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Generalized Unified Power Flow Controller for Optimal Reactive Power Dispatch by Considering Practical Constraints

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Abstract

Objectives: One of the drawbacks of the power system network, i.e. Optimum Reactive Power Dispatch (ORPD) is optimized. Due to this, system transmission power losses and bus voltage magnitudes are optimized **Methods/Statistical Analysis:** A unique optimization rule, Uniformly Distributed Two-stage Particle Swarm Optimization (UDTPSO) are enforced in conjunction with the traditional Particle Swarm Optimization (PSO).The power injection model for the Generalized Unified Power Flow Controller (GUPFC) is used to enhance the power flow in a power system network. **Findings:** The proposed technique has fast convergence rate in less number of iterations which validates the effectiveness of UDTPSO. The study is tested on a standard IEEE-30 bus system and the results obtained with UDTPSO are valid with the existing PSO. **Applications:** Effective utilization of a Flexible Alternating Current Transmission system (FACTS) device called Generalized Unified Power Flow Controller (UPFC) for power flow control which will improve existing transmission capability.

Keywords: Generalized Unified Power Flow Controller, Loss Minimization, Optimal Reactive Power Dispatch, Uniformly Distributed Two Stage Particle Swarm Optimization, Voltage Deviation

1. Introduction

The one amongst the very important subproblems with Optimal Power Flow (OPF) to improve the protection and economical operation of the power system is Optimal Reactive Power Dispatch (ORPD). Linear adaptive genetic algorithmic program[1], Interior linear-quadratic programming[2] and plenty of mathematical programming approaches[3] are used to solve ORPD and OPF problems. Evolutionary Programming (EP) in[4] is applied to accomplish best reactive power dispatch and voltage management. The nonlinear programming (NLP) and linear programming (LP) strategies[5] have applied for reactive power calculations. However, these strategies have difficulties in handling the objectives having multiple native minima. Recently, Differential Evolution[6,7], Harmony Search algorithmic program (HSA)[8] and Artificial Bee Colony algorithmic program (ABC)[9], has been enforced to optimize ORPD downside. Particle Swarm Optimization (PSO) was applied to manage voltage and assess the voltage security[10]. The OPF downside was solved supported 2 stage

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initialization method[11] by avoiding mutation operation in American state algorithmic program. Thanks to this, the ultimate convergence of the OPF downside is obtained in less time with increased accuracy. During this paper, a unique optimization algorithmic program supported the uniform distribution of random management variable generations and 2 stage initialization processes area unit enforced alongside the traditional PSO algorithmic program to boost the OPF performance has been developed.

The main objective of the reactive power management is to spot the situation of latest power unit sources and settings of the already put in power unit sources or tap settings of the tap changing transformers or Flexible AC Transmission Systems (FACTS).

Optimization of transmission losses and system bus voltage magnitude deviations have been optimized by using UDTPSO algorithmic program with FACTS controllers. The power injection model of GUPFC and its integration proved to identify the best location of FACTS device for enhancement of power system network performance. This approach has been verified with results obtained on IEEE-30 bus system with the supporting validations.

2. GUPFC Modeling

In general, GUPFC consists of two/more series converters and one shunt converter. Figure 1. indicates the basic configuration of GUPFC, two series converters square measure coordinated with one shunt converter.

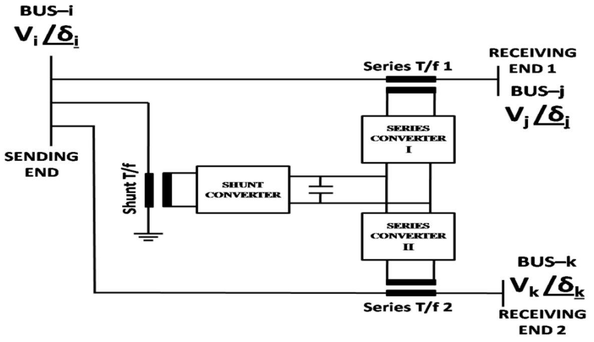

Figure 1. Basic configuration of two series converter GUPFC.

In this paper, based on heuristic rules possible locations[12] are identified. The steady state power injection model of GUPFC is shown in Figure 2.

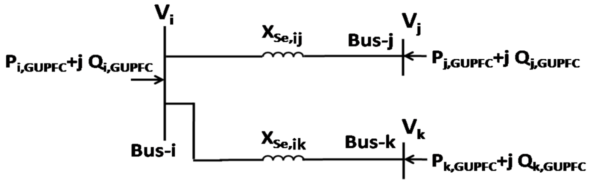

Figure 2. Injection model of two series converter GUPFC.

