second objective function to refine the overall voltage stability of the system. It was stated mathematically in equation (2).

Minimization of real power loss (F_3)

This objective function is enforced to diminish total active power losses and is given in equation (6).

$$AP\_L = \sum_{i=1}^{i=N_{br}} G_{cd} \left(V_c^2 + V_d^2 - 2V_c V_d \cos\left(\delta_c - \delta_d\right) \right) \quad (6)$$

Where,

AP_L	Active power loss
G_{cd}	Conductance of the branch c-d
$\delta_c - \delta_d$	Load angle at bus c and d.

Minimization of reactive power loss (F_4)

This objective function had emphasizedd to curtail total reactive power losses and is given in equation (7).

$$RP\_L = \sum_{i=1}^{i=N_{br}} B_{cd}\left(V_c^2 + V_d^2 - 2V_c V_d \sin\left(\delta_c - \delta_d\right)\right) \quad (7)$$

Where,

RP_L	Reactive power loss
B_{cd}	Susceptance of the branch c-d
$\delta_c - \delta_d$	Load angle at bus c and d.

Overall objective function is framed as Equation (8)

$$\textbf{Overall objective function (f)} = \mathbf{VD\_I + U\_I_{Gross} + AP\_L + RP\_L} \quad (8)$$

The objective function of the problem statement = min(f) (9)

The objective function f is subjected to the following equality constraint (Power balance constraint). The equations (10) and (11) mentioned below shows power balance equation.

$$P_{gc} - P_{dd} - \left|V_c\right|\sum_{c=1}^{NB}\left|V_d\right|(G_{cd}\cos\theta_{cd} + B_{cd}\sin\theta_{cd}) = 0 \quad (10)$$

$$Q_{gc} - Q_{dd} - \left|V_c\right|\sum_{c=1}^{NB}\left|V_d\right|(G_{cd}\sin\theta_{cd} + B_{cd}\cos\theta_{cd}) = 0 \quad (11)$$

The objective functions f subjected to the following inequality constraint are represented in equations (12) and (13)

$$P_{gc}^{min} \le P_{gc} \le P_{gc}^{max} \text{ for } c = 1, 2, \ldots..n \text{ generator bus} \quad (12)$$

$$a = 1,\ Q_{gc}^{min} \le Q_{gc} \le Q_{gc}^{max} \text{ for } c = 1, 2, \ldots..n \text{ generator bus} \quad (13)$$

Bus voltage limits

$$0.95 \le V_c \le 1.05 \text{ for } c = 1, 2, \ldots..n \text{ load bus} \quad (14)$$

$$0.95 \le V_c \le 1.1 \text{ for } c = 1, 2, \ldots..n \text{ generator bus} \quad (15)$$

Susceptance of STATCOM Constraint

$$-0.9 \le B_{STAT\_COM} \le 0.9 \text{ in p.u} \quad (16)$$

Where,

Y_{cd} & θ_{cd} are the magnitude and phase angle of bus admittance matrix
P_{gc} & Q_{gc} are the active and reactive power generation at bus c
P_{gc} & Q_{gc} are the active and reactive power load at bus c
V_c & V_d are the voltage magnitude at bus c and bus d
B_{STAT_COM} is Susceptance added to the bus by STATCOM

The objective value of the each particle in the swarm should be within a feasible range. Prior to estimating the value of the objective function value of a particle, the susceptance assessment of STATCOM must satisfy the constraints given in equations (10-16).

PARTICLE SWARM OPTIMIZATION (PSO)

Historical Background

Particles Swarm Optimization is a population-based search algorithm. Here, population is described as swarm, and each entity/agent is labelled as particle. It replicates sociological manners associated with bird flocking and fish schooling [27].

Constriction Factor PSO (CFPSO) Approach

Clerc et al [28] was made an amendment in the velocity equation by annexing a new phrase called as the constriction factor to wash out early convergence in the optimization process. The flow chart of this scheme is shown in Figure 1.

$$V^1[\ ]=C\_F\{W*V[\ ]+C_1*U\_R_{(0,1)}*\left(P_{\_best}[\ ]-X[\ ]\right)+C_2*U\_R_{(0,1)}*\left(G_{\_best}[\ ]-X[\ ]\right)\} \quad (17)$$

$$X^1[\ ]=X[\ ]+V^1[\ ] \quad (18)$$

$$V_{max\_l}\leq V^1[\ ]\leq V_{min\_l} \quad (19)$$

$$C\_F=\frac{2}{\left|2-\rho-\sqrt{\rho^2-4*\rho}\right|}\ \text{Where},\rho=C_1+C_2, 4.1\leq\rho\leq 4.2 \quad (20)$$

$$C_1=\left(C_{1e}-C_{1s}\right)*\frac{Pre\_run}{max\_run}+C_{1s}\ \ \&\ \ C_2=\left(C_{2e}-C_{2s}\right)*\frac{Pre\_run}{max\_run}+C_{2s} \quad (21)$$

Where,

V[ ] & X[ ]	=	Velocity and position of the particle of present generation
W	=	Inertia weight of the particle
V^1[ ] & X^1[ ]	=	Velocity and position of the particle in next generation
$P_{\_best}$[ ]	=	Particle with best objective value in the present generation
$G_{\_best}$[ ]	=	Particle with best objective value until the present generation
$U\_R_{(0,1)}$	=	Random numbers generated between zero and one

A scaling factor S is established in equations (22) to get minimum and gradual deviation in velocity. Dissimilar values of S were explored. After numerous trials, S = 1.45 had elected and it furnished better results. Through the equation (22), convergence performance is enriched. Similarly, it takes less execution time to conquer optimal solution.

