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Application of Imperialist Competitive Algorithm (ICA) in Minimization of Cost of Energy Loss after Capacitor Allocation in Distribution System

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Abstract. In this article, a new meta-heuristics optimization algorithm called imperialist competitive algorithm (ICA) is proposed. This is inspired by the competition of imperialistic. ICA initializes the random population, which is known as country. Colonies and imperialists are the two categories of countries that are part an empire. Empire with minimum costs gives the optimal solution for placement of capacitor with finest size and site in the distribution system (DS). The objective function is minimizing the cost of energy loss. The ICA is examined on the IEEE 69-Bus system with different load levels. Results showed that ICA has superior performance and more efficient to find optimal solution compared to other algorithms.

Keywords: Distribution system, Cost of energy loss, Capacitor placement, voltage profile, distribution generation.

INTRODUCTION

In today's scenario power distribution system (DS) suffers with large amount of power losses which is causing high costs. It is known that distribution usually runs at a low voltage level and high current amplitude. As the bus moves away from the substation, the voltage drops and the power losses increase. Overall power losses in the DS are made up of reactive and real power losses. The flow of real and imaginary current components, respectively, causes active and reactive power losses in DS. Active power losses are more significant as it reduce the voltage profile and affecting the capability of power transfer. According to various research studies, the total dissipated loss is almost 13% of total generated powerat the distribution level [1]. Due to the limitation of radial line capacity, it is important to ensure good supply quality with an improved voltage profile via the appropriate method.

Nowadays DG and capacitor installation are the most appropriate method to overcome major challenges like minimization of cost, power losses, reduction in voltage, and CO2 emission. Reactive power compensation provided by the Capacitors is enhancing the voltage profile and power factor as well as mitigate the losses. In recent years, it is acknowledged by the researchers that size and site of capacitor andDG should be optimum to attain the objectives. Even though DG and capacitor maximize the benefits in the DS, but inappropriate insertion of capacitor as well as DG can reduce the benefits. Thus insertion of capacitor and DG in DS is still a challenging task.

In order to accomplish the aforesaid benefits, DG and capacitor size and location should be optimal. So many appropriate algorithms proposed by researchers. Some analytical [2], numerical [3], programming, and heuristics [4, 5] methods have been used literature. Finest site and size of DG in the DS to reduce the losses were explained in [6, 7, 8, 9]. In [10], an artificial bee colony algorithm is used to select the best DG site and size with the aim of mitigating losses. For cost-benefit analysis, an unsullied methodical technique was offered to determine the position and size of the shunt capacitor as well as DG [11]. Mehta et al. [12] explained an optimization model to decrease the losses in the DS using DG. To reduce losses, a hybrid Grey Wolf Optimizer technique is employed to decide the size and site of the dg unit [13]. To assign the dg in the DS using the loss sensitivity factor, simulated annealing and harmony search processes were utilized [14, 15].

To mitigate the losses in the DS capacitor placement firstly introduce by baran & wu. [16]. Integrated Particle Swarm Optimization and rough set theory is explained for the combined placement ofautomatic voltage regulators (AVRs), capacitor banks, and DGs to decrease the costs [17]. Ant Lion Optimization [18] and Artificial Bee Colony [19] is employed to minimize the power loss by allocating capacitor in addition to cost minimization & improvement of the voltage profile. In ref. [20], injecting reactive and active power with a capacitor and DG combination is elaborated todiscover the best size and site.In ref. [21], a hybrid optimization-based artificial immune system and artificial bee colony were used to trace the optimumsite of the capacitor and dg simultaneously for loss reduction and voltage profile enhancement. To trace the optimal location of capacitor in the DS was explained in

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using the optimization methodologies like dice game optimizer algorithm [22], Particle Swarm optimization [23],evolutionary programming (EP) [24] and Enhanced Grey Wolf Algorithm [25] to improve the voltage profile, minimizing the capacitor cost andreduce the losses. Literature [26] represented the back-tracking search algorithm for the optimum allocation of tcsc, capacitor bank, and DG to reduce the losses. Further optimal allocation of dg & capacitor banks consideringload balancing & voltage stability index improvement, loss reduction, voltage profile enhancement has been addressed in [27] using imperialist competitive algorithm & GA.
In this paper, ICA is utilized to allocate capacitor units in distribution system with an objective function of cost minimization of energy loss. This algorithm is tested on 69 bus system with different load scenarios.

