Optimal sizing and placement of Static and Dynamic VAR devices through Imperialist Competitive Algorithm for minimization of Transmission Power Loss

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Abstract— This paper presents the applications of static and dynamic VAR sources for Transmission Power Loss (TPL) minimization using Imperialist Competitive Algorithm (ICA). Static VAR sources consists of switchable shunt capacitors whereas, the dynamic VAR sources are flexible AC transmission system (FACTS) devices. A novel approach of simultaneous optimal placement and sizing of static and dynamic VAR sources has been proposed which proves to be more efficient in TPL minimization when compared to their individual counter parts. Usage of static and dynamic VAR sources simultaneously makes the power system optimization problem more complex, which needs special optimization tool. Hence, a novel ICA optimization algorithm is also proposed in this paper to achieve a global optimization solution for the above mentioned complex problem. The proposed ICA is inspired by imperialistic competition in which all the countries are divided into two types: imperialist states and colonies. Imperialistic competition is the main part of proposed algorithm and hopefully causes the colonies to converge to the global minimum of the optimization problem. The proposed method is tested on the standard IEEE-14 bus and IEEE-118 bus test systems. Results obtained are compared against the individual usage of VAR sources and as well as with the other proven optimization algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). Results indicate that the proposed method obtains a better optimal solution when compared to that of the conventional approaches.

Keyword- VAR sources, Transmission Power Loss, Imperialist Competitive Algorithm, Particle Swarm Optimization, Genetic Algorithm

I. INTRODUCTION

In the present competitive power market situation, due to ever increase in demand, optimal operation of power system is extremely important in context with economy of power generation. The foremost and viable method in improving power system operation is by reducing Transmission Power Loss (TPL). Minimization of TPL results in the following: increase in existing transmission capacity, reduction in cost of power generation and increase in meeting additional demand with existing generation facility [1].

TPL minimization can be conventionally achieved by optimally placing static VAR sources in the network. Static VAR sources include switchable capacitors and reactors; tap changing transformers , etc.[2].

Dynamic VAR sources which include synchronous condensers, Flexible AC transmission system (FACTS) devices are also used in minimization of TPL. These devices control the circuit parameters there by controlling the power flow and minimize the transmission power loss [3]-[4].

So far in many of the reported research works either static or dynamic VAR sources are considered in minimization of TPL. From [5], it is understood that simultaneous placement of static and dynamic VAR sources can mitigate the problem of minimization of TPL better when compared to their individual counterpart. Further, in [5] shunt compensation devices in static and dynamic VAR sources such as shunt capacitors and static VAR compensator (SVC), respectively alone are considered. From [6]-[7], it is understood that series compensation dynamic devices such as Thyristor Controlled Series Compensation (TCSC) can also effectively minimize TPL.

Thus, optimal usage of both series and shunt compensation in static and dynamic VAR devices makes the problem of minimization of TPL as a complex non-linear mixed integer optimization problem. The solution methodologies to solve the above problem can be broadly classified as mathematical methods and intelligent methods [8]-[9].

Though mathematical methods [10]-[12] such as successive quadratic programming method, interior point method, the P-Q decomposition approach, etc. are straight forward, implementation of constrains are much complex and further does not guarantee global optimal solution.

Intelligent methods include Neural, Fuzzy and Meta-heuristic methods [13]-[15]. The major disadvantage of neural networks is that, they cannot always guarantee a completely certain solution, arrive at the same solution again with the same input data, or always guarantee the best solution. They are also very sensitive and may not perform well if their training covers too little or too much data. Fuzzy logic is comparatively hard to develop a model of the proposed problem, requires finer tuning and simulation before operational. These disadvantages can be overcome by using meta-heuristic algorithms. From the literatures it is understood that many meta-heuristic algorithms such as Genetic Algorithm (GA) [16]-[17], Particle Swarm Optimization (PSO) [18], Differential Evolution (DE) [19] and Artificial Bee Colony (ABC) [20] has proved in providing better optimal and practically feasible solution for the problem of TPL minimization. Recently, a novel optimization algorithm, Imperialist Competitive Algorithm (ICA) [20], has been implemented for many mathematical functions and also for the solution of Unit Commitment (UC) problem [21]. ICA is inspired by imperialistic competition in which all the countries are divided into two types: imperialist states and colonies. Imperialistic competition is the main part of ICA algorithm and hopefully causes the colonies to converge to the global minimum of the optimization problem. When compared to conventional evolutionary algorithms such as GA, PSO etc., ICA is the computer simulation of human social evolution rather than based on biological evolution of species. ICA can also be thought of as the social counterpart of Genetic Algorithm (GA). From [21] it is also evident that ICA provides better optimal solution for UC problem when compared to other meta-heuristic methods such as GA and PSO, etc.