The real and reactive power injections are expressed as

$$P_{i,GUPFC} = -V_i^2\left[\sum_{q=j,k} r_{iq} B_{se,iq} \sin\gamma_{iq}\right] - 1.03\left(\sum_{q=j,k} r_{iq} V_i V_q B_{se,iq} \sin(\delta_{iq} + \gamma_{iq}) - r_{iq} V_i^2 B_{se,iq} \sin\gamma\right) \quad (1)$$

$$Q_{i,GUPFC} = -V_i^2\left[\sum_{q=j,k} r_{iq} B_{se,iq} \cos\gamma_{iq}\right] + Q_{sh} \quad (2)$$

$$P_{p,GUPFC} = r_{ip} V_i V_p B_{se,ip} \sin(\delta_{ip} + \gamma_{ip}) \ \forall \ p = j,k \quad (3)$$

$$Q_{p,GUPFC} = r_{ip} V_i V_p B_{se,ip} \cos(\delta_{ip} + \gamma_{ip}) \ \forall \ p = j,k \quad (4)$$

The switching loss factor coefficient is represented as a 1.03.

Here 'r' and 'γ' are respective per unit magnitude and phase angles of the series voltage sources. However, the operating limits are $0 \le r \le r_{max}$ and $0 \le \gamma \le \gamma_{max}$ respectively.

2.1 GUPFC Power Mismatch Equations

Due to inclusion of GUPFC, the power mismatch equations in Newton-Raphson (NR) technique can be revised as

$$\Delta P_{i,new} = \Delta P_{i,old} + P_{i,GUPFC} \quad (5)$$

$$\Delta Q_{i,new} = \Delta Q_{i,old} + Q_{i,GUPFC} \quad (6)$$

where, $\Delta P_{i,old}$ and $\Delta Q_{i,old}$ are the power mismatches without FACTS device.

2.2 GUPFC Jacobian Elements

The Jacobian elements can be revised as $\left(H^{new} = H^{old} + H^{'}\right)$.

$$H^{'}_{ii} = \frac{\partial P_{i,GUPFC}}{\partial \delta_i} = -1.0 \left[\sum_{q=j,k} r_{iq} V_i V_q B_{se,iq} \cos\left(\delta_{iq} + \gamma_{iq}\right) \right] \quad (7)$$

$$H^{'}_{qq} = -r_{iq} V_i V_q B_{se,iq} \cos(\delta_{iq} + \gamma_{iq}) = -Q_{q,GUPFC} \quad \forall \quad q = j,k \quad (8)$$

$$H^{'}_{iq} = 1.0 \left[r_{iq} V_i V_q B_{se,iq} \cos(\delta_{iq} + \gamma_{iq}) \right] = 1.0 \; Q_{q,GUPFC} \quad \forall \quad q = j,k \quad (9)$$

$$H^{'}_{qi} = r_{iq} V_i V_q B_{se,iq} \cos(\delta_{iq} + \gamma_{iq}) = Q_{q,GUPFC} \quad \forall \quad q = j,k \quad (10)$$

where H^{old} is the Jacobian element without device. Similar modifications can be obtained for all the elements.

2.3 Optimal Location

The severity operate (Fseverity) may be expressed as[13]

$$F_{Severity} = \sum_{i=1}^{N_{line}} \left(\frac{S_i}{S_i^{\max}} \right)^{2q} + \sum_{j=1}^{N_{bus}} \left(\frac{V_{j,ref} - V_j}{V_{j,ref}} \right)^{2r} \quad (11)$$

3. Optimization Problem Formulation

Optimal Power Flow (OPF) problem can be formulated mathematically as a constrained nonlinear objective optimization problem as given in[14]

4. Uniformly Distributed Two Stage Particle Swarm Optimization (UDTPSO)

All generated initial population is processed in two stage low-level formatting methodology[10], to decrease the amount of population for PSO repetitious method. The inertia weight (W) and acceleration coefficients (C1 and C2) want to update rate in repetitious method area unit calculated dynamically in the methodology enforced in[15] Thus the ultimate international resolution is achieved in less range of iterations in comparison to standard PSO. The rate (V) and position (X) of the ith particle within the next iteration (k) area unit calculated in the procedure given in[16,17]. The flow chart of the projected methodology is shown in Figure 3.

