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OPTIMAL PLACEMENT OF CAPACITOR BANKS FOR POWER LOSS MINIMIZATION IN TRANSMISSION SYSTEMS USING FUZZY LOGIC

DEBASHISH BHOWMIK[1], PUSHPA GAUR[2,*]

[1]Electrical Engineering Department, Tripura Institute of Technology Narsingarh Agartala, Tripura, India
[2]Electrical Engineering Department, National Institute of Technology Silchar, Assam, India
*Corresponding Author: pushpa_gaur@yahoo.com

Abstract

In a power system, it is essential to retain the voltage under permissible limit and to deliver active power through transmission lines. This paper presents a method to identify the optimal location and sizing of capacitors in a system for refining the voltage profile and curtailing system losses. There are two important tasks to be accomplished in this work, one is to determine the size of the capacitor to be placed on the bus and the other is to determine the location of the capacitor in the system. Firstly, the size of the capacitors to be installed is estimated. Then, the calculation of power loss indices (PLI) is done with the help of the estimated size of capacitors. The PLI and per unit nodal voltage are given as input to the fuzzy expert system (FES) for determining the suitability index, which will decide the most suitable location for capacitor placement. Newton-Raphson method for load flow analysis is carried out to find the voltages at each node and the system losses. The overall reliability and accuracy of the proposed method is validated by testing on three different IEEE test bus systems.

Keywords: Fuzzy logic, Load flow, Optimal capacitor placement, Reactive power compensation, Voltage profile.

1. Introduction

In any power system network there are mainly four components; generation, transmission, distribution and customers. Transmission and distribution are the crucial elements because these links with the consumers. According to estimation about 13% of the generated power is lost in the form of transmission losses. Some percentage of the losses are caused due to the flow of reactive current. Voltage control plays an important role in power system for smooth functioning of electrical equipment. Shunt capacitors play a major role in maintaining system voltage within prescribed limits and hence enhancing the voltage profile. Also, it helps in minimizing the overall system losses and maximizing the overall saving.

Many literatures are available solving the capacitor allocation problems. Grainger and Lee [1] used classical method to estimate the size and position for placing the capacitors. Researchers have been trying new methods every day to improve the performance of the power system. Santoso and Tan [2] tried to place the capacitors in a real time system. They also have employed two stage neural networks for controlling the equipped capacitors in the system so as to decrease system losses. Chiang et al. used simulated annealing as optimization method [3, 4] for determining capacitor location, types and its size. Baghzouz and Ertem [5] developed an algorithm to optimize capacitor size so as to bring the voltages and harmonic distortion within acceptable limits.

Baghzouz [6] studied the effects of non-linear loads on capacitor placement problems. Gradually the researchers started exploring different heuristic algorithms for optimization. The use of genetic algorithm is presented in [7, 8] for optimal selection of capacitors. Conventionally, allocation of capacitors is done to minimize the system losses and improvement of voltage profile, but other aspects such as improvement of power quality are explored in [9].

Delfanti et al. [10] and Levitin et al. [11] used a hybrid technique of some computation method and genetic algorithm. The effects of placing a capacitor on a radial system using tabu search method are presented by Mori and Ogita [12] and Chang and and Lern [13]. After the use of different heuristic algorithms, some researchers have also tried using artificial intelligence for solving capacitor allocation problems. Ng et al. [14], Ladjavardi and Masoum [15] and Ramadan et al. [16] employed fuzzy logic for sizing and siting of capacitors and estimating the number of capacitors to be installed.

Gonzalez et al. [17] used a pseudo-polynomial algorithm for solving capacitor allocation problem considering both fixed and switched capacitors. For finding out the solutions to capacitor allocation problems, the researchers have focused on using different recently developed heuristic algorithms like bio- inspired [18], monkey search [19], bacteria foraging [20].

Vuletić and Todorovski [21] used a new concept of penalty free genetic algorithm, which has been proved to perform much better than other previously used algorithms. A two stage procedure consisting of the calculation of loss indices and then use of ant colony optimization for finding the optimal size and location of capacitor banks has been presented in [22]. Nezhad et al. [23] and Hoseinzadeh and Azadi [24] used Matlab/Simulink for modelling and simulation of the system that is used for aviculture. The programming used in this work is done with the help of Matlab software.

The literature survey reveals that limited works have been done by using fuzzy in solving capacitor allocation problems. Moreover, the use of indices like power loss reduction index and sensitivity index are also not that much investigated in the past. In view of the above, the main objectives of the work are to determine the size of the capacitor to be placed in the system by the use of power loss index. Then to make the use of this index in finding out another index called sensitivity index for determining the optimal location of capacitor banks in the system so that the loss of the system is minimized and also the voltage profile is improved.