PROBLEM FORMULATION

The problem is to minimize the cost of energy loss by finding the optimal location and size of capacitor in DS.
The objectives function is described below: -

Cost of energy losses

Total Cost can be computed by given equation: -

$$\boldsymbol{Minimum\ Cost = K_p P_{loss} + \sum_{k=1}^{n} K_{fc} Q_{fc}} \quad (1)$$

Where K_p is the coefficient of loss cost in rupees/KW, The total power loss of DS is given by P_{loss}. K_{fc} is the purchased costs of capacitor rupees/KVAr and Q_{fc} is the size of the capacitor. n is the total number of capacitor.

IMPERIALIST COMPETITIVE ALGORITHM

ICA was firstly acknowledged by Lucas andGargari. It is encouraged by the competition of imperialist [28]. **Fig.2** exhibits theICA's flow chart. ICA contains the initial population, which is called as country, just like the other algorithms. Countries with the minimum cost value are assigned as imperialists. Rest of the countries assigned as colonies. In our problem imperialist demonstrating the best candidate bus for allocation of capacitor and colonies are demonstrating the rest of the buses. Candidate bus, including rest of the buses together forms an empire.All colonies are shared among the imperialists. This sharing is done on the basis of power. Now, buses changes position according to most powerful candidate bus. These colonies approach towards most powerful imperialists. The Movement of colonies is revealed in **Fig.1.**If any bushas more power than candidate bus, the candidate bus position will be interchanged with that bus. An empire's entire power is determined by the sum of power ofcandidate bus and power of all buses.

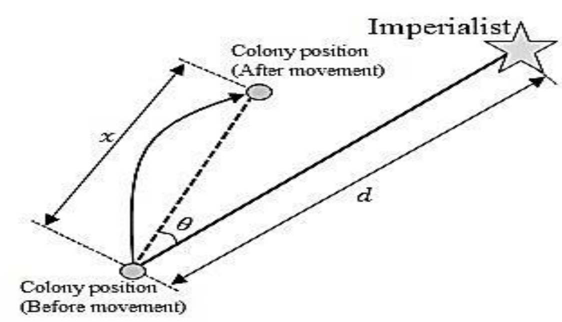

FIGURE 1. Colony Moving Towards Their Pertinent Imperialist

The imperialistic competition begins in the next step. Any empire, which is not able to increase its power, is eliminated. The competition will result in a moderate increase in the power of powerful and a decline in the weaker one. Weak empire will downfall after competition. In this process, the association of colonies on the way to their respective imperialist will force all countries to converge to a condition in which there is just one empire remain, and all countries grow into its colonies. In such conditions, imperialistic competition stops.