Based on the above mentioned advantages, in this paper ICA is proposed to mitigate the problem of TPL minimization using static and dynamic VAR sources. The proposed method is implemented on the standard IEEE-14 bus and IEEE-118 bus test systems. For comparison, the problem of TPL minimization is also done with other proven optimization algorithms such as GA and PSO.

The remaining part of the paper is organized as follows: Section II deals with the problem formulation for TPL minimization. Section III gives the brief description and the general Imperialist Competitive Algorithm and Section IV details the implementation of ICA for TPL minimization. Section V presents the results and discussion. Finally, conclusions are made in section VI.

II. PROBLEM FORMULATION

In this paper, the minimization of TPL is done with the simultaneous optimal placement of static and dynamic VAR sources. In dynamic VAR sources, commercially available devices such as TCSC and SVC alone are considered in this paper. Also in static VAR sources, the shunt capacitors alone are considered. Based on these assumptions the formulation of the problem of TPL minimization can be stated as below.

$$\text{Min}\ \{P_{loss}\} = \sum_{\substack{k \in N_{line} \\ k=(i,j)}} g_k \left\{ V_i^2 + V_j^2 - 2V_iV_j\ \cos(\delta_i - \delta_j) \right\} \quad (1)$$

Subject to the following power flow constraints:

Equality Constraints

$$\left. \begin{array}{l} P_{Gi} - P_{Di} - |V_i| \sum_{j=1}^{N_{bus}} |Y_{ij}||V_j| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \\ \text{for } i = 1,2,3,...,N_{bus};\ i \neq \text{slackbus} \end{array} \right\} \quad (2)$$

$$\left. \begin{array}{l} Q_{Gi} - Q_{Di} - \left[-|V_i| \sum_{j=1}^{N_{bus}} |Y_{ij}||V_j| \sin(\theta_{ij} - \delta_i + \delta_j) \right] = 0 \\ \text{for } i = 1,2,3,...,N_{bus};\ i \neq \text{slackbus};\ i \neq \text{P-V bus} \end{array} \right\} \quad (3)$$

Inequality Constraints

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad (4)$$

$$T_k^{min} \leq T_k \leq T_k^{max} \quad (5)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad (6)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (7)$$

$$S_k \le S_k^{max} \tag{8}$$

$$Q_{Ci}^{min} \le Q_{Ci} \le Q_{Ci}^{max} \tag{9}$$

$$-0.5 \le X_{ij,TCSC} \le 0.5 \tag{10}$$

$$-100MVAr \le Q_{iSVC} \le 100MVAr \tag{11}$$

Where,

P_{loss}	is the real power transmission loss in MW
N_{line}	is the total number of transmission lines
V_i , δ_i	are the voltage and angle, respectively at the ‘i^{th}’ bus
V_j , δ_j	are the voltage and angle, respectively at the ‘j^{th}’ bus
P_{Gi}	is the real power of generator ‘i’
P_{Di}	is the real power demand at bus ‘i’
Y_{ij}	is admittance element of Y bus between ‘i’ and ‘j’
θ_{ij}	is the load angle between ‘i’ and ‘j’
N_{bus}	is the total number of buses
Q_{Gi}	is the reactive power of generator ‘i’
Q_{Di}	is the reactive power demand at bus ‘i’
T_k	is the transformer tap setting in line ‘k’
S_k	is the MVA limit of the line ‘k’
Q_{Ci}	is the static reactive power compensation at bus ‘i’
$X_{ij,TCSC}$	is the reactance of TCSC between bus ‘i’ and ‘j’
Q_{iSVC}	is the SVC reactive power compensation at bus ‘i’

The modeling of dynamic VAr compensators i.e. TCSC and SVC for power flow is considered form [3]. The range for the reactance of TCSC is assumed to be ± 50% of the reactance of the transmission line. Similarly the upper and lower limit for SVC is considered as ± 100 MVAr [3].

III. IMPERIALIST COMPETITIVE ALGORITHM

The ICA algorithm is adopted from ref.[20]. ICA is inspired by imperialistic competition in which all the countries are divided into two types: imperialist states and colonies. The generalized procedure of ICA algorithm is as explained below:

A. General Algorithm of ICA

Generating Initial Empires

- Like other evolutionary algorithms, initial population say a size of ‘N’ called as countries are initialized.
- Calculate the power for each country i.e., similar to fitness of evolutionary algorithm.
- Based on best fitness, select ‘N_{imp}’ number of imperialist and the remaining countries are treated as colonies say ‘N_{col}’.
- Based on a random number, allot a segment of ‘N_{col}’ to each of ‘N_{imp}’ imperialist. Hence, a imperialist with its associated colonies forms an empire.

Moving colonies of an empire towards Imperialist

- The positions of the colonies are updated in such a way to move these colonies towards their imperialist.

Compare and exchange the position of Imperialist and colony

- Since the colonies move towards the imperialist, there are chances for the power or the fitness value of a colony to be better that their imperialist. Under that case the position of imperialist and the corresponding colony are interchanged.