2. Fuzzy logic system

Fuzzy logic system or fuzzy expert system (FES) has four major components; fuzzifier, fuzzy rules, inference engine and defuzzifier. The function of FES is to map crisp inputs to crisp outputs. Figure 1 shows a schematic diagram of FES.

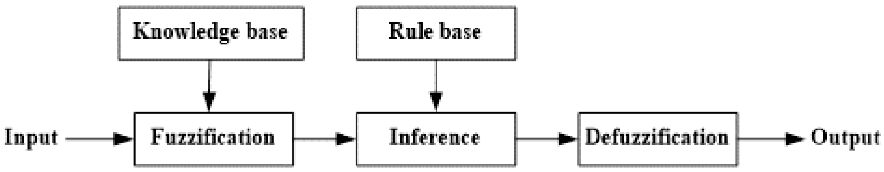

Fig. 1. Schematic diagram of a fuzzy logic system.

Fuzzification is the process of converting a crisp quantity fuzzy. It comprises of measuring the value of input variables, performing a scale mapping transferring input variables into universes of discourse; and finally converting input data into suitable linguistic values viewed as labels of fuzzy sets.

A fuzzy logic system is characterized by a set of declarations based on skilled knowledge. The knowledge base covers knowledge of the area in which it is to be applied and the goals of an attendant. It involves a 'database' and a 'rule base'. The database provides required definitions for describing control rules and data manipulation. Fuzzy logic systems use IF-THEN rule, that is, IF X THEN Y, where and Y are fuzzy sets.

Fuzzy logic principles are employed to chain fuzzy rules into a mapping from fuzzy input sets to fuzzy output sets in a fuzzy inference engine.

The defuzzification performs a scale mapping which translates the collection of values of yield into the equivalent universes of discourse; and defuzzification. The actual function of defuzzifier is to produce a crisp output from the output of the inference block.

3. Framework of the approach

A schematic diagram showing the framework of the approach is shown in Fig. 2. The overall structure of the presented work is to analyse the optimal placement of capacitor, which is based on numerical techniques coupling with the Fuzzy Expert System (FES). Initially a power flow program estimates loss reduction after reimbursing the total reactive load current at each node of the system. The reductions in losses are then normalized into a range of 0 to 1. The loss reduction indices together with the node voltages are fed as inputs into the FES, which decides the most apposite node for capacitor placement.

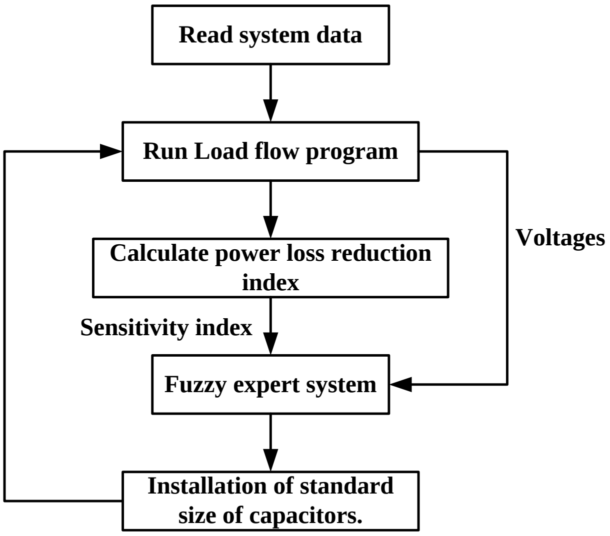

Fig. 2. Framework of the approach.

3.1. Mathematical formulation for capacitor placement and sizing

The problem of capacitor location deals with the estimation of the site, size and number of capacitors to be placed, bound by certain operational limitations, in a system to accomplish the maximum profits. The total real power loss of a system is given by Eq. (1).

$$TP_L = \sum_{i=1}^{n} I_i^2 r_i \tag{1}$$

where, I_i = current of branch 'i' and r_i = resistance of the branch 'i'. Splitting the active and reactive parts of current, the power loss is given by Eq. (2).

$$TP_L = \sum_{i-1}^{n} I_{ai}^2 r_i + \sum_{i-1}^{n} I_{ri}^2 r_i \tag{2}$$

Therefore,

$$TP_L = TP_{La} + TP_{Lr} \tag{3}$$

where TP_{La} is power loss because of real current and TP_{Lr} is power loss because of reactive current. The assignment of the capacitor aims to maximize the reduction in loss of the system.

For a capacitor of current I_{ck} allocated at a node k, the overall active power loss is given by Eq. (4).

$$TP_L = \sum_{i-1}^{n} I_{ai}^2 r_i + \sum_{i-1}^{n} I_{ri}^2 r_i + \sum_{i=b(j)}^{n} I_{ri}^2 r_i + \sum_{i=1}^{n} I_{ai}^2 r_i \tag{4}$$

Here '*b*' is the branch from source to candidate nodes.