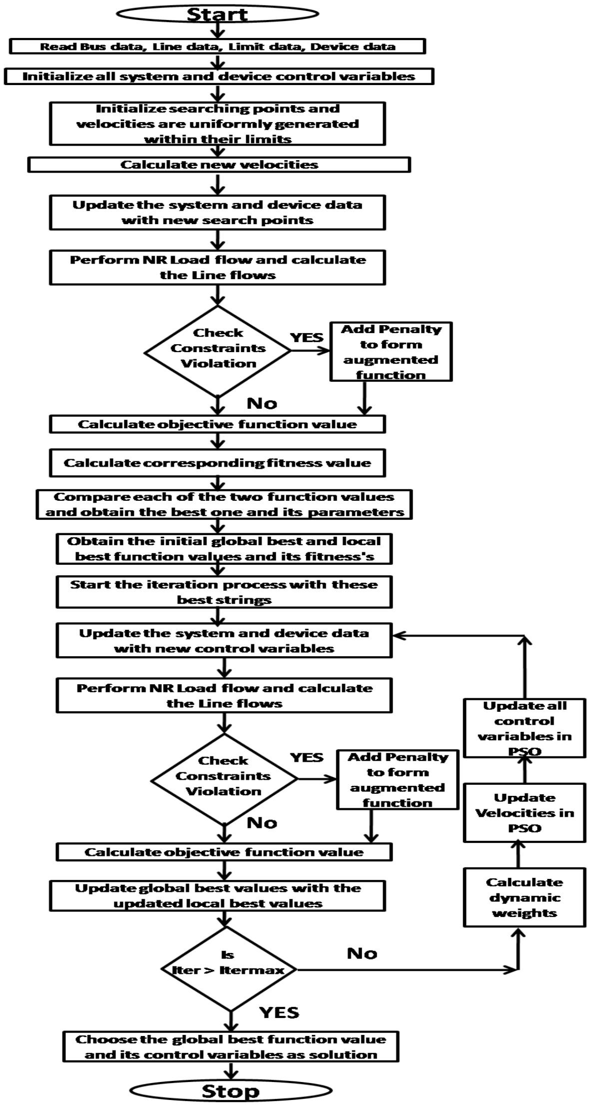

Figure 3. Flow chart of the proposed UDTPSO method.

5. Results and Analysis

IEEE-30 bus system with forty-one transmission lines is taken into account[18-20]. The overall controlling variables during this system are eighteen, and they are six active power generations and voltage levels of six generators, four tap settings of tap-changing transformers and a pair of shunt volt-ampere sources. The overall analysis is split into 3 possibilities, explained as follows.

5.1 Scenario-1

The corresponding results square measure tabulated in Table.1. From this table, it's determined that the overall power losses have a bearing of sensible constraints, the losses square measure changed from 2.929 MW to 4.482 MW i.e. 1.553 MW with the planned technique. The planned technique takes 18.911 sec less time when put next to existing PSO. The comparison of the obtained results with the present literature is listed in Table.2. From this table, the revised technique yields higher results than the present ways.

Table 1. Comparison of results of UDTPSO with PSO for total power losses

Control variable	PSO		Proposed UDTPSO	
	Without practical constraints	With practical constraints	Without practical constraints	With practical constraints
PG1, MW	51.34102	105.18	51.37179	100.6577
PG2, MW	80	50	80	60
PG5, MW	49.99036	49	50	48.79148
PG8, MW	35	25	34.99606	23.43232
PG11, MW	30	24.26527	30	25
PG13, MW	40	35	39.96126	30
VG1, p.u.	1.1	1.029377	1.1	1.1
VG2, p.u.	1.097101	1.015088	1.098632	1.094233
VG5, p.u.	1.078998	0.993046	1.080406	1.074555
VG8, p.u.	1.086761	1.000623	1.088237	1.078492
VG11, p.u.	1.097831	1.010285	1.1	1.011014
VG13, p.u.	1.1	1.024551	1.099797	1.027177
Tap 6-9, p.u.	1.022742	1.067524	1.042689	0.982864
Tap 6-10, p.u.	0.958291	0.978219	0.933103	1.1
Tap 4-12, p.u.	0.982414	1.026629	0.972678	1.012513
Tap 28-27, p.u.	0.971979	1.001525	0.974054	1.0282
Qc 10, p.u.	19.34063	11.34559	21.31203	19.33169
Qc 24, p.u.	11.84832	21.81164	13.12569	18.24929
TPL, MW	**2.931375**	**5.045315**	**2.929107**	**4.481504**
Voltage deviation, p.u.	**1.864171**	**0.52247**	**1.953416**	**0.712813**
Time (sec)	**30.2981**	**47.2718**	**18.2737**	**28.3610**