Evaluate the total power of all the empires

- The power or the fitness value for the empire i.e,, imperialist and their corresponding colonies are calculated.
- The above procedure is repeated for all empires.

Imperialistic Competition for eliminating powerless empires

- Based on possession probability, each imperialist is allowed to perform completion for the possession of weakest colony from the weakest empire.
- Only the strongest empire has the like hood of possessing the weakest colony.
- Hence, by repeating this procedure the weakest empire will collapse by losing all of its colonies.

Check for convergence

After certain specific decades of above procedure the algorithm is stopped or in imperialistic competition the empires except the most powerful one will collapse and all the colonies will be under this unique empire. Under this condition the algorithm is stopped.

IV. IMPLEMENTATION OF ICA FOR TPL MINIMIZATION

Similar to other Evolutionary algorithms the fundamental part in the application of ICA to TPL minimization is the solution representation. In GA, they are called as chromosomes whereas, in ICA the solution representation is referred to as countries. A typical representation of country in ICA for TPL minimization considering static and dynamic VAR sources is shown in Fig. 1. Let the number of dynamic VAR and static VAR be '2' and '3', respectively. Hence, the number of control variables is '10'. Then each country representation is:

$$\overbrace{\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline X_1 & X_2 & X_3 & X_4 & X_5 & X_6 & X_7 & X_8 & X_9 & X_{10} \\ \hline\end{array}}^{\text{Country}}$$

Fig. 1. Solution representation in a country

Where,

X_1 Location of first dynamic VAR source

X_2 Size of first dynamic VAR source

X_3 Location of second dynamic VAR

X_4 Size of second dynamic VAR source

X_5 Location of first static VAR source

X_6 Size of first static VAR source

X_7 Location of second static VAR source

X_8 Size of second static VAR source

X_9 Location of third static VAR source

X_{10} Size of third static VAR source

ICA routine as explained in section 3, finds the optimal values of 'X' such that the objective function as given in (1) is minimized satisfying the equality constraints from (2) to (3) and inequality constraints from (4) to (11). Further, Newton Raphson power flow algorithm is used to solve the power flow equations (2) and (3). The detailed procedural steps of ICA for TPL minimization is given below.

A. Algorithm for TPL minimization using ICA

The algorithm to minimize TPL with static and dynamic VAR sources using ICA is given below

Step 1: Set the number of countries, number of generations, power flow data, etc.

Step 2: Initialize the countries as given in Fig 1.

Step 3: Set counter for number of decades.

Step 4: Set counter for number of countries.

Step 5: From each country (Fig. 1) obtain the values of settings and location of static and dynamic VAR devices and incorporate these changes in the power flow data.

Step 6: Solve power flow using NR method.

Step 7: Evaluate fitness using (1). Check whether fitness is evaluated for all countries If, YES then GO TO *Step* 8 else increment the counter for countries and GO TO *Step* 5.

Step 8*:* Form imperialist with its associated colonies based on the fitness.

Step 9*:* Update the position of colonies. If the fitness of any colony is better than that of its imperialist then exchange the position of colonies and imperialist. This process is repeated for all imperialist and its associated colonies.

Step 10: The fitness or power is calculated for all empires.

*Step*11: Perform Imperialist competition to eliminate powerless empire.

Step 12: Check for convergence or maximum decades reached. If YES, then GO TO *Step* 13 else GO TO *Step* 9.

Step 13: Print the optimal values and STOP.

V. SIMULATION RESULTS AND DISCUSSION

This section presents the results of simultaneous placement of static and dynamic VAR sources using the proposed ICA algorithm on the standard IEEE-14 and -118 bus test systems. To substantiate the results obtained using ICA, they are compared with that of GA [22] and PSO [23]. The control parameter values for all the optimization algorithms are given below.

ICA: Countries = 50, Decades = 500, Revolution rate = 0.3, assimilation coefficient = 0.2, assimilation angle coefficient = 0.5.

- GA: real coded, population = 30, generations = 300, crossover probability = 0.5, mutation probability = 0.1.
- PSO: population = 30, generations = 300, cognitive learning factor = 2, cooperative factor = 2, social learning factor = 0.5, inertial constant = 0.5 and the number of neighbors = 5.

The power flow data for the test systems are considered from [24]-[25]. Load flow programs are executed in MATLAB using MATPOWER [26] coding in INTEL core 2 Duo CPU T5500@ 1.66 GHz processor under Windows XP professional operating system. The simulation results for the test systems are classified into three cases:

Case1: Static compensation (Shunt capacitors)

Case 2: Dynamic compensation (TCSC and SVC)

Case 3: Static and Dynamic compensation (Shunt capacitors, TCSC and SVC)

The base MVA for the load flow is assumed to be 100 MVA. In dynamic VAR source, only one TCSC and one SVC are considered for placement at a time in the given

A. *IEEE 14 Bus test system*

The IEEE 14 bus system consists of 5 generators, 20 transmission lines with TPL of 13.393 MW in base case (i.e. without compensation). The simulation results for IEEE 14 bus system is presented in Table 1. The case wise discussions are given below.

