International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 8, Number 4 (2015), pp. 389-402

http://www.irphouse.com

Capacitor Sizing For Reactive Power Control By Using Particle Swarm Optimization

M. Suneetha, Dr. R. Srinivas Rao and Dr. B. Subramanyam,

Associate Professor, Department of EEE, NEC, Nellore, AP.
Associate Professor, Department of EEE, JNTUCE, Kakinada, AP.
Ex-Principal, S. V. U college of engg, Tirupathi, AP.

Abstract

Reactive power control is a very essential and necessary strategy to maintain the safe and reliable operation of power system. There are different methods available for the optimization of reactive power. In spite of the advantages of power electronic devices, placement of the capacitors still remains technically viable and an economically affordable option for reactive power control. In this paper, we have proposed a method of reactive power control by optimum sizing of capacitor with the help of particle swarm optimization. Two approaches are studied, where in the PSO optimizes losses in real power in one approach and losses in reactive power in another approach. To validate the proposed approach an IEEE 30 bus, test bus is considered. A tool in the form of Graphical User Interface is also presented as part of this work.

Key words: Reactive power-PSO-IEEE 30 Bus- Sizing of capacitor, tool.

I. INTRODUCTION

Voltage control in an electrical power system is an important operational task essential for reducing the transmission losses and to enhance the ability of the system to avoid and withstand voltage collapse. The importance o reactive power control can be inferred from the fact that the current has to be increased to sustain the supplied power.

These results in cascading effect which can make the transmission lines overloaded and result in possible line outages. Similarly if the voltage drops too low, some of the generators may also trip to protect themselves. This is a cyclic effect in which any loss of transmission capacity or generation capacity which subsequently leads to voltage drops that will eventually result in outages of more transmission lines and generators. This will ultimately result in the failure of the power system. In addition to these facts, the power equipment is designed to operate typically within range of voltage low or high voltage below or beyond the specified voltage; it will result in poor performance of the system and sometimes can result in damage to the equipment. The importance of reactive power control can also be understood from the fact that the reactive power consumes transmission and generation resources. So in order to maximize the amount of real power that can be transferred across a transmission line, the reactive power flows must be minimized. Similarly, the reactive power will also compromise the generators real power capability. Additional capacity and energy are required to compensate for the loss of real power. India is one nation which has significant transmission and distribution losses, shunt capacitors have long been used for reducing the power and energy loss. Apart from reducing transmission and distribution losses, the shunt capacitors are also capable of providing reactive power compensation and enhancing overall power factor of the system. Even though, power electronic devices have multiple capabilities and are capable of providing reactive power compensation, capacitors still remain one of the best possible options that can provide reactive power compensation at an affordable cost.

II. LITERATURE SURVEY

Heinz K. Tyll, SM [1] proposed a Reactive power compensation scheme with the help of power electronics; they proposed that Broad variety of FACT devices can be used to provide reliable solution for most challenging circumstances in power transmission. Guomei PAN, Yonggang PAN, Xuhang ZHANG [2] collected data from recorder and real time dynamic simulation system RTDs and focused on the impact of switching capacitors on dynamic power quality under different situations. Surya Santoso, [3] proposed a method to identify the relative location of switched capacitor Bank by using voltage and current waveforms recorded at a single point measurement. Om Prakash Mahela, Devendra Mittl and Lalit goyal [4] presented details about different strategies that can be employed for optimal location of capacitor banks the proposed solutions that can bring about line loss reduction. A. A. E. Shammah, Ahmed M. Azmy and A. Abou ElEla [5] presented a technique to optimize the placement and sizing of fixed bank capacitors in a radial distribution network. They proposed to monitor and regulate the network voltage centrally and maintain the overall voltage profile of power transmission system. Mrs. V. Usha Reddy, Dr T. Gowri Manohar and P. Dinakara Prasad Reddy [6] formulated a new strategy for different levels substation voltage reduction by strategic placing of capacitors. A proposed that such a method utility can avoid paying high prices and can save on energy charges. Brahim GASBAOUI, Abd-el-Kader CHAKER[7] obtain minimization of total active power loss and optimize reactive power loss by optimally placing the capacitors at proper location in electrical distribution system. M. Damodar Reddy and Prof. V. C. Veera Reddy [8] presented a method to reduce power loss and improve voltage profile by placing the capacitors in the primary feeders of radial distribution system through fuzzy and real coder genetic algorithm. Seyed Abbas Taher, Ali Karimian[9] proposed method for improvement of power quality to optimal placement of fixed capacitors by considering their operation in presence of voltage and current harmonics. Mohd Nabil Muhtazaruddina*, Jasrul Jamani Jamianb[10] investigated the solution to determine the location and size of capacitors to help artificial be colony algorithm. Jagadeesh Gunda and Nasim Ali Khan[11] presented a study detailing how differential evolution algorithm can utilize for identifying the location and size of the capacitors. Dr. Balwinder Singh Surjan[12] proposed a novel technique to determine the optimum capacitor placement in distribution system to the help of Tabu search.