Table 2. Validation and Summary of test results for TPL

S. No	Method	TPL (MW)
1	DE [6]	5.011
2	SQP [6]	5.043
3	PSO [10]	5.0921
4	IPM [21]	5.101
5	Mixed Integer NLP [22]	3.1567
6	PSO	2.931375
7	Proposed UDTPSO	2.929107

The variation of the control variables for the 100 iterations for the proposed UDTPSO method with practical constraints is shown in Figure 4.

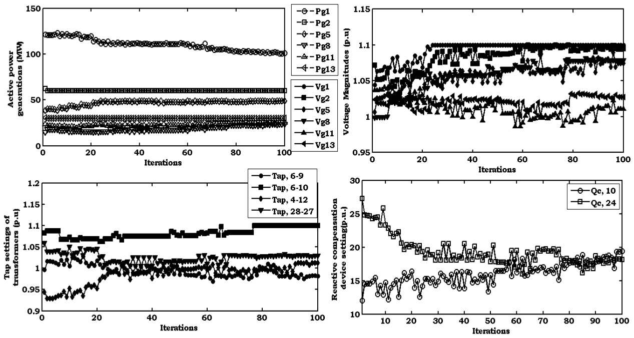

Figure 4. Variation of the control variables for UDTPSO with practical constraints.

From Figure 5, it is observed that the proposed UDTPSO method starts with good initial function value and reaches best final function value when compared to existing PSO method.

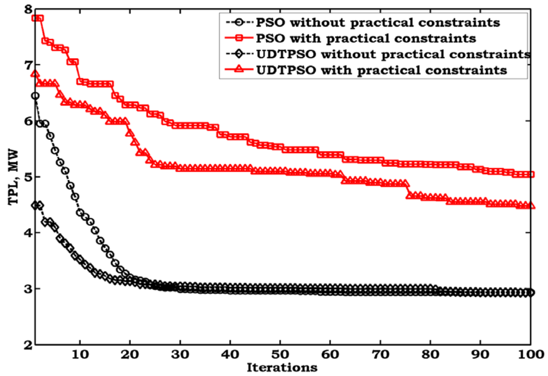

Figure 5. Convergence characteristics of scenario-1 with UDTPSO and PSO for total power loss objective.

5.2 Scenario-2

The results of contingency analysis for this technique is given in Table.3. To keep up the continuity either in supplying/receiving the facility, the contingency analysis is not performed on lines between buses 12-13, and 25-26. The results of solely high a pair of contingencies are tabulated. From Table.3, it is clear that the line connected between buses 2 and 5 is that the most critical one. By following on top of rules given in section-II, the attainable UPFC installation locations are thirty-eight. Severity perform is evaluated all possible locations with UPFC and also the major five least severe perform valued locations are tabulated in Table.4 below rank-1 contingency.

Table 3. Results of contingency ranking

S. No.	LINE NO	OUTAGE LINE	OVER LOADED LINES (Line flow/ MVA limit)	NOLL	Voltage Violated Buses	NVVB	PI	Rank
1	5	2-5	(1-2) (171.399/130) (2-4) (77.671/65) (2-6) (105.434/65) (4-6) (121.418/90) (5-7) (110.190/70) (6-8) (35.828/32)	6	-	0	6	1
2	36	28-27	(1-2) (180.949/130) (22-24) (20.246/16) 24-25) (19.501/16)	3	27 (0.8989) 29 (0.8760) 30 (0.8627)	3	6	2

Table 4. Severity function values under rank-1 contingency with UPFC

S.No.	UPFC LOCATION		Severity function value
	Sending end bus	Receiving end bus	
1	**12**	**14**	**1.608**
2	30	27	1.6479
3	15	14	1.6484
4	27	25	1.6503
5	6	4	1.6573

Similarly, total possible installation locations for GUPFC are 23. Corresponding severity function values are tabulated in Table.5.