Case 1: Static compensation

As shown in Table 1, GA optimally places the three shunt capacitors at bus 5, 7 and 14 with a rating of 25, 5 and 5 MVAr, respectively. Hence, the TPL is 13.2775 MW, which is 0.8623% less when compared to the base case. PSO chooses the optimal points as bus 5, 13 and 14 with a rating of 20, 5 and 5 MVAr, respectively. The TPL using PSO is 13.2551 MW, which is 1.029% less when compared to the base case.

Parameters		GA	PSO	ICA
Case 1: (Static compensation)	Capacitor: 1	25 MVAr - Bus 5	20 MVAr - Bus 5	25 MVAr - Bus 5
	Capacitor: 2	5 MVAr - Bus 7	5 MVAr - Bus 13	5 MVAr - Bus 13
	Capacitor: 3	5 MVAr - Bus 14	5 MVAr - Bus 14	5 MVAr - Bus 14
	TPL (MW)	13.2775	13.2551	13.2525
	TPL minimization (%)	0.8623	1.029	1.049
Case 2: (Dynamic compensation)	SVC (Qsvc)	28 MVAr - Bus 5	28 MVAr - Bus 5	28 MVAr - Bus 5
	TCSC (X_{TCSC})	0.5 X_L - Line 1-2	0.5 X_L - Line 1-2	0.5 X_L - Line 1-2
	TPL (MW)	13.1584	13.1584	13.1584
	TPL minimization (%)	1.752	1.752	1.752
Case 3: (Static and Dynamic compensation)	Capacitor :1	5 MVAr - Bus 4	30 MVAr - Bus 5	5 MVAr - Bus 10
	Capacitor: 2	5 MVAr - Bus 7	35 MVAr - Bus 9	5 MVAr - Bus 13
	Capacitor: 3	5 MVAr - Bus 14	5 MVAr - Bus 14	5 MVAr - Bus 14
	SVC (Qsvc)	25.4 MVAr - Bus 5	-32 MVAr - Bus 7	24.3 MVAr - Bus 5
	TCSC (X_{TCSC})	0.5 X_L - Line 1-2	0.5 X_L - Line 1-2	0.5 X_L - Line 1-2
	TPL	13.1371	13.1112	13.0941
	TPL minimization (%)	1.911	2.104	2.232

Table 1. Simulation Results for IEEE 14 bus test system

The proposed algorithm ICA chooses the same optimal points as selected by PSO but with different ratings, i.e., 25, 5 and 5 MVAr. The TPL using ICA is 13.2525 MW which is 1.049% lesser when compared to the base case. The convergence characteristic is shown in Fig 2.

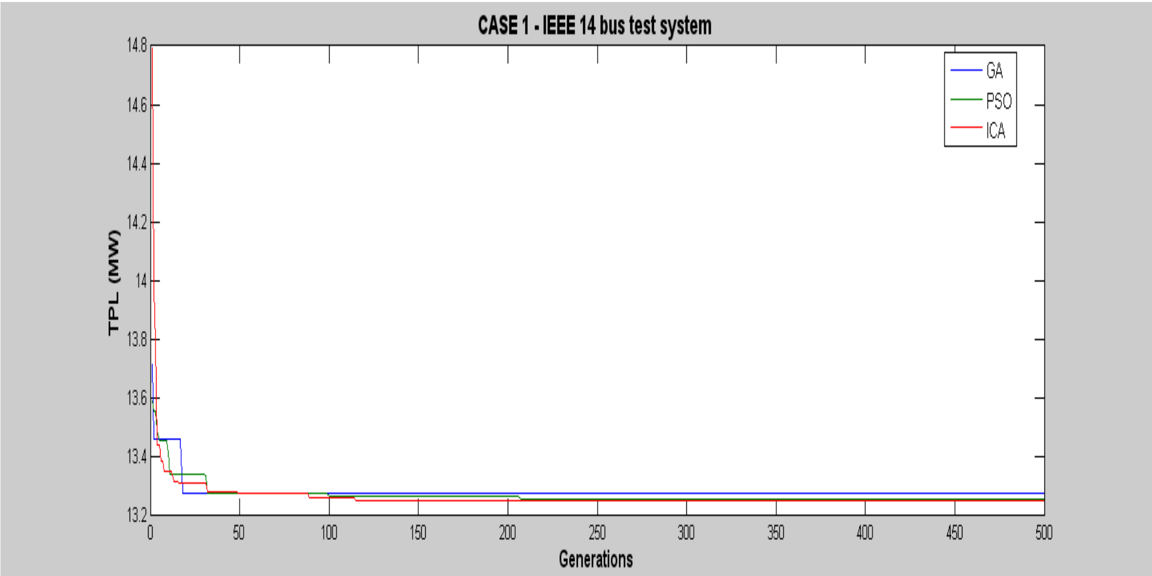

Fig. 2 Convergence for Case 1 of IEEE-14 bus system

Case 2: Dynamic compensation

In this case all the three algorithms, GA, PSO and ICA optimally places SVC at bus 5 with Qsvc of 28 MVAr and TCSC in line 1-2 with X_{TCSC} of 0.5 thereby minimizing TPL to 13.1584 MW which is 1.752% less when compared to base case. Table 1 depicts the results of case 2 and Fig. 3 shows the convergence characteristics.