III. PROBLEM FORMULATION

Optimal control of reactive power is a classic case of optimization problem which has complex interaction between multiple parameters. The reactive power as such can be controlled by numerous parameters which include adjusting the input generator bus voltages changing the tap ratio of transformers etc., Controlling and optimizing the reactive power output through a shunt compensator like a capacitor play a very critical role and controlling power losses. In this research work a constrained optimization approach is proposed reducing power loss by optimizing the capacitor values. It is expected that the constrained optimization approach will provide better results, in terms of convergence of solution and also minimization of loss by taking into account the complex nature of reactive power.

The constraints that are included (a) Active power flow by excluding slack bus. (b). Reactive power flow in load bus (c) any quality constraint like reactive power generation limit for each generator bus(d) voltage magnitude limit for each bus. The fitness function formulated for above objective can be described below:

$$\min \sum_{k \in N_E} P_{kloss} = \sum_{k \in N_E} g_k (v_i^2 + v_j^2 - 2 v_i v_j \cos\theta_{ij}) \tag{1}$$

where,

$k = (i, j);\ i \in N_B$ (Total no. of buses)

$j \in N_i$ (No. of buses adjustment to bus i,including bus i)

$\sum_{k \in N_E} P_{kloss}$ = Total active power losses in the transmission system

g_k = Conductance of branch k(pu)

v_i, v_j = voltage magnitude(pu) of bus i and j respectively

θ_{ij} = load angle difference between bus i and j(rad)

The Equality constraints are defined as follows

Active power flow balance equations at all buses excluding slack bus

The equality constraints are defined as below the flow of active power at all buses excluding slack bus is given in equation (2)

$$P_{gi} - P_{di} - v_i \sum_{j \in N_i} v_j (g_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \tag{2}$$

Reactive power flow balance equations at all PQ buses (load buses)

Reactive power flow balance at all PQ buses as given in equation (3)

$$Q_{gi} - Q_{di} - v_i \sum_{j \in N_i} v_j (g_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}) = 0 \tag{3}$$

The inequality constraints are defined as mentioned below

reactive power generation limit for each generator bus

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}, i \in N_g$$

voltage magnitude limit for each bus

$$v_i^{\min} \le v_i \le v_i^{\max}, i \in N_B$$

in equality constraints for Reactive generation limit and voltage magnitude limit are given equations (4) and (5)

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times (p_{best_i} - x_i^k) + c_2 \times r_2 \times (g_{best} - x_i^k) \tag{4}$$

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1} \tag{5}$$

Where,

v_i^{k+1} : The velocity of i^{th} particle at $(k+1)^{th}$ iteration

w : Inertia weight of the particle

v_i^k : The velocity of i^{th} particle at k^{th} iteration

$c_{1,}c_2$: Positive constants having values between [0, 2. 5]

r_1, r_2 : Randomly generated numbers between [0, 1]

p_{best_i} :The best position of the i^{th} particle obtained based upon its own experience

g_{best} : Global best position of the particle in the population

x_i^{k+1} : The position of i^{th} particle at $(k+1)^{th}$ iteration

x_i^k : The position of i^{th} particle at k^{th} iteration

χ : Constriction factor. It may help insure convergence.

Suitable selection of inertia weight w provides good balance between global and local explorations.

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter$$

Where, $w_{\max}$ is the value of inertia weight at the beginning of iterations, $w_{\min}$ is the value of inertia weight at the end of iterations, $iter$ is the current iteration number and $iter_{\max}$ is the maximum number of iterations.

IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization was proposed by Ederhart and Kennedy (13). It is a fast, simple and efficient population based optimization method. A random population of particle is initially generated; each particle represents a potential solution which is represented by a position vector. A swarm of particles will move through problem space with each particle having specific velocity represented by a velocity vector. Each particle is capable of tracking its own best position in relation to the best fitness vector available in the solution space. At each time step quality measure is calculated by using the position vector as input. Each particle is capable updating its own position by inferring its best position, global best position and previous velocity vector which can be defined by following equation(4) and(5)

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times (p_{best_i} - x_i^k) + c_2 \times r_2 \times (g_{best} - x_i^k) \quad (4)$$

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1} \quad (5)$$

V. GRAPHICAL USER INTERFACE (GUI)

In order to make the research work delivered in the form of a tool, a GUI is created. The objective of the GUI can be listed as below:

1. To be an effective Research tool that can be used to analyze the suitability of the proposed optimization approach on different test bus system and real time system.
2. To provide generalized and defined structure for giving input and analyzing different PSO parameters.
3. To provide the user with flexibilities and ease of use.