$$V_{max\_l}=S\left(\frac{V_{high}-V_{low}}{2}\right)\quad \&\quad V_{min\_l}=-S\left(\frac{V_{high}-V_{low}}{2}\right) \quad (22)$$

Where,

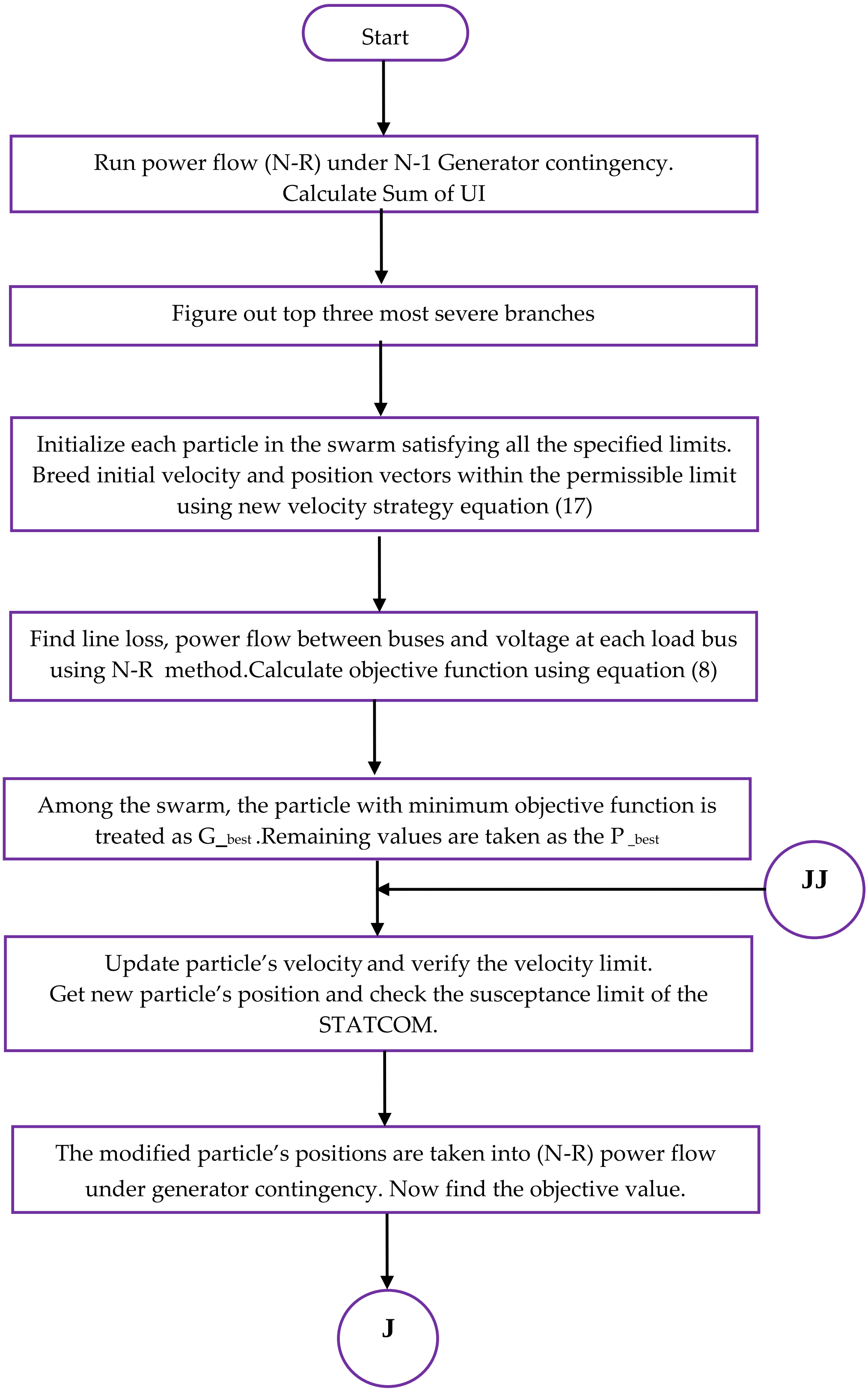
V_{max_l} and V_{min_l}	=	Particle's maximum and minimum velocity boundary
S	=	Scaling factor
V_{high} and V_{low}	=	Sum of maximum voltage limit and minimum voltage limit of load bus

Mutation is a some sort of artificial diversification in the population to circumvent untimely convergence. The primary task of the mutation operators is to improve the quality of solution through global search capacity and speed of convergence and offered global minimal solutions.

In the research work, Gaussian and Cauchy mutation operators were incorporated with particle's position equation of the CFPSO approach and branded as Gaussian Mutation-CFPSO (GM-CFPSO) and Cauchy Mutation-CFPSO (CM-CFPSO). Since the accomplishment of the recommend approaches highly relies on input parameters. The best input control parameter values of different approaches are indexed in Table 1.

Table 1: Initial parameter values for various approaches

Control Parameter	PSO	CPSO	CM-CFPSO	GM-CFPSO
Population size	10, 20 & 50	10, 20 & 50	10, 20 & 50	10, 20 & 50
Max. No. of generation	100	100	100	100
W_{max} & W_{min} (Linearly decreasing)	0.9 & 0.35	0.9 & 0.35	0.9 & 0.35	0.9 & 0.35
C_1	2	C_{1s}=2.5	C_{1s}=2.5	C_{1s}=2.5
	-	C_{1e}=0.5	C_{1e}=0.5	C_{1e}=0.5
C_2	2	C_{2s}=0.5	C_{2s}=0.5	C_{2s}=0.5
	-	C_{2e}=2.5	C_{2e}=2.5	C_{2e}=2.5
Convergence criterion	Minimum 30 runs			