Case 3: Static and Dynamic compensation

In this case both GA optimally places the three shunt capacitors at bus 4, 7 and 14 with a rating of 5 MVAr each and the SVC at bus 5 with Qsvc of 25.4 MVAr and TCSC in line 1-2 with X_{TCSC} of 0.5 thereby minimizing TPL to 13.1371 MW which is 1.911% less when compared to base case. Further, PSO chooses the optimal points for the three shunt capacitors at bus 5, 9 and 14 with a rating of 30, 35 and 5 MVAr and the SVC at bus 7 with Qsvc of -32 MVAr and TCSC in line 1-2 with X_{TCSC} of 0.5 thereby minimizing TPL to 13.1112 MW which is 2.104% less when compared to base case.

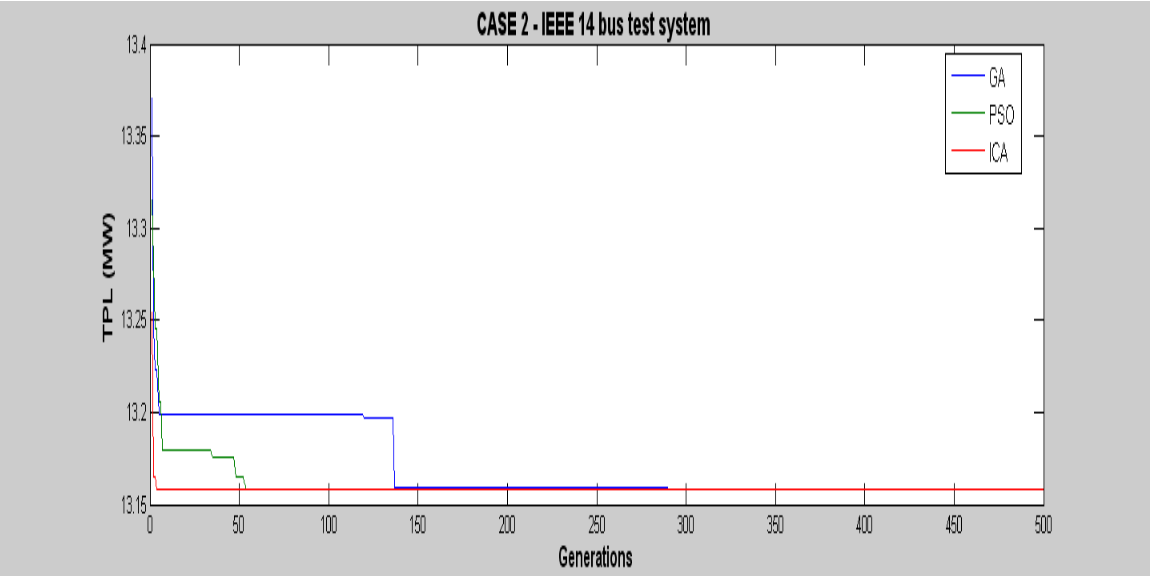

Fig. 3 Convergence for Case 2 of IEEE-14 bus system

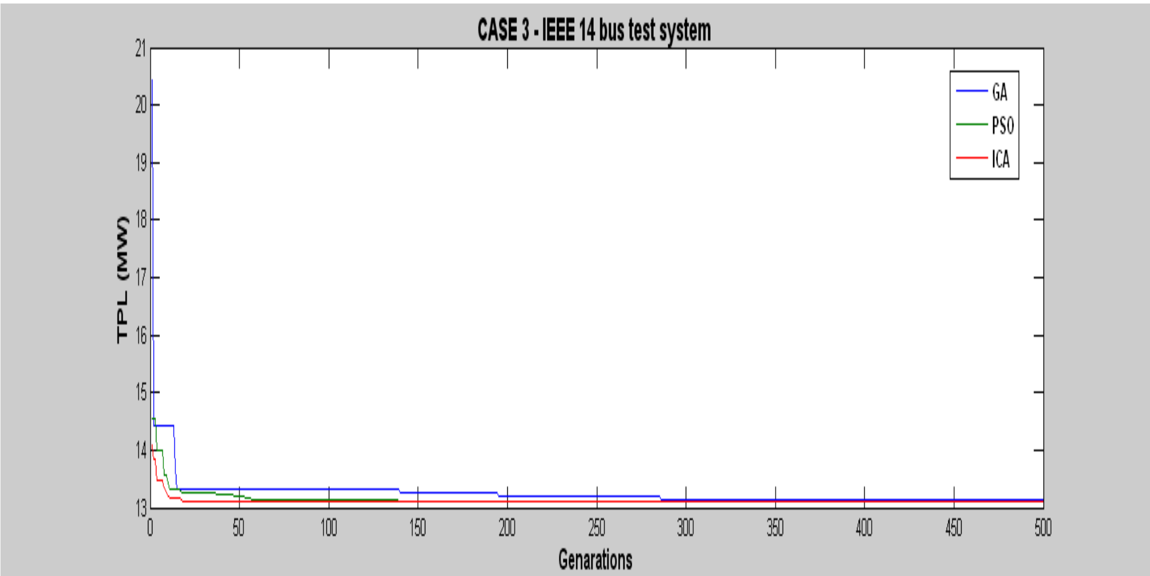

Fig. 4 Convergence for Case 3 of IEEE-14 bus system

On the other hand, the proposed algorithm ICA optimally the three shunt capacitors at bus 10, 13 and 14 with a rating of 5 MVAr each and the SVC at bus 5 with Qsvc of 24.3 MVAr and TCSC in line 1-2 with X_{TCSC} of 0.5 thereby minimizing TPL to 13.0941 MW which is 2.232% less when compared to base case. The convergence characteristics for GA, PSO and ICA of case 3 are shown in Fig. 4. From Table 1, it is evident that case 3 is better when compared to case 1 and case 2 in TPL minimization and also in case 3 using the proposed ICA algorithm the TPL value is 0.1306% and 0.3284% lesser when compared to PSO and GA, respectively.

B. *IEEE 118 Bus test system*

The IEEE-118 bus system consists of 54 generators, 186 transmission lines with TPL of 132.863 MW in base case (i.e. without compensation). The simulation results for IEEE-118 bus system is presented in Table 2.

Table 2: Simulation results for IEEE-118 bus system

Parameters		GA	PSO	ICA
Case 1: (Static compensation)	Capacitor: 1	100 MVAr - Bus 38	100 MVAr - Bus 38	100 MVAr - Bus 38
	Capacitor: 2	60 MVAr - Bus 94	40 MVAr - Bus 96	100 MVAr - Bus 64
	Capacitor: 3	5 MVAr - Bus 118	5 MVAr - Bus 118	40 MVAr - Bus 95
	TPL (MW)	132.4502	132.3727	132.3188
	TPL minimization (%)	0.3107	0.3690	0.4096
Case 2: (Dynamic compensation)	SVC (Qsvc)	100 MVAr - Bus 38	-19.6MVAr - Bus 17	99 MVAr - Bus 38
	TCSC (X_{TCSC})	$0.5X_L$ - Line 23-25	$-0.2X_L$ - Line 38-65	$-0.2X_L$ - Line 38-65
	TPL (MW)	132.0855	131.9272	131.8440
	TPL minimization (%)	0.5852	0.7043	0.7669
Case 3: (Static and Dynamic compensation)	Capacitor :1	80 MVAr - Bus 38	10 MVAr - Bus 21	100 MVAr - Bus 30
	Capacitor: 2	100 MVAr - Bus 63	100 MVAr - Bus 38	100 MVAr - Bus 38
	Capacitor: 3	5 MVAr - Bus 118	90 MVAr - Bus 64	100 MVAr – Bus 63
	SVC (Qsvc)	45.14MVAr-Bus 94	38 MVAr - Bus 95	-100MVAr - Bus 17
	TCSC (X_{TCSC})	$0.5X_L$– Line 23-32	$0.5X_L$ - Line 49-69	$0.5X_L$ - Line 23-25
	TPL	131.7903	131.7666	131.6523
	TPL minimization (%)	0.8074	0.8252	0.9112

The case wise discussions based on Table 2 are given below.

Case 1: Static compensation

GA optimally places the three shunt capacitors at bus 38, 94 and 118 with a rating of 100, 60 and 5 MVAr, respectively. The resultant TPL after compensation is 132.4502 MW, which is 0.3107% less when compared to the base case as shown in Table 2. PSO selects bus 38, 96 and 118 as the optimal buses for compensation with a rating of 100, 40 and 5 MVAr. Thus using PSO the TPL value is minimized to 132.3727 MW which is 0.3690 % less when compared to base case. Whereas, the proposed algorithm ICA selects bus 38, 64 and 95 as optimal buses with a rating of 100, 100 and 40 MVAr thereby reducing TPL to 132.3188 MW which is 0.4096 % less when compared to base case, shown in Table 2.

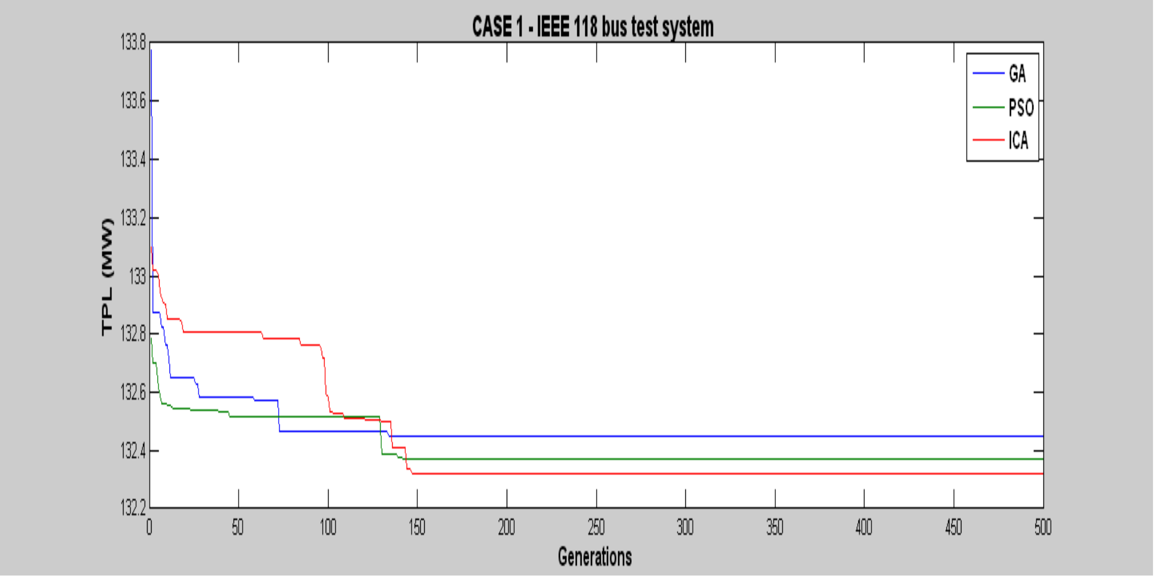

Fig.5 Convergence for Case 1 of IEEE-118 bus system

Case 2: Dynamic compensation

In this case GA optimally places SVC at bus 38 with Qsvc of 100 MVAr and TCSC in line 23-25 with X_{TCSC} of 0.5 thereby minimizing TPL to 132.0855 MW which is 0.5852 % less when compared to base case.

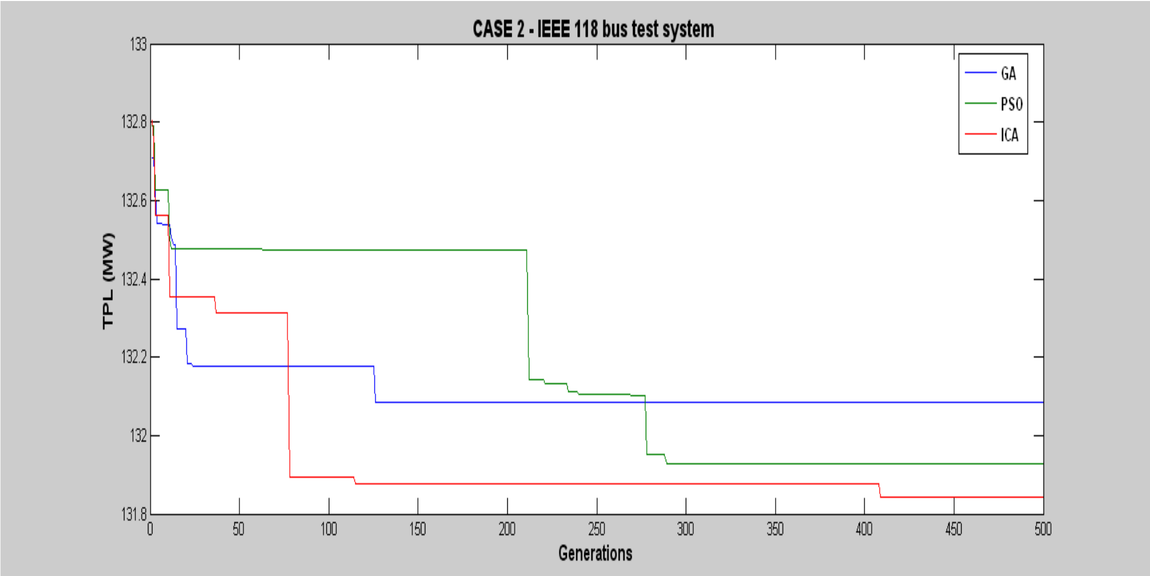

Fig.6 Convergence for Case 2 of IEEE-118 bus system

PSO optimally places SVC at bus 17 with Qsvc of -19.6 MVAr and TCSC in line 38-65 with X_{TCSC} of -0.2 thereby minimizing TPL to 131.9272 MW which is 0.7043% less when compared to base case. On the other hand the proposed algorithm ICA optimally places SVC at bus 38 which is similar to GA placement but with Qsvc of 99 MVAr and TCSC in line 38-65 with X_{TCSC} of -0.2 which is similar to PSO thereby minimizing TPL to 131.844 MW which is 0.7669 % less when compared to base case.

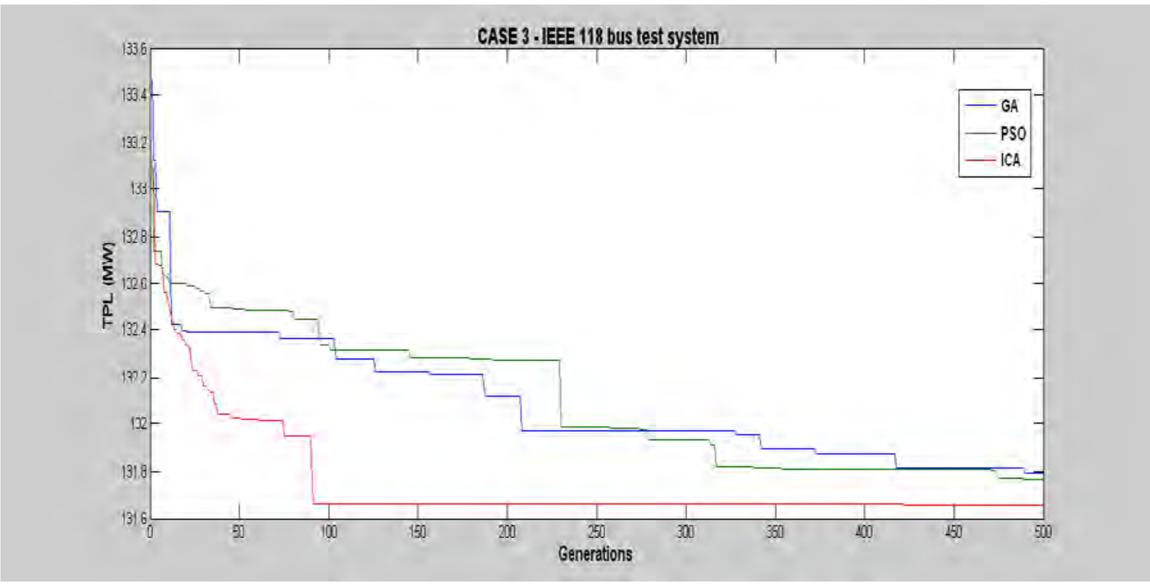

Fig.7 Convergence for Case 3 of IEEE-118 bus system

Case 3: Static and Dynamic compensation

In Case 3, GA optimally places the three shunt capacitors at bus 38, 63 and 118 with a rating of 80 MVAr, 100 MVAr and 5 MVAr, respectively and the SVC at bus 94 with Qsvc of 45.14 MVAr and TCSC in line 23-32 with X_{TCSC} of 0.5 thereby minimizing TPL to 131.7903 MW which is 0.8074 % less when compared to base case.

Further, PSO chooses the optimal points for the three shunt capacitors at Bus 21, 38 and 64 with a rating of 10, 100 and 90 MVAr and the SVC at Bus 95 with Qsvc of 38 MVAr and TCSC in line 49-69 with X_{TCSC} of 0.5 thereby minimizing TPL to 131.7666 MW which is 0.8252 % less when compared to base case.

On the other hand the proposed algorithm ICA optimally places the three shunt capacitors at bus 30, 38 and 63 with a rating of 100 MVAr each and the SVC at bus 17 with Qsvc of -100 MVAr and TCSC in line 23-25 with X_{TCSC} of 0.5 thereby minimizing TPL to 131.6523 MW which is 0.9112 % less when compared to base case.

Figs. 5, 6 and 7 show the convergence characteristics for GA, PSO and ICA in case 1, 2 and 3, respectively for IEEE- 118 bus system. From Table 2, it is evident that case 3 is better when compared to case 1 and case 2 in TPL minimization and also in case 3 using the proposed ICA algorithm the TPL value is 0.0868 % and 0.1048 % lesser when compared to PSO and GA, respectively.

VI. CONCLUSION

This paper presented a novel approach of simultaneous static and dynamic compensation for TPL minimization. ICA algorithm is implemented in optimal sizing and placement of static and dynamic compensation. Test results of the proposed method under three cases (Case 1: Static compensation, Case 2: Dynamic compensation, Case 3: Static and Dynamic compensation) on IEEE-14 and IEEE- 118 bus test systems are also presented. Results obtained using ICA is compared against GA and PSO approaches. Results indicate that Case 3 compensation is better in TPL minimization when compared to Case 1 and Case 2. Further, the proposed ICA algorithm outperforms GA and PSO in all the three cases.

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