The Graphical user interface has the scope for inputting different Particle swarm optimization parameters. These parameters are particle population, number of iterations and particle velocity (Both forward and reverse direction). Once the suitable Particle swarm optimization parameter is chosen using the parameters load button, the user can input these parameters for subsequent particle swarm optimization. By running pre optimization tool, optimum power flow calculation can reveal the amount of real power loss and reactive power loss before optimization. By clicking the Particle swarm optimization button, the user can initiate the process of proposed optimization and the results are tabulated. The tabulated results including real and reactive power losses post optimization and the difference between pre and post optimization. It also provides the capacitor values that should be added in order to achieve that amount of loss of real and reactive power. An overall analysis of cost comparing the cost of capacitor installation and cost saved by reducing the power losses is also given. This gives a very good pointer towards the amount of capital that may be invested and saved. A plot which depicts the reduction of real power in the due course of optimization is also provided.

VI. RESULTS

The result of the proposed approach is discussed in this section. To validate the proposed approach an IEEE 30 Bus system is considered. The load flow is done using Newton Raphson method.

Two different types of results are compared and presented in this work. One is the result of optimization where the objective function is to optimizing the real power to suitably identify the size of capacitors. The other result is the result of optimization approach in which the objective function is to minimize the reactive power loss. Both the approaches, approach1 and approach2 are validated by choosing different number of iterations and number of particles in the implementation of PSO. The velocity of positive direction is maintain at point 0. 1 and the velocity negative direction is -0. 1. The results of optimization of the both the approaches are presented in Run 1 & Run 2. The screen shot of the designed tool is depicted in the figure below.

Both the tables illustrates among other things the amount of power saved total capacitance added, cost of power saved etc., it can be inferred table 1 and table 2 the real and reactive loss as before optimizated stands at 18. 02 MW and 70. 94MVAR respectively. The losses are calculated by executing Dc power flow for base case. From the table 1 Approach 1, it can be observed there are 8 runs pertaining to different number of iterations and different particles for the PSO optimization. Each run comprises of 25 trial runs and best result of those trials is presented here. Similar number of runs and trials are adopted for both the approaches.

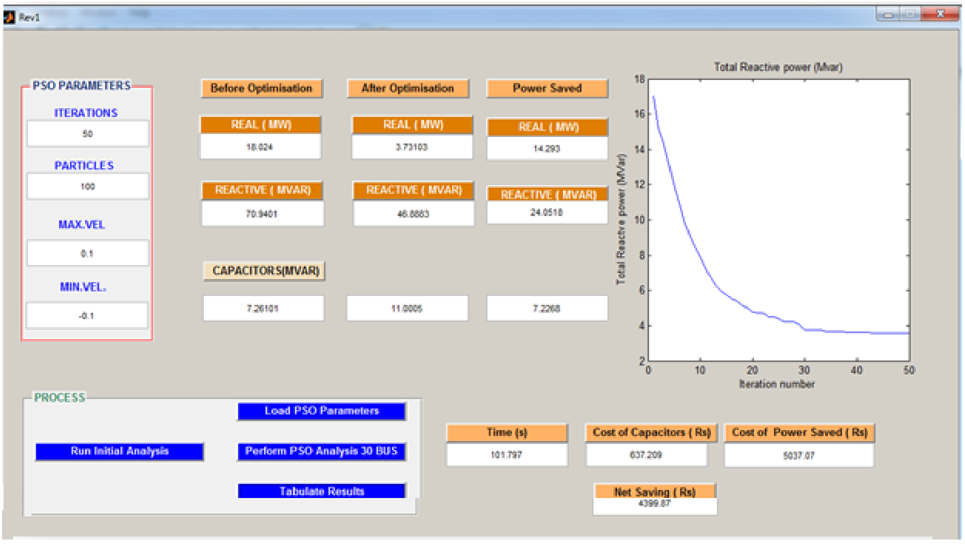

Figure 1:'Sizing of capacitors based on reactive power' for Approach1.

Table 1: Approach 1: 'Sizing of capacitors based on reactive power'

S. No	Iterations	Particles	Before optimization		After optimization		Power saved		Capacitors MVAR	Cost of capacitors	Cost of power saved	Net saving
			P	Q	P	Q	P	Q				
Run1	50	100	18. 02	70. 94	3. 73	46. 88	14. 29	24. 05	25. 48	637. 20	5037. 07	4399. 87
Run2	100	100	18. 02	70. 94	4. 95	27. 91	13. 1	43. 02	24. 95	624. 06	7761. 38	7137. 3
Run3	150	100	18. 02	70. 94	2. 86	26. 08	15. 2	44. 85	22. 53	563. 57	8244. 12	7680. 5
Run4	200	100	18. 02	70. 94	3. 72	22. 06	14. 3	48. 87	24. 43	610. 89	8760. 58	8149. 5
Run5	50	50	18. 02	70. 94	5. 16	68. 9	12. 6	2. 03	23. 3	582. 69	1591. 28	1008. 5
Run6	100	50	18. 02	70. 94	4. 38	35. 9	13. 6	35. 03	25. 82	645. 76	6618. 85	5973. 1
Run7	150	50	18. 02	70. 94	3. 72	23. 88	14. 3	47. 05	25. 95	648. 94	8488. 53	7839. 5
Run8	200	50	18. 02	70. 94	6. 44	27. 77	11. 6	43. 16	25. 0	591. 76	7633. 21	7041. 4