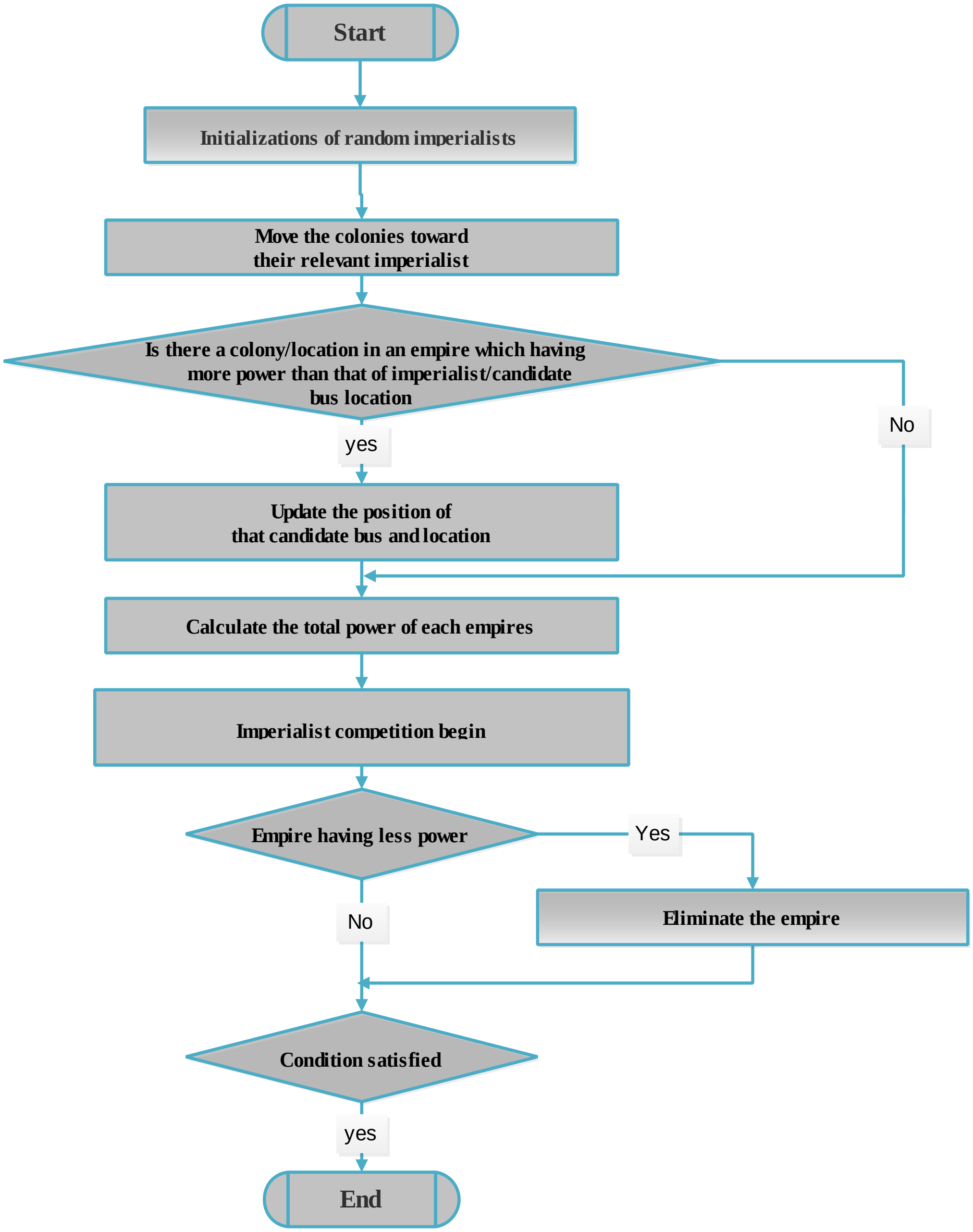

FIGURE 2. Flow Chart of ICA

RESULTS AND DISCUSSION

The proposed approach for minimizing cost of energy loss by allocating capacitor was evaluated on a standard IEEE 69-bus system to demonstrate its superiority. To analysis the effectiveness and performance of the proposed algorithm, three different load levels are considered as 0.5 loading, nominal loading, and 1.5 loading.This algorithm programmed in MATLAB software to perform load flow and calculate the power losses. Value of loss cost coefficient (K_p) is assumed as 168 $/KW [18] and capacitor cost (K_{fc}) is assumed as 3 $/KVAr [30]. Here values of 1$ (dollar) taken 71 rupees.

IEEE 69-Bus Syatem

IEEE 69- bus distribution system has reactive power andreal power load 2.69MVAr and3.8MW respectively. It consists of 68 branches and 69 buses. The substation voltage is considered as 12.66KV. Reactive and Active power losses are 102.02KVAr and 224.66KW respectively before placing capacitor. **Fig**.3 exhibits the single line diagram of the 69-bus system.