Table 5. Severity function values under rank-1 contingency with GUPFC

S.No.	GUPFC LOCATION			Severity function value
	Sending end bus	Receiving end buses		
1	**12**	**14**	**15**	**1.517**
2	12	14	16	1.6164
3	12	15	16	1.6492
4	15	12	23	1.6505
5	15	14	18	1.6668

From Tables 4 and 5, it is determined that initial location is that the best location for putting the UPFC and GUPFC, as a result of it's the least severity perform worth. The analysis is performed by inserting device at this location.

The obtained optimum Power Flow (OPF) results for the cases-1 and 2 are tabulated in Table. 6. From this table, it's determined that there's an impact of FACTs device on the thought about the objective. With GUPFC, the overall power losses and voltage deviations square measure reduced by 0.27854 MW and 0.000251 p. u when compared to UPFC. The convergence characteristics of the thought about objectives square measure is shown in Figures 6 and 7. From these figures, it's determined that higher convergence performance is obtained with GUPFC when compared with UPFC cases. Finally, the convergence rate is incredibly high with GUPFC, because the final convergence is obtained in less number of iterations when compared to the remaining cases.

Table 6. OPF results for cases-1 and 2 without and with FACTS device

Control variables	TPL			VOLTAGE DEVIATION		
	Without	With UPFC	With GUPFC	Without	With UPFC	With GUPFC
PG1, MW	100.6577	103.9343	85.5787	149.9173	135.9303	157.6777
PG2, MW	60	49.995	63	35.3772	60	25.4257
PG5, MW	48.7915	48.9721	49	36	24.796	48.7341
PG8, MW	23.4323	25	30	22.2158	19.0648	22.5628
PG11, MW	25	24.9543	25	23.1599	21.9384	13.021
PG13, MW	30	35	35	24	30	24
VG1, p.u.	1.1	1.1	1.0499	1.0402	1.013	1.0108
VG2, p.u.	1.0942	1.0315	0.9979	1.0134	1.0026	0.9817
VG5, p.u.	1.0746	1.0765	1.0271	1	1.0144	1.0126
VG8, p.u.	1.0785	1.0998	1.0336	0.9977	0.992	1.0486
VG11, p.u.	1.011	1.0998	1.0487	1.0767	1.0657	1.0218
VG13, p.u.	1.0272	0.9821	1.0498	1.0493	1.0388	1.0155
Tap 6-9, p.u.	0.9829	0.992	1.0342	1.1	1.0767	0.9768
Tap 6-10, p.u.	1.1	0.9678	0.9942	0.9537	0.986	1.0331
Tap 4-12, p.u.	1.0125	0.9225	1.0013	1.0238	1.017	0.9845
Tap 28-27, p.u.	1.0282	0.9642	0.9756	0.9613	0.9647	0.9615
Qc 10, p.u.	19.3317	19.0959	24.0943	14.5031	14.5013	19.16
Qc 24, p.u.	18.2493	17.0017	14.0054	17.2136	29.9605	22.0561
r_{ij}, p.u.	-	0.0006	0.0001	-	0.0115	0.0003
r_{ik}, p.u.	-	-	0.0026	-	-	0.0106
γ_{ij}, deg.	-	240.717	206.3759	-	315.0066	212.3214
γ_{ik}, deg.	-	-	164.2577	-	-	191.0205
$X_{se,ij}$, p.u.	-	0.0177	0.0094	-	0.023	0.0092
$X_{se,ik}$, p.u.	-	-	0.0121	-	-	0.0131
Qsh, p.u.	-	0.081	0.0762	-	0.022	0.0412
TPL, MW	**4.4815**	**4.4557**	**4.1771**	**7.2702**	**8.3295**	**8.0151**
Vdev, p.u.	**0.7128**	**2.0965**	**0.5656**	**0.1647**	**0.1607**	**0.1605**

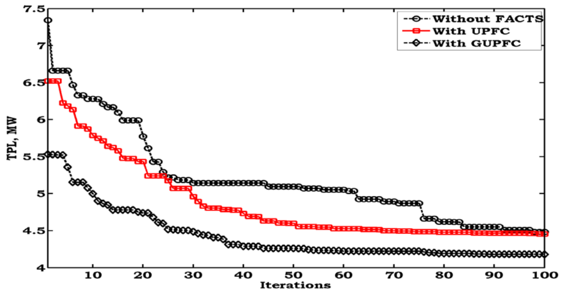

Figure 6. Convergence characteristics of TPL without and with FACTs.

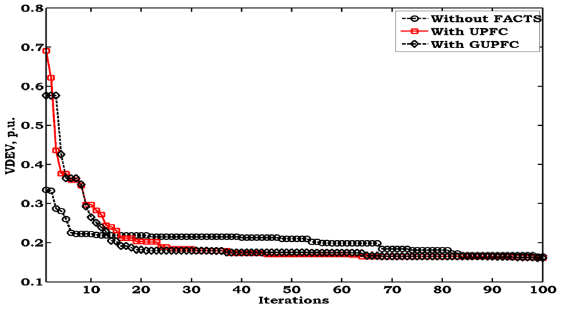

Figure 7. Convergence characteristics of voltage deviation without and with FACTs.

The voltage magnitude variation at the system buses for the voltage deviation minimization case is shown in Figure 8. From the figure, it is observed that the voltage deviations are minimized with GUPFC than the UPFC.

Considerable voltage deviation is observed at the GUPFC connected buses; since GUPFC has the capability to control the voltage magnitude other than power flows.

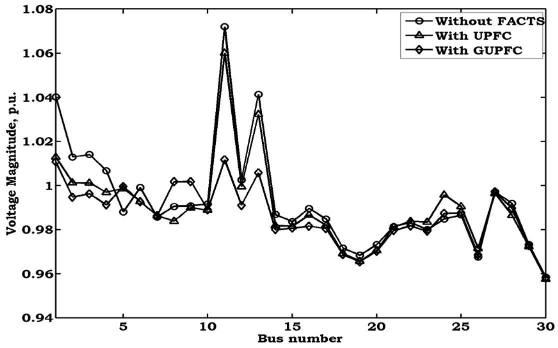

Figure 8. Variation of voltage magnitudes in voltage deviation minimization without and with FACTs.

5.3 Scenario-3

The proposed UDTPSO technique, as well as GUPFC, is performed for 3 trials. The corresponding convergence patterns, variance and ordinary deviations for the 3 trials are shown in Figure 9. From this figure, it's ascertained that all told trials the beginning price is totally different. However, the ultimate best price has very small deviation. Thus, the convergence rate of the proposed technique is very high, as final price is obtained in below forty iterations. It's confirmed by observant the variance and commonplace deviations reminiscent of 3 trials.

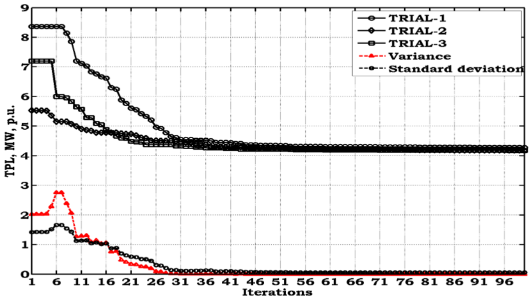

Figure 9. Effect of initial population with the proposed UDTPSO including GUPFC.

Similarly, the effect of population size on the objective function is identified with the proposed UDTPSO including GUPFC, by taking 25, 50 and 100 populations respectively. The corresponding convergence pattern for the TPL objective is shown in Fig.10. From the fig below it is observed that the final best value is obtained with the population size of 100. The nature of the control variables is high with 100 populations when compared to less population.

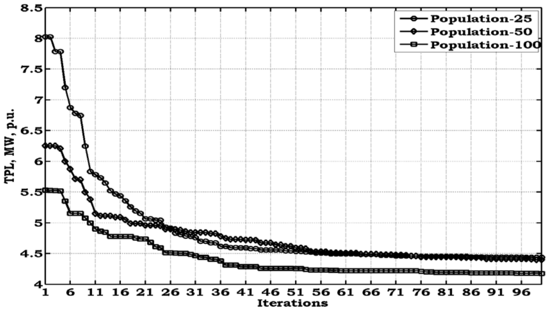

Figure 10. Effect of population size with the proposed UDTPSO including GUPFC.

6. Conclusion

In this paper, the entire power injection model of GUPFC and its incorporation in standard NR flow has been given. A unique severity performs the system security within the presence of GUPFC. ORPD drawback has been solved within the presence of standard constraints like equality, inequality and sensible constraints. The in-equality constraints were handled exploitation penalty approach. The transmission power loss and system bus voltage deviation objectives were optimized with GUPFC while satisfying the constraints. The projected technique has well-tried its effectiveness by beginning repetitive method with sensible initial price and reaches final best price in less range of iterations compared to existing strategies.

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