Table 2: Approach 2: 'Sizing of capacitors based on optimizing real power'

S. No	Iterations	Particles	Before optimization		After optimization		Power saved		Capacitors MVAR	Cost of capacitors	Cost of power saved	Net saving
			P	Q	P	Q	P	Q				
Run1	50	100	18. 02	70. 94	6. 455	24. 96	11. 57	45. 97	17. 8	445. 24	8053. 01	7607. 7
Run2	100	100	18. 02	70. 94	4. 64	18. 35	13. 37	52. 58	20. 32	508. 52	9225. 1	8716. 5
Run3	150	100	18. 02	70. 94	5. 63	21. 77	12. 38	49. 16	19. 75	494. 113	8612. 74	8118. 6
Run4	200	100	18. 02	70. 94	5. 26	20. 33	12. 76	50. 6	17. 99	450. 05	8866. 75	8416. 7
Run5	150	50	18. 02	70. 94	6. 11	23. 9	11. 9	47. 03	24. 53	613. 5	8245. 99	7632. 4
Run6	150	100	18. 02	70. 94	5. 63	21. 77	12. 38	49. 16	19. 75	450. 05	8866. 75	8416. 7
Run7	150	150	18. 02	70. 94	4. 33	17. 47	13. 68	53. 46	21. 16	529. 31	9388. 09	8858. 7
Run8	150	200	18. 02	70. 94	5. 42	20. 73	12. 59	50. 2	18. 06	451. 98	8790. 81	8338. 8

Figure 2:'Sizing of capacitors based on optimizing Real power' for Approach2

Considering the run in which the total number of iterations is 50, the size of the particles 100 for Table 1:approach1. The real power loss after optimization is 3. 73MW and reactive power loss is 46. 88MVAR, for same corresponding run in the Table 2:approach 2 the Total real power losses or Total Active power losses after optimization is 6. 45MW while the reactive power loss is 24. 96 MVAR. Figure3&4 illustrates the results of approach 1 and approach2 respectively. Similarly for the run in which the number of iterations is fixed at 100, the particle size at 100 for approach1 the real power loss after optimization stands at 4. 95MW while the reactive power loss falls down to 27. 91MVAR. For the same scenario for approach 2 the real power loss falls down to 4. 64MW and reactive power loss falls down to 18. 35MVAR. Figure5&6 illustrates the results of approach 1 and approach2 respectively, it can be observed for this run the approach2 performs better for reduction of both real power loss and reactive power loss when compared to approach1.

TABLE (3): Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 1 when Number of iteration:50, Particles :100

	Real Power Loss	Reactive Power Loss
Before Optimization	18. 02	70. 94
After Optimization	3. 73	46. 88

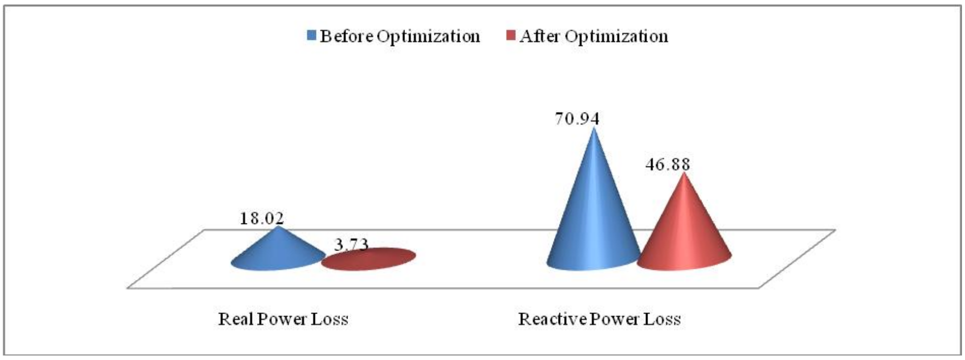

Figure 3: Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 1 when Number of iteration:50, Particles :100

TABLE (4): Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 2 when Number of iteration:50, Particles :100

	Real Power Loss	Reactive Power Loss
Before Optimization	18. 02	70. 94
After Optimization	6. 455	24. 96