The total loss reduction ΔTP_{Lk} can be expressed by Eq. (5).

$$\Delta TP_{LK} = -2I_{ck}^{2}\sum_{i=b(j)}^{k} I_{ri}r_i - I_{ck}^{2}\sum_{i=b(j)}^{k} r_i \tag{5}$$

I_{ck} providing the maximum loss saving can be found by taking the first derivative of Eq. (5) with respect to I_{ck},

$$\frac{\delta(\Delta TP_{Lk})}{\delta I_{ck}} = -2\left(\sum_{i=b(j)}^{k} I_{ri}r_i + I_{ck}\sum_{i=b(j)}^{k} r_i\right) = 0 \tag{6}$$

Solving Eq. (6), I_{ck} for maximum loss saving is given by Eq. (7).

$$I_{ck} = -\left(\frac{\sum_{i=b(j)}^{k} I_{ri}r_i}{\sum_{i=b(j)}^{k} r_i}\right) \tag{7}$$

It is presumed that no noteworthy development takes place in V_k upon capacitor allocation. Hence, the capacity of the capacitor to be installed at required node can be found out by Eq. (8):

$$Q_{ck} = I_{ck}V_k \tag{8}$$

3.2. Load flow solution by NR-method

Bus data and line data are provided as inputs to the power flow program. Power loss and bus voltage are obtained from this which is utilized for further study. The method is applied on IEEE 5-bus, 14-bus and 30-bus systems.

3.3. Application of Fuzzy logic

Fuzzy system consists of a number of rules established from qualitative explanations. Rules are fixed for determining the appropriateness of a bus for capacitor placement. The inputs required are bus voltage and power loss indices (PLI), and yield is the fittingness of placing the capacitors. The power loss index at each i^{th} node is calculated using Eq. (9). The rules for estimating the location of capacitors are précised in fuzzy decision matrix and is given in Table 1.

$$PLI(i) = \left(\frac{X(i) - Y}{Z - Y}\right) \tag{9}$$

where, X = loss reduction, Y = minimum reduction, Z = maximum reduction and i=1, 2,…, n.

The fuzzy variables are symbolized by membership functions (MF). The MFs for the inputs and outputs are shown in Figs. 3 to 5.

Reactive power compensation at each bus is completed by placement of capacitors. Evaluation of loss reduction is done and the bus voltages are obtained by carrying out load flow analysis. Power loss reduction having the highest value is assigned '1' and those having lowest loss reduction are assigned '0'. The rest of the loss reductions are included between 0 and 1. Voltages are given in pu.

Table 1. Fuzzy rules for capacitor placement (PLI vs. voltage).

And		Bus voltage					
		V-Low	**Low**	**L-Norm**	**Norm**	**Hi-Norm**	**High**
PLI	**L**	M	LM	LM	L	L	L
	LM	HM	M	LM	LM	L	L
	M	H	HM	M	LM	L	L
	HM	H	HM	HM	M	LM	L
	H	H	H	HM	M	LM	LM

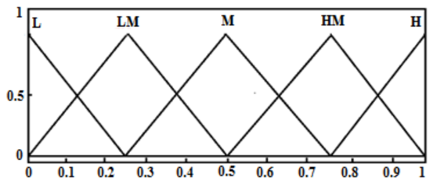

Fig. 3. Membership function for power loss.

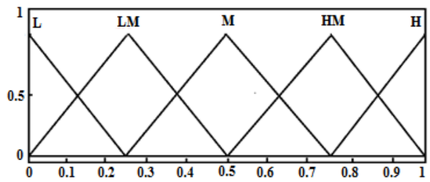

Fig. 4. Membership function for bus voltage.

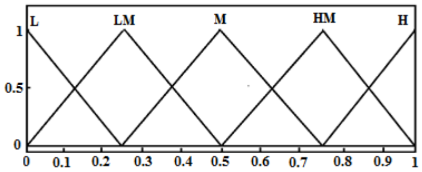

Fig. 5. Membership function for sensitivity index.

4. Results and analysis

4.1. Case-I: 5-Bus system

The proposed algorithm is tried on 5-bus system. For the determination of capacitor position, the values of voltages, PLI and the equivalent sensitivity index (SI) obtained are presented in Table 2.

Table 2. Determination of suitable capacitor position (5-bus system).