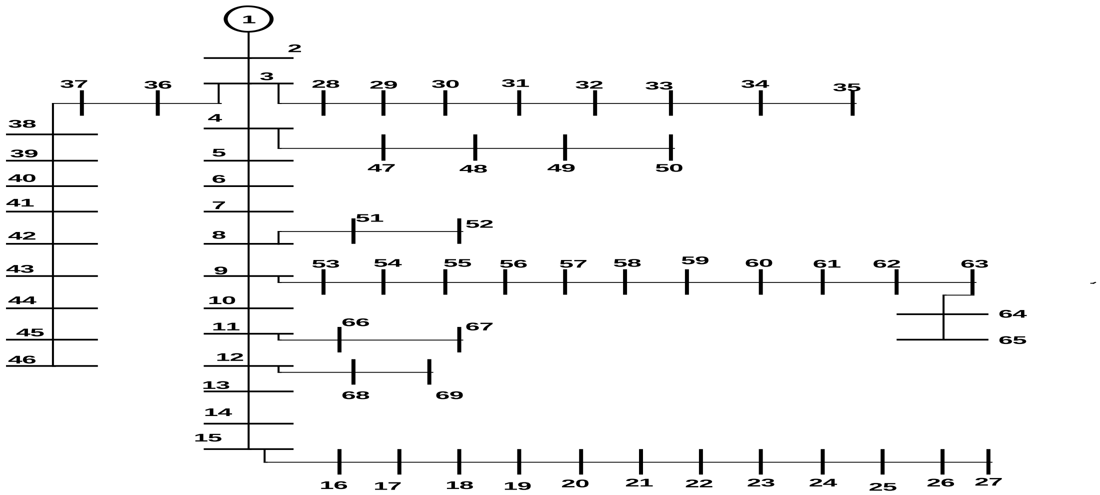

FIGURE 3. IEEE 69- Bus System

TABLE 1. Results of 69-Bus System at Nominal Loading

		Base case	With capacitor
loss	KW	224.66	146.56
	KVAr	102.02	68.29
location and size (KVAr)		-	16 397.5 61 1200
V(min)		-	0.9301
CO2(Kton)		1484.5	1484.1
Loss Cost (rupees)		2679744.48	1748167.68
Capacitor Cost (rupees)		-	340267.5
total Cost (rupees)		2679744.48	2088435.18

TABLE 2. Results of 69-Bus System at 0.5 Loading

		Base case	With capacitor
loss	KW	51.59	34.41
	KVAr	23.55	16.09
location and size (KVAr)		-	12 265 61 600
V(min)		-	0.9665
CO2(Kton)		724.52	724.43
Loss Cost (rupees)		615365.52	410442.48
Capacitor Cost (rupees)		-	184245
total Cost (rupees)		615365.52	594687.48

TABLE 3.Results of 69-Bus System at 1.5 Loading

		Base case	With capacitor
loss	KW	560.46	353.90
	KVAr	253.05	164.03
location and size (KVAr)		-	17 530 61 1950
V(min)		-	0.8928
CO2(Kton)		2289.9	2287.2
Loss Cost (rupees)		6685166.88	4221319.2
Capacitor Cost (rupees)		-	528240
total Cost (rupees)		6685166.88	4749559.2

The results of different load levels shown in **TABLE 1, 2 and 3**of 69-bus system. The results show that in all cases after placing capacitor at candidate buses, objectives like cost reduction, to enhance voltage profile and power loss minimization are improved.It can observe in **TABLE 4,** that total annual energy cost is reduced from 2679744.48 rupees to 2088435.18 rupees with reduction of 22.06%. this is the best result when it compared to 19.60% of IHA [29], 20.96% of ALO [18], 21.54% of TLBO [30] and 20.26% of DSA [31]. Real power loss is146.56KW by proposed ICA, which is also best in comparison to 148.48KW, 146.80KW and 147KW of IHA [29], TBLO [30] and DSA [31] respectively.

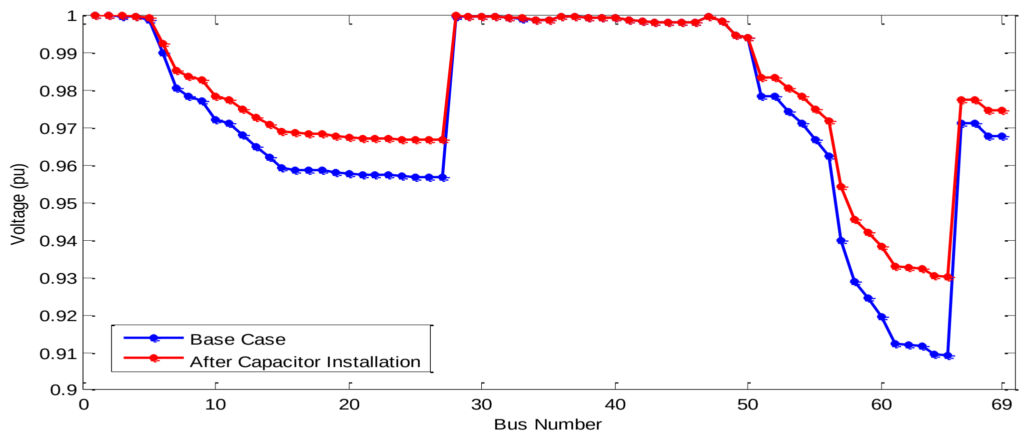

FIGURE 4. Voltage Profilewithout Capacitor and with Capacitorsat Nominal Loading of 69-Bus System