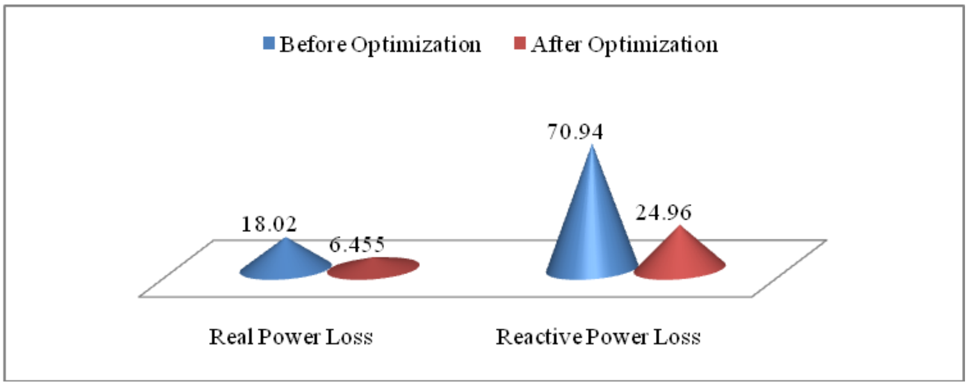

Figure 4: Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 2 when Number of iteration:50, Particles :100

TABLE (5): Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 1 when Number of iteration:100, Particles :100

	Real Power Loss	Reactive Power Loss
Before Optimization	18. 02	70. 94
After Optimization	4. 95	27. 91

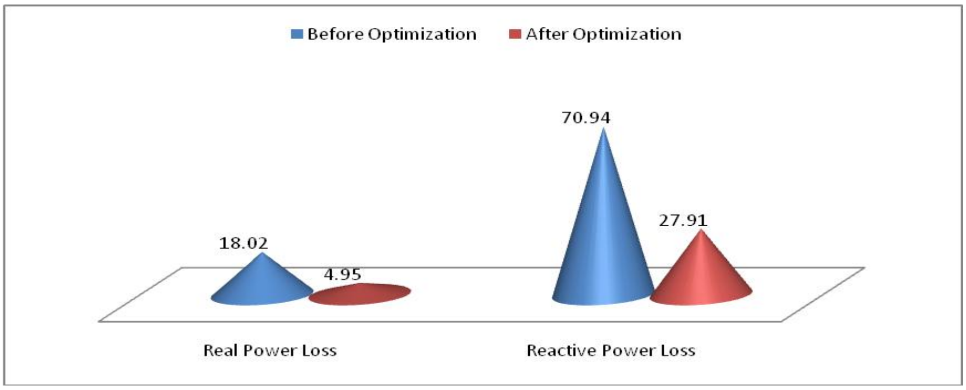

Figure 5: Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 1 when Number of iteration:100, Particles :100

TABLE (6): Comparison between Before optimization and after optimization of Real and Reactive power loss for Approach 2 when Number of iteration: 100, Particles: 100

	Real Power Loss	Reactive Power Loss
Before Optimization	18. 02	70. 94
After Optimization	4. 64	18. 35

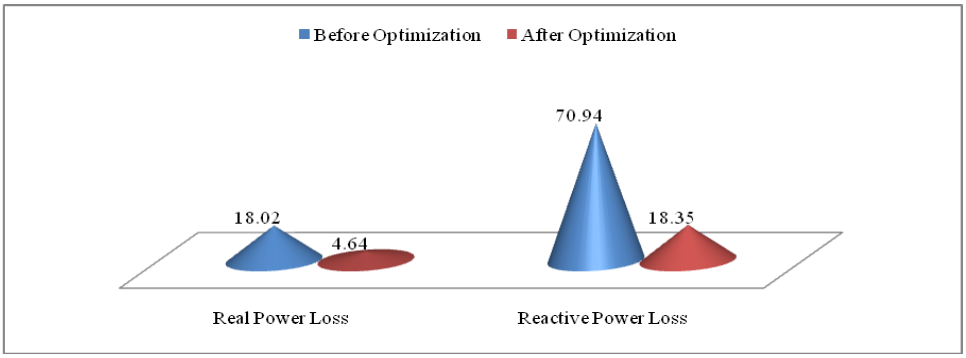

Figure 6: Comparison between before optimization and after optimization of Real and Reactive power loss for Approach 2 when Number of iteration:100, Particles :100

When the total size of capacitor added is compared case1 and case 2 can be inferred for approach 1 the capacitance for the total capacitors added for optimizing is 25. 48 and for approach2 the capacitance is 17. 8 MVAR. Similarly for case2 approach 1 identified the size of capacitor to be added as 24. 95MVAR while approach2 result in additional capacitance for 20. 32 MVAR.
Fig 7&8 illustrates the additional capacitance implied by both optimizations.