Start
Run power flow (N-R) under N-1 Generator contingency. Calculate Sum of UI
Figure out top three most severe branches
Initialize each particle in the swarm satisfying all the specified limits. Breed initial velocity and position vectors within the permissible limit using new velocity strategy equation (17)
Find line loss, power flow between buses and voltage at each load bus using N-R method.Calculate objective function using equation (8)
Among the swarm, the particle with minimum objective function is treated as G_best .Remaining values are taken as the P _best
JJ
Update particle's velocity and verify the velocity limit. Get new particle's position and check the susceptance limit of the STATCOM.
The modified particle's positions are taken into (N-R) power flow under generator contingency. Now find the objective value.
J

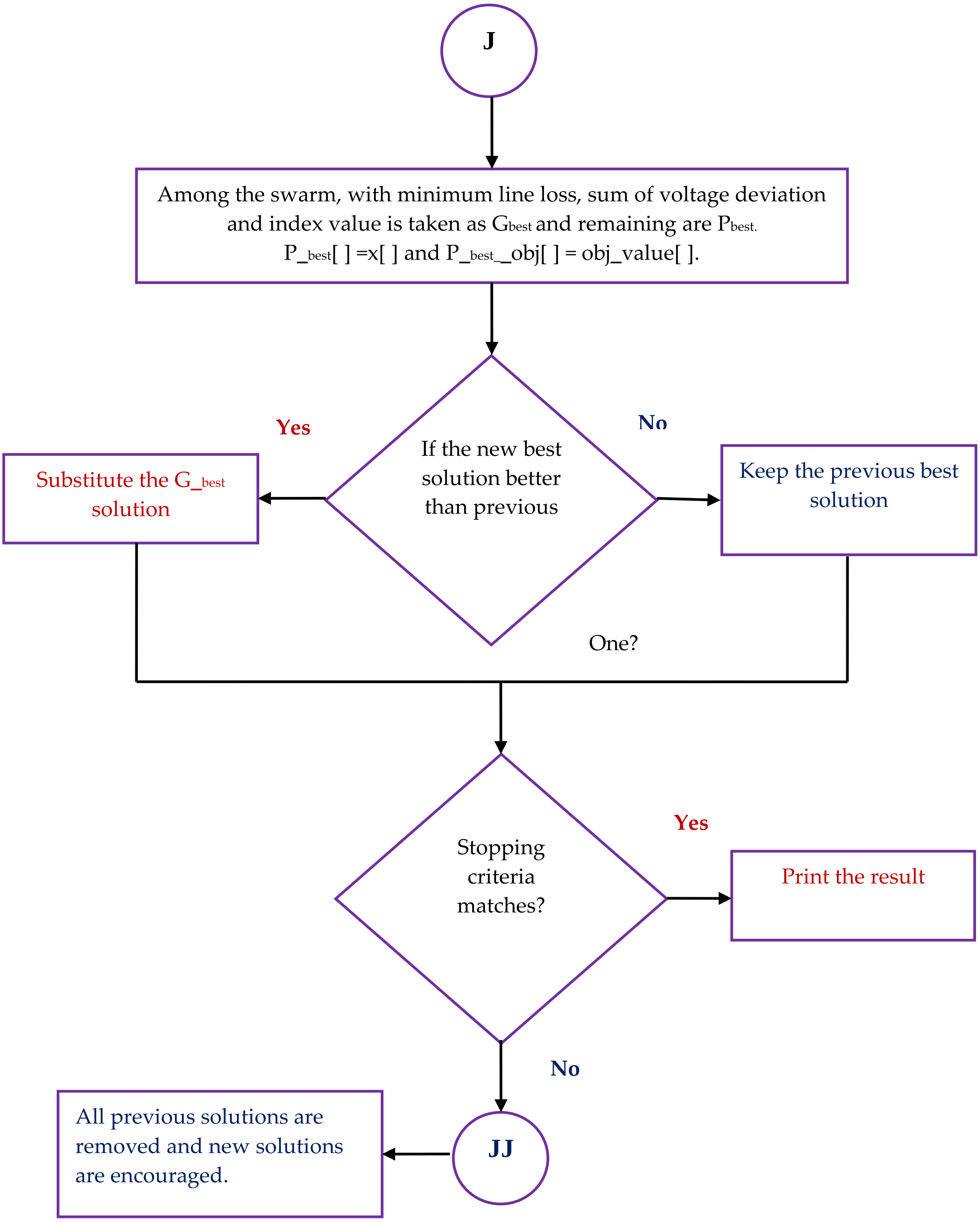


Figure 1: Flow chart of CFPSO approach

Search Procedure of Cauchy Mutation - CFPSO (CM-CFPSO) Approach

The amendment in explore point $X^1[\ ]$ is commenced from the each particle by augmenting each component X[ ] with a Cauchy random variable as given in equation (23).

$$X'[\ ] = X[\ ] + \sigma_i^2 C_i\ (0,1) \qquad (23)$$

Where,

C_i is a Cauchy random variable with a scale parameter with t = 1 centred at zero.

This variable has mean of zero and a standard deviation of σ_i.

Search Procedure of Gaussian Mutation -CFPSO (GM-CFPSO) Approach

The amendment in explore point X1[ ] is commenced from the each particle by augmenting each component X[ ] with Gaussian random variable as shown in equation(24).

$$X^{'}[\ ] = X[\ ] + N_i(0, \sigma_i^2) \quad (24)$$

Where,

$N_{(i)}(0, \sigma_i^2)$ – Gaussian random variable with mean of zero and a standard deviation

RESULT AND DISCUSSION

An IEEE 14 bus system has totally five generator buses (bus 1 is termed as slack bus 2, 3, 6 and 8 are PV buses) fourteen PQ buses and twenty transmission lines. Among these, three transmission lines (4-7), (4-9) and (5-6) are with tap changing transformers. Each of the four generator buses was isolated from the network sequentially for the purpose of contingency analysis. Using N-R power flow method, the performance of the generator outage was indexed in Table 2. It was noticed that, for instance, termination of generator bus number 2. The branch 2-3 had the peak U_I value, was the severe-most line of the system. However, bus 2 and 3 are generator buses. In this research study as per norms, the best location for installing STATCOM should be a load bus. For the same, the second most sever line 12-13 are taken from Table 3. The STATCOM is located at the bus number of 12 delivered best results among all.