Bus No.	Voltage (pu)	PLI	SI
1	1.06	0	0.08
2	0.9968	0.079	0.25
3	0.9261	1	0.92
4	0.9288	0.5388	0.918
5	0.9769	0	0.25

The percentage measure of average voltage profile improvement and an average decrease in total real power loss attained after placing the capacitor of calculated size (Qck) at the respective nodes is detailed in Table 3. The assessment of voltage sketch earlier and the later appointment of capacitor is shown in Figs. 6 and 7. The value of capacitor placed and the location is shown in Table 4. The voltage profile improvement and power loss reduction with respect to capacitor placed at respective nodes are shown in Fig. 8. From the above discussions it is found that bus number 3 having PLI 1 and SI 0.92 is the most appropriate position to place a capacitor. The optimal size of the capacitor to be placed is of capacity 42.6 MVAR.

Table 3. Determination of capacitor size.

Bus No.	Capacitor size (MVar)	Improvement in voltage (%)	Real power loss reduction (%)
2	2.492	0.88	0.13
3	42.6	4.49	55.9
4	22.92	2.95	33.26
5	12.97	1.12	7.2

Table 4. Capacitor location and capacitor value.

Sl. No.	Capacitor location (bus no.)	Capacitor value (MVar)
1	3	42.2
2	4	23.28

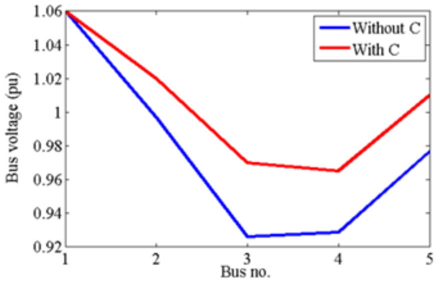

Fig. 6. Comparison of voltage profile before and after capacitor placement at bus no. 3.

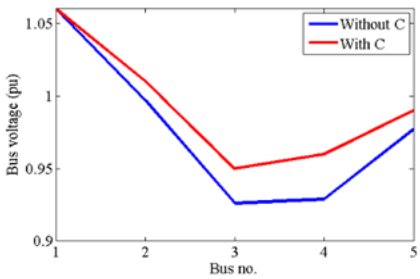

Fig. 7. Comparison of voltage profile before and after capacitor placement at bus no. 4.

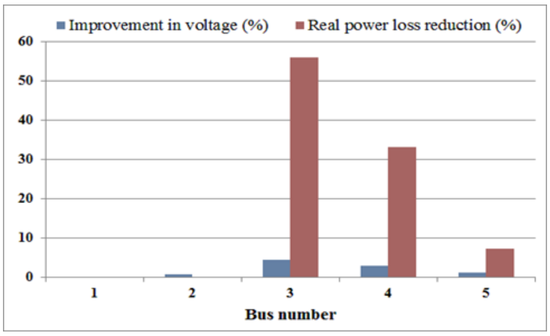

Fig. 8. Average voltage profile improvement and power loss reduction after capacitor placement.

4.2. Case-II: 14 bus system

Again, the proposed method is experimented with a 14-bus system. The size of the capacitor to be placed at a particular bus is found out and the voltage profile before the placement of capacitor and that obtained after placing the capacitor are compared and shown in Fig. 9. Table 5 represents the values of voltages at each node, PLIs and the corresponding SIs. The percentage measure of average voltage profile improvement and average reduction in total real power loss attained after placing the capacitor of calculated size (Qck) at the respective nodes is detailed in Table 6. The value of capacitor placed and the location is shown in Table 7. Figure 10 shows the voltage profile improvement and power loss reduction with respect to capacitor placed at respective nodes.

Table 5. Determination of suitable capacitor position (14-bus system).

Bus No.	Voltage (pu)	PLI	SI
1	1.06	0	0.08
2	1.015	0	0.0902
3	0.99	0	0.25
4	0.9898	0.0704	0.25
5	0.9926	0.2269	0.25
6	1.03	0	0.08
7	0.9893	0.0997	0.25
8	1.04	0	0.08
9	0.9468	0.2626	0.751
10	0.9459	1	0.91
11	0.9835	0.0983	0.25
12	1.0071	0	0.0884
13	0.9952	-0.0044	0.25
14	0.9317	0.8645	0.907

Table 6. Determination of capacitor size.

Bus No.	Capacitor size (MVar)	Improvement in voltage (%)	Real power loss reduction (%)
4	3.36	0.14	0.18
5	10.48	0.8	-0.078
7	3.41	0.5	-0.14
9	3.18	0.88	0.15
10	12.57	2.6	2.12
11	2.78	1.16	-0.121
12	0.1077	0.02	0.1
13	1.013	1.04	-0.37
14	10.13	3.26	2.3

Table 7. Capacitor location & Capacitor value.

Sl. No.	Capacitor location (bus no.)	Capacitor value (MVar)
1	9	3.18
2	10	12.57
3	14	10.13

From the above discussions, it is found that bus number 10 having PLI 1 and SI 0.91 is the most suitable location or the optimal position to place a capacitor. The optimal size of the capacitor to be placed is of capacity 12.57 MVAR.