TABLE (7): Comparison between Run 1- Approach1 and Run 1-Approach2 for Capacitors in MVAR

	Capacitor- MVAR
Run1-Approach1	25. 48
Run1-Approach2	17. 8

When the total size of capacitor added is compared Approach1 and Approach 2 can be inferred for approach 1-Run1 the capacitance for the total capacitors added for optimizing is 18. 41 and for Approach2-Run1 the capacitance is 17. 8 MVAR. Similarly for Approach 1-Run2 identified the size of capacitor to be added as 24. 95MVAR while Approach2-Run2 result in additional capacitance for 20. 32 MVAR. Fig 7&8 illustrates the additional capacitance implied by both optimizations.

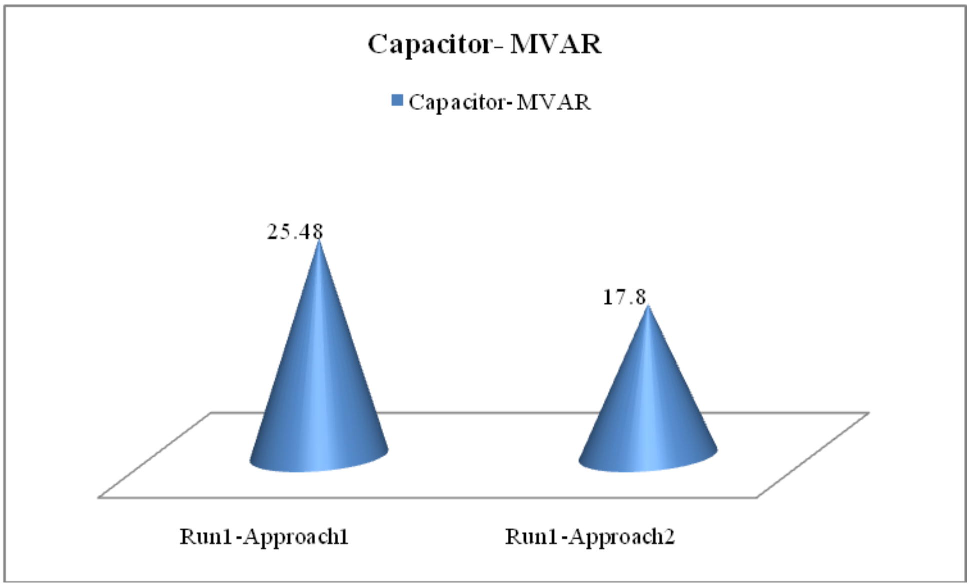

Figure 7: Comparison between Run 1- Approach1 and Run 1-Approach2 for Capacitors in MVAR

TABLE (8): Comparison between Run 2- Approach1 and Run 2-Approach2 for Capacitors in MVAR

	Capacitor- MVAR
Run2-Approach1	24. 95
Run2-Approach2	20. 32

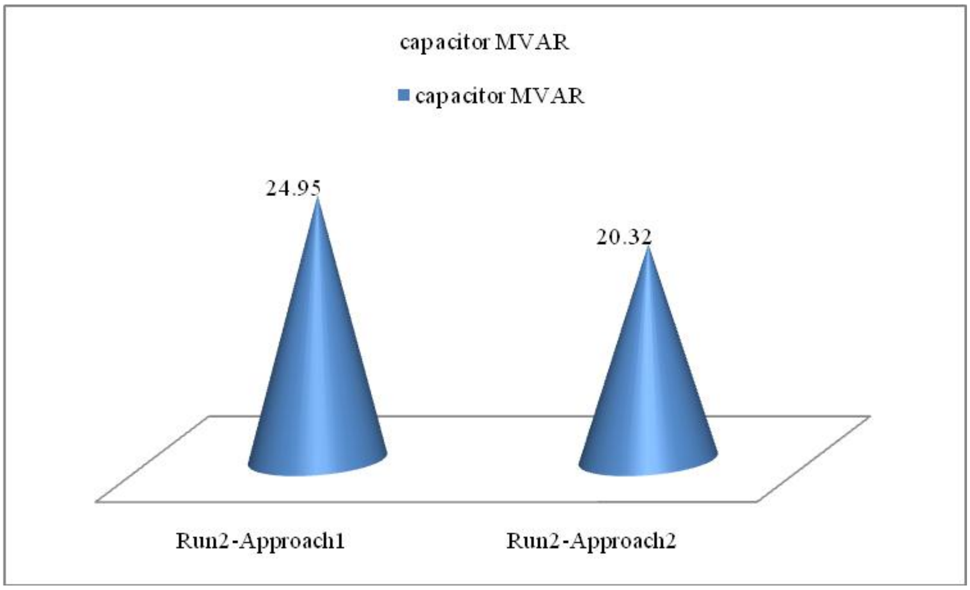

Figure 8: Comparison between Run 2- Approach1 and Run 2-Approach2 for Capacitors in MVAR

Reduction in power losses and subsequent reduction in size of the capacitance the result in net savings as compared to cases prior to optimization. It can be observed from fig 9, for case(i) the net savings resulted in by approach 1 is 4399. 87 lakh rupees and the saving resulted is approach 2 is 7607. 7 lakh rupees. Similarly case 2 is fig 10, the approach 1 produces net saving to the tune of 7137. 3 lakh rupees and savings resulted in by approach 2 is 8716. 5.