Table 2: Generator Contingency analysis on IEEE 14 bus network

S.No.	**Generator bus Number**	**∑ of UI**
1	2	0.554
2	6	0.552
3	8	0.549

Table 3: Generator Contingency analysis (outage of bus no. 2) IEEE 14 bus network

S.No.	**Transmission line**		**∑ of UI**
	Starting bus	**Ending bus**	
1	**2**	**3**	0.076
2	12	13	0.0463
3	5	6	0.037
4	13	14	0.034

The footprint of STATCOM on voltage magnitudes of IEEE 14 bus system during omission and existence of STATCOM (post outage of generator bus number 2) were tabulated in Tables 4. The graphical analysis of the Table 4 is shown in Figure 2.

Table 4: Bus voltage magnitude (p.u) without & with STATCOM compensation (During outage of generator bus number 2)

Bus No.	**Base Case**	**Bus voltage without STATCOM**	**Bus voltage with STATCOM**
1	1.06	1.06	1.06
2	1.045	1.025	1.028
3	1.01	1.01	1.01
4	1.018	1.009	**1.0097**
5	1.02	1.011	**1.014**
6	1.07	1.07	1.07
7	1.06	1.058	**1.054**
8	1.09	1.09	1.09
9	1.056	1.052	**1.048**
10	1.051	1.048	**1.049**
11	1.057	1.055	**1.048**
12	1.055	1.0549	**1.0498**
13	1.05	1.049	**1.048**
14	1.03	1.033	**1.0339**

Table 5: Comparison of system parameters based on population size 10 25 and 50 with various approaches

S. No	Parameters	W/o contingency	With contingency @ bus no. 2	With STATCOM @ bus no. 12 (Population size 10)				With STATCOM @ bus no. 12 (Population size 25)				With STATCOM @ bus no. 12 (Population size 50)			
				Different approaches				Different approaches				Different approaches			
				PSO	CFPSO	CM-CFPSO	GM-CFPSO	PSO	CFPSO	CM-CFPSO	GM-CFPSO	PSO	CFPSO	CM-CFPSO	GM-CFPSO
1	P_G (MW)	273.93	275.07	273.58	273.36	273.21	**272.86**	273.51	273.25	273.13	**272.77**	273.51	273.25	273.13	**272.77**
2	P_D (MW)	259	259	259	259	259	259	259	259	259	**259**	259	259	259	**259**
3	P_L (MW)	14.93	16.07	14.58	14.36	14.21	**13.86**	14.51	14.25	14.13	**13.77**	14.51	14.25	14.13	**13.77**
4	P_S (KW)	0	0	1490	1710	1860	**2210**	1560	1820	1940	**2300**	1560	1820	1940	**2300**
5	Q_G (MVAr)	135.87	137.05	135.36	135.18	134.89	**134.52**	135.28	135.09	134.8	**134.46**	135.28	135.09	134.8	**134.46**
6	Q_D (MVAr)	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	**73.5**	73.5	73.5	73.5	**73.5**
7	Q_L (MVAr)	62.38	63.56	61.86	61.68	61.39	**61.02**	61.78	61.59	61.3	**60.96**	61.78	61.59	61.3	**60.96**
8	Q_S (KVAr)	0	0	1697.7	1877.7	2164.15	**2536.46**	1777.7	1967.7	2257.7	**2597.7**	1777.7	1967.7	2257.7	**2597.7**
9	VCPI of severe line (p.u)	0.091	0.0927	0.0923	0.092	0.0916	**0.091**	0.0921	0.0912	0.0914	**0.0902**	0.0921	0.0912	0.0914	**0.0902**
10	U_I of severe line (p.u)	0.048	0.0484	0.0471	0.0469	0.0467	**0.0464**	0.0470	0.0465	0.0466	**0.0460**	0.0470	0.0465	0.0466	**0.0460**
11	∑U_I (p.u)	0.543	0.554	0.552	0.548	0.545	**0.5401**	0.551	0.545	0.542	**0.5398**	0.551	0.545	0.542	**0.5398**
12	∑VDI	-	2.878	2.876	2.873	2.869	**2.862**	2.875	2.8715	2.865	**2.858**	2.875	2.8715	2.865	**2.858**
13	Elapsed time (s)	0.015	0.01	8.4	10.2	12.4	11.3	15.01	19.5	24.18	20.51	15.01	19.5	24.18	20.51

P_G and P_D– Real power generation and demand; P_S and Q_S Real power and reactive power saving; P_L and Q_L Real power and reactive power loss