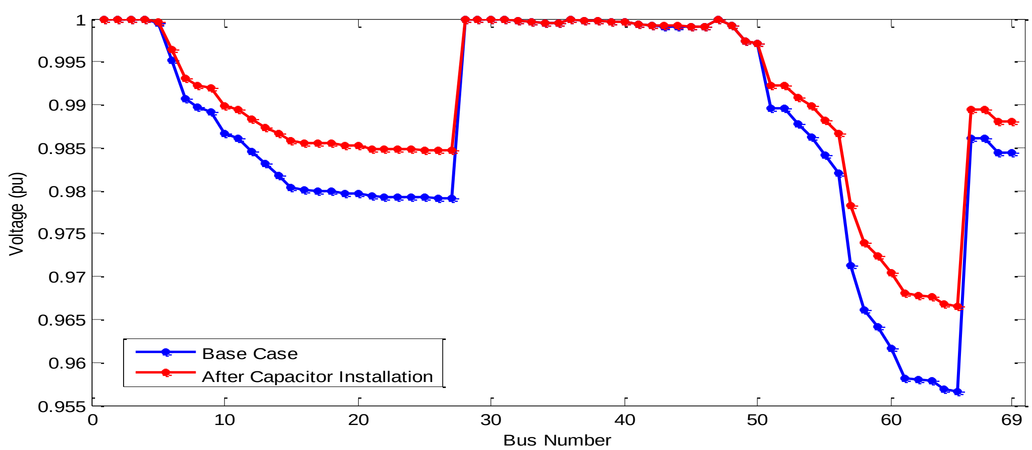

FIGURE 5. Voltage Profile without Capacitor and with Capacitorsat 0.5 Loading of 69-Bus System

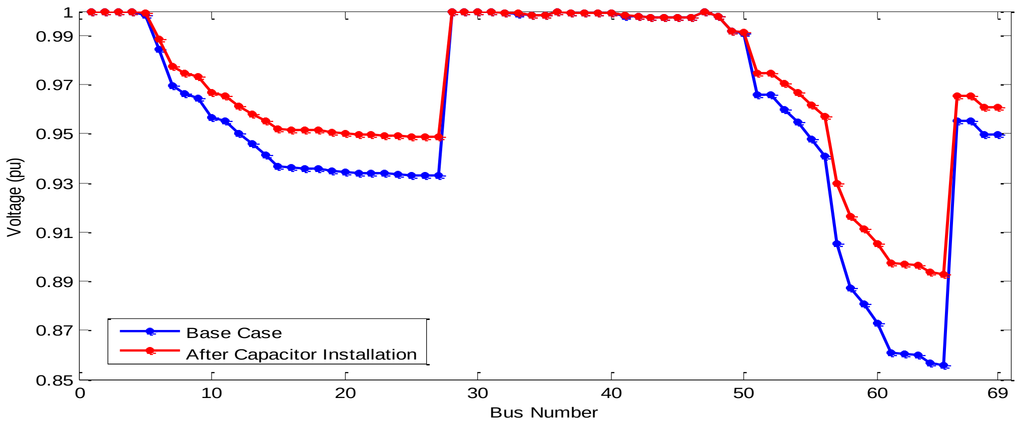

FIGURE 6. Voltage Profile without Capacitor and with Capacitorsat 1.5 Loading of 69-Bus System

Fig.4, 5 and 6 showsthe base case and after capacitor installation voltage profile comparison at nominal loading, 0.5 loading and 1.5 loading respectively. These results clarify that ICA hasoutstanding performance compared to other methods.

TABLE 4. Optimal Results for Cost Minimization of IEEE 69-Bus System

	Base case	With capacitor									
		IHA[29]		ALO[18]		TLBO[30]		DSA[31]		Proposed ICA	
Optimal location & size (KVAr) of capacitors	-	8 58 60	600 150 1050	22 12 61	150 450 1200	22 61 62	300 1050 300	15 60 61	450 450 900	16 61	397.5 1200
Total KVAr		1800		1800		1650		1800		1597.5	
Power loss(KW)	224.66	148.48		145.4061		146.80		147		146.56	
Loss costs(rupees)	2679744.48	1771069.44		1734403.9608		1751030.4		1753416		1748167.68	
Capacitor costs(rupees)	-	383400		383400		351450		383400		340267.5	
Total costs(rupees)	2679744.48	2154469.44		2117803.9608		2102480.4		2136816		2088435.18	
Total cost reduction(%)	-	19.60		20.96		21.54		20.26		22.06	

CONCLUSION

This paper presents a method known as the ICA algorithm to solve the problem of allocation of capacitor in DS. The placement and size of capacitor is calculated to minimizing cost of energy loss. ICA tested on 69 test system at different load levels. Obtained results have been compared with other algorithms. Comparison proves the superiority of ICA, as it has lowest cost of energy loss, higher loss reduction, improved bus voltage, and excellent performance of convergence.

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