TABLE (9): Comparison between Run 1- Approach1 and Run1-Approach2 for Net saving

	Net saving
Run1-Approach1	4399. 87
Run1-Approach2	7607. 7

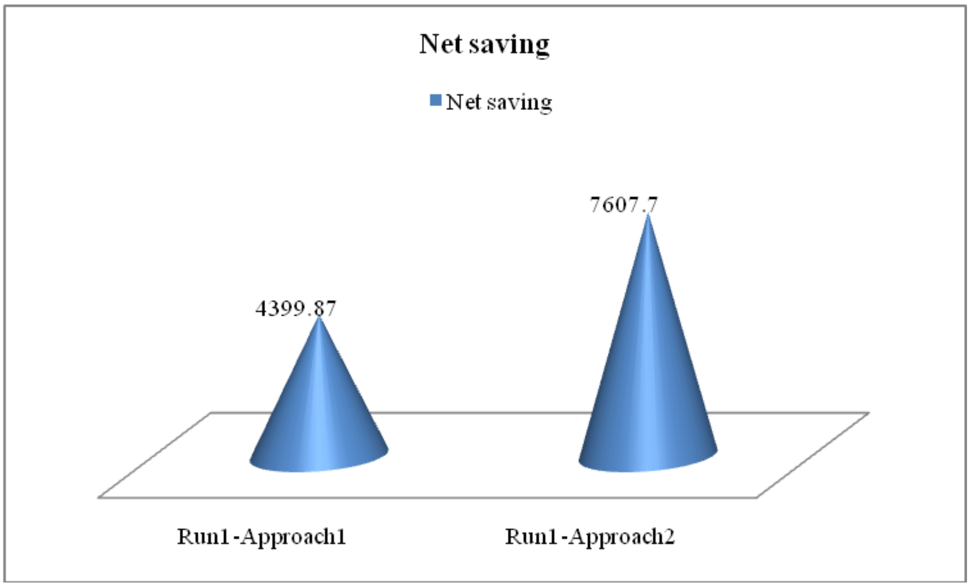

Figure 9: Comparison between Run 1- Approach1 and Run1-Approach2 for Net saving

TABLE (10): Comparison between Run 2- Approach1 and Run2-Approach2 for Net saving

	Net saving
Run2-Approach1	7137. 3
Run2-Approach2	8716. 5

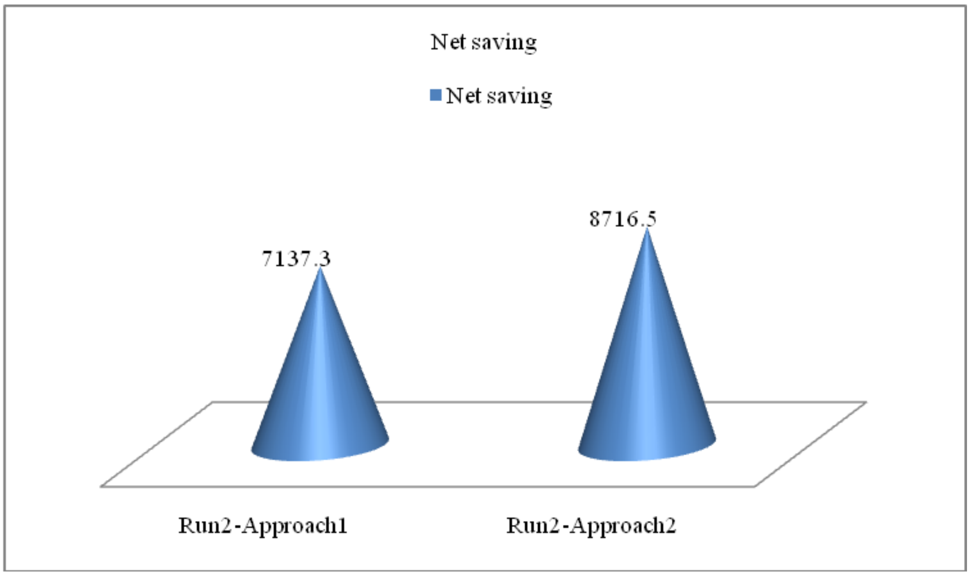

Figure 10: Comparison between Run 2- Approach1 and Run2-Approach2 for Net saving

VII. CONCLUSION

In this paper we have proposed and discussed a method of reactive power control by suitably sizing the capacitors with the help of particles Swarm optimization algorithm. In order to understand the efficiency of the approach to different optimization parameters are studied and then effect on reactive power control is presented. Even though any reduction in real power loss will eventually result in reduce reactive power, it can be observed that the results are slightly better when the optimization algorithm optimizes the reactive power directly. Even though the changes are marginal, these changes can be significant in larger and more specifically real time power systems. It can also be observed both the approaches have resulted significant in optimizing real and reducing reactive power loss. The pre-optimization and post optimization results suitably illustrates efficacy of proposed methods in the ensuring control of reactive power. It can also be observed that the additional cost that is incurred because of addition of capacitance is compensated by the increased savings resultant by reduced power losses.