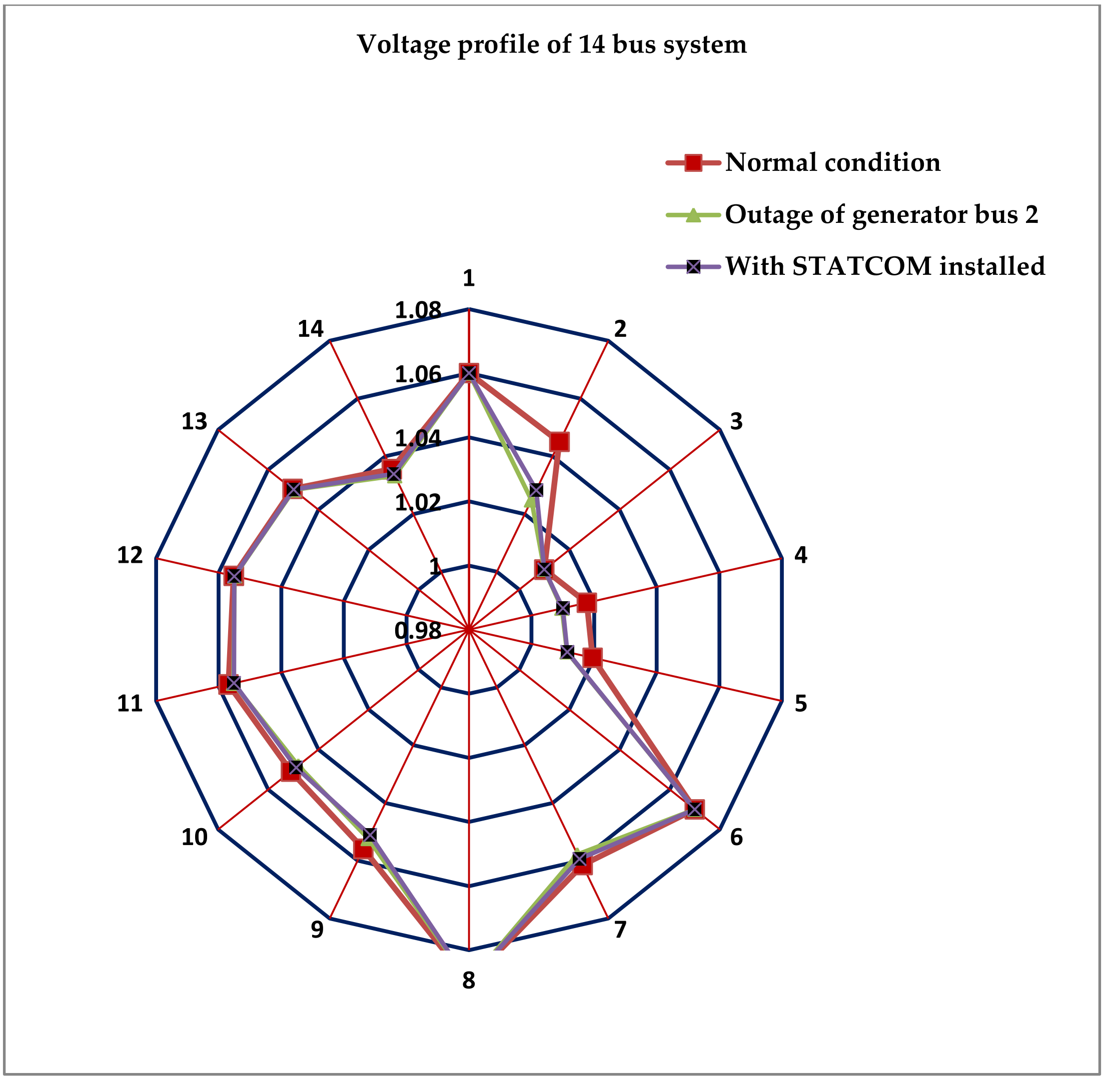


Figure 2: Comparison of voltage profile of IEEE 14 bus network during different scenarios

STATCOM susceptance parameter was fine-tuned using PSO and with mutation. The outcomes (with population size of 10, 25 and 50) had put forwarded in Table 5. On account of generator 2 outage (with respect to population size of 50), total active and reactive power loss were stimulate from 14.93MW and 134.87.56MVAR to 16.07MW and 163.56MVAr respectively. Subsequent to the placement of STATCOM at bus number 24, in respect of population size - 50, using PSO, CFPSO and CM-CFPSO the active power losses diminish to 14.48MW, 14.13MW and 14.02MW respectively. Similarly, the reactive power descended to 135.39MVAr, 134.98MVAr and 134. 71MVAr. Tuning of STATCOM using GM-CFPSO further curtailed the losses to 13.58MW and 134.32MVAr respectively. Similarly, other parameters of the system also squashed to least values when PSO and with mutation was implemented through amendment in susceptance of STATCOM.

From the Tables 5 it is extrapolated that, GM-CFPSO attained best power loss reduction, power saving, progress in stability margin analogized to other methodologies. The graphical analyses with respect to voltage stability margin, summation of voltage deviation index were represented in Figures 3 and 4. Investigation based on the population size (50), a power loss curtailment through traditional PSO, CFPSO, CM-CFPSO were 9.89%, 12.07%, and 12.75%. However, GM-CFPSO achieved power loss reduction of 15.49% from the initial system loss. The GM-CFPSO approach took more execution time compared with other methods but the optimal solution accomplished by GM-CFPSO is fantabulous to others.

The graphical analyses of the power loss reduction were revealed in Figures 5 to 8. From the graphs it is inferred that, using GM-CFPSO the amount of active and reactive power saving are 2490KW and 2737.7KVAr respectively; whereas, in other approaches the power saving were less. Among all, GM-CFPSO scheme offered minimum power loss hence power generation also condensed.

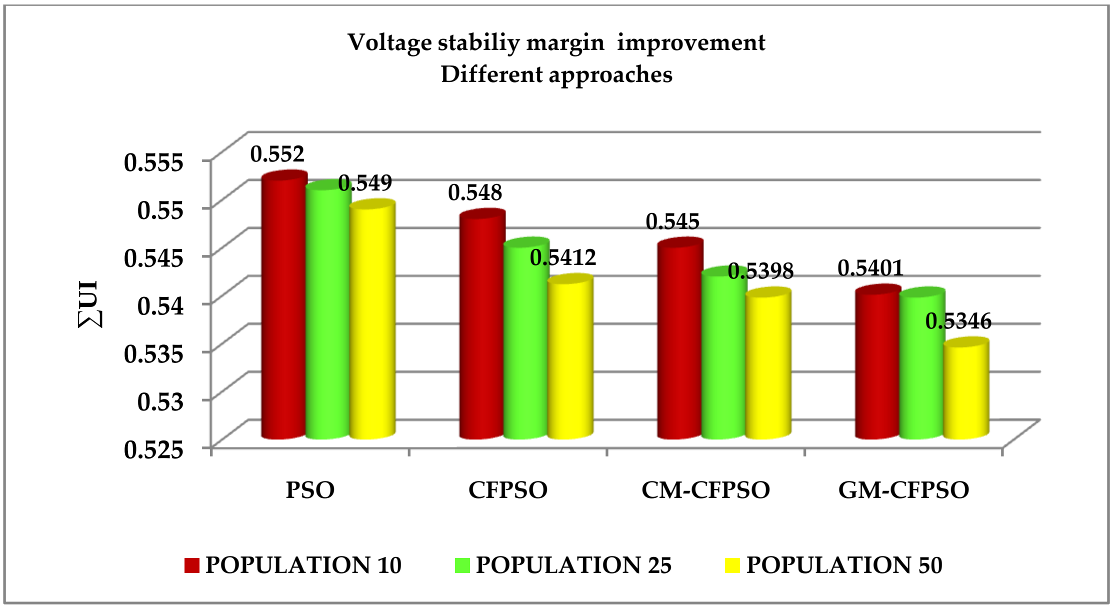


Figure 3: Voltage stability margin improvements – different approaches

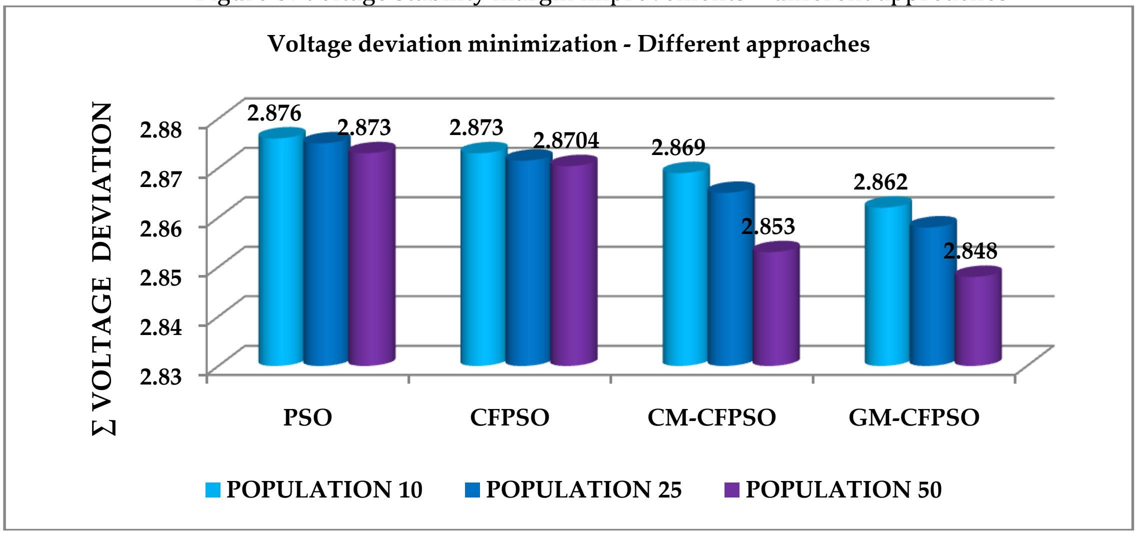


Figure 4: Voltage deviation index – different approaches

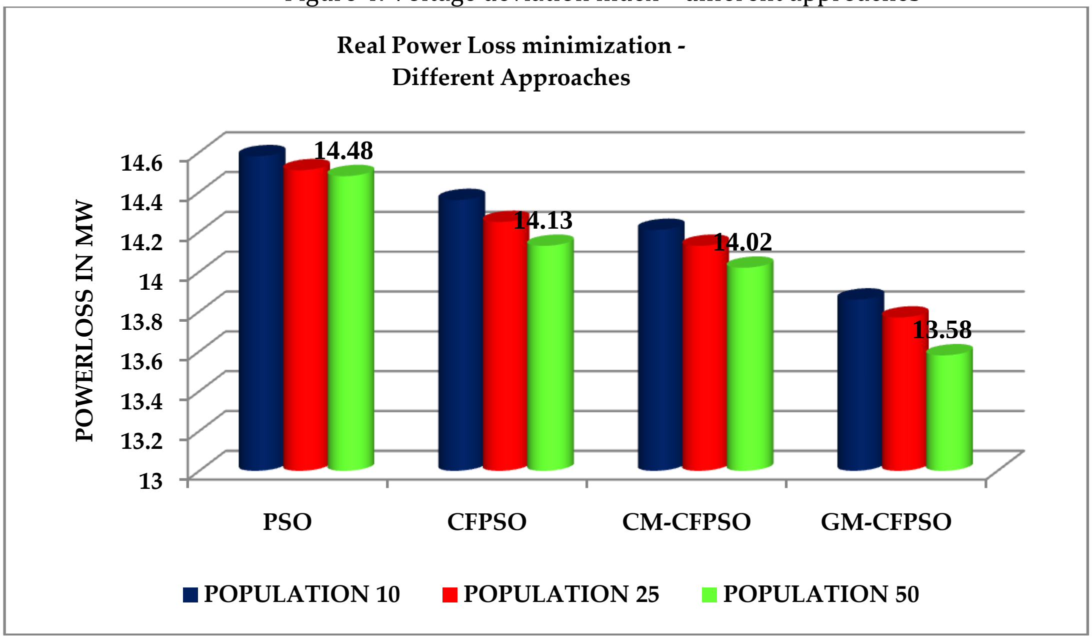


Figure 5: Comparison of real power loss of IEEE 14 bus network with different approaches

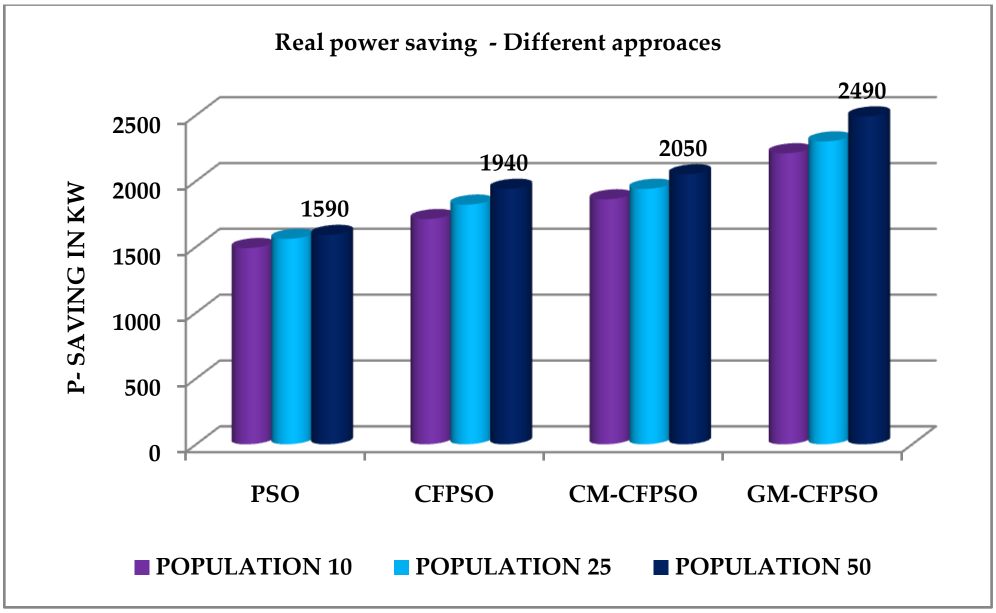


Figure 6: Comparison of real power saving of IEEE 14 bus networks with different approaches

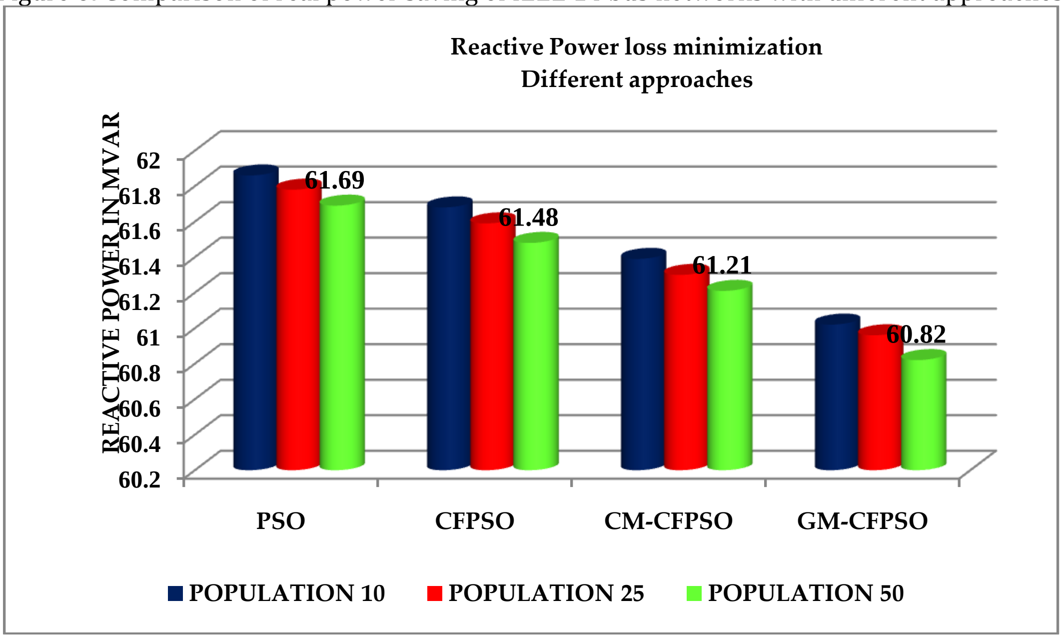


Figure 7: Comparison of reactive power loss of IEEE 14 bus network with different approaches

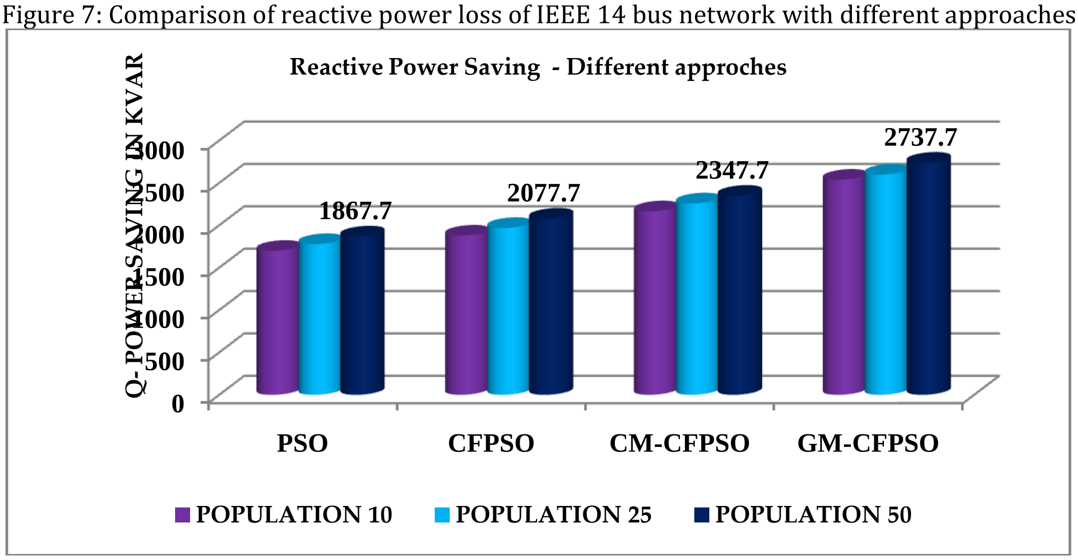


Figure 8: Comparison of reactive power saving of IEEE 14 bus network with different approaches

Figure 9 depicted the graphical outcomes of competitor's convergence properties (objective function versus iteration). From the Figure 9, it is inspected that, the objective function is progressively reduced as the iteration count magnified. At the concluding part of the approach, it converged with minimal objective value, i.e., the optimal location and size of STATCOM for each case. PSO converged at 58 iterations with an objective value of 105.55. The CFPSO approach converges earlier than the conventional PSO (at 53rd iterations), with an objective value of 104.25. The CM-CFPSO approach converged swiftly at 38th iterations with a minimum objective value of 103.2 respectively. The GM-CFPSO is the fastest among all competitors accomplish a minimum value of 102 at 33th run of 42nd iteration.

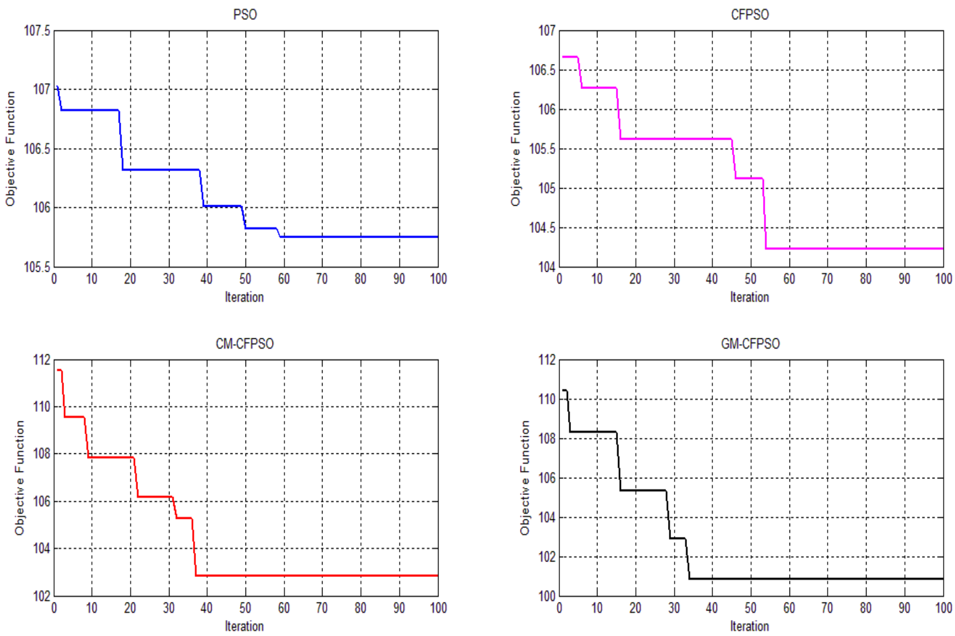


Figure 9: Convergence histories of best solutions of different approaches after installation of STATCOM

The outcomes of optimal location and sizing of STATCOM had been observed for IEEE 14 bus system using PSO, CFPSO, CM-CFPSO and GM-CFPSO approaches and it is shown in Tables 6.

Table 6: Optimal placement and Susceptance rating of STATCOM during generator contingency in IEEE 14 bus using different approaches

Generatorbus outage	**PSO**		**CFPSO**		**CM-CFPSO**		**GM-CFPSO**	
	Location	**Susceptance rating (p.u)**	**Location**	**Susceptance rating(p.u)**	**Location**	**Susceptance rating(p.u)**	**Location**	**Susceptance rating(p.u)**
Outage of PV bus 2	13	0.0983	13	0.0972	12	0.096	12	0.081

CONCLUSION

An investigation had been accomplished to curtail 1.Line losses 2. Sum of voltage deviation and to augment voltage stability margin by using shunt family FACTS device- STATCOM during the outage of a single generator bus. This device was appended at most severe bus via PSO; CFPSO,CM-CFPSO & GM-CFPSO were submitted. The most critical buses were recognized through a novel approach called Unification Index (U_I). MATLAB codes for PSO, CFPSO, CM-CFPSO & GM-CFPSO were drafted to diagnose the opportune position and sizing of STATCOM in order to meet the desire objectives. The analysis had been carried out with respect to population size as well as following dynamically varying parameters: learning factor and inertia weight. The potency of the proposed GM-CFPSO approach was investigated on a standard IEEE 14 bus system. The main conclusion can be drawn from this research is that; 1. Comparative result shows the proposed approach is competent. 2. Convergence of the objective function is with fewer numbers of iterations in GM-CFPSO compared with other schemes. Hence this proposed scheme is highly suitable for optimal location and susceptance rating of STATCOM.

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