VIII. REFERENCES

1). Heinz K. Tyll, SM, IEEE, and Dr. Frank Schettler, "Historical overview on dynamic reactive power compensation solutions from the begin of AC power transmission towards present applications ", power systems conference and exposition, 2009, PSCE 09.

2). Guomei PAN, Yonggang PAN, Xuhang ZHANG, "Effects of capacitor Switching on Dynamic power Quality in Urban Distribution Networks", Electricity distribution- part1, 2009, CIRED 2009, 20th International conference and exhibition on 11th June, 2009, pages:1-4.

3). Surya Santoso, 'On Determining the Relative Location of Switched Capacitor Banks', IEEE TRANSACTIONS ON POWER DELIVERY, VOL, 22, NO. 04469957. pdf, April, 2007.

4) Om Prakash Mahela, Devendra Mittl and Lalit goyal "Optimal capacitor placement Techniques in Transmission and Distribution Networks to Reduce Line losses and voltage stability Enhancement " IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) ISSN:2278-1676 Volume 3, Issue 4 (Nov-Dec 2012).

5) A. A. E. Shammah, Ahmed M. Azmy and A. Abou ElEla "Optimal sitting and sizing of capacitor Banks in Distribution Networks using Heuristic Algorithms" J. Electrical Systems 9-1 (2013): 1-12, Regular paper.

6) Mrs V. Usha Reddy, Dr T. Gowri Manohar and P. Dinakara Prasad Reddy ' Optimal Capacitor Placement for loss reduction in Distribution Systems by using BAT Algorithm" ISSN 0976 – 6545, Volume 4, Issue 2, March – April.

7) Brahim GASBAOUI 1*, Abdelkader CHAKER2, Abdellah LAOUFI1, Abdessalam ABDERRAHMANI 1 and Boumediène ALLAOUA1"Optimal Placement and Sizing of Capacitor Banks Using Fuzzy-Ant Approach in

Electrical Distribution Systems" ISSN 1583-1078, Issue 16, January-June 2010.

8) M. Damodar Reddy and Prof. V. C. Veera Reddy" OPTIMAL CAPACITOR PLACEMENT USING FUZZY AND REAL CODED GENETIC ALGORITHM FOR MAXIMUM SAVINGS" Journal of Theoretical and Applied Information Technology©2005 - 2008 JATIT.

9) Seyed Abbas Taher, Ali Karimian and Mohammad Hasani " A new method for optimal location and sizing of capacitors in distorted distribution networks using PSO algorithm"Department of Electrical Engineering, University of Kashan, km 6 Ravand Road, Kashan 87317-51167, Iran. Tel. : +98 9131614352; fax: +98 3615559930. Copyright © 2010 Elsevier B. V. All rights reserved.

10) Mohd Nabil Muhtazaruddina*, Jasrul Jamani Jamianb, Danvu Nguyena Nur Aisyah Jalalludina, Goro Fujitaa" Optimal capacitor placement and sizing via artificial bee colony" Manuscript received June 14, 2013; revised July 18, 2013. Corresponding author Tel. : +8180-4607-5124; E-mail address: na11502@shibaura-it. ac. jp

11) Jagadeesh Gunda and Nasim Ali Khan" Optimal Location and sizing of DG and shunt capacitors using differential evolution" International Journal of Soft Computing, Year: 2011, Volume:6 DOI: 10. 3923/ijscomp. 2011. 128. 135.

12) Mr. Manish Gupta, Dr. Balwinder Singh Surjan" Optimal sizing and Placement of Capacitors for Loss Minimization In 33-Bus Radial Distribution System Using Genetic Algorithm in MATLAB Environment"ISSN: 2278 – 1323 International Journal of Advanced Research in Computer Engineering & Technology (IJARCET) Volume 1, Issue 8, October 2012.

13) R. D. Zimmerman et al., "MATPOWER: Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education, " IEEE Trans. On Power Systems, vol. 26, no. 1, Feb. 2011, pp. 12-19.

14) Kennedy J. and Eberhart R, "Particle swarm optimization", In Proc. of the IEEE international conference on Neural networks, 1995, pp. 1942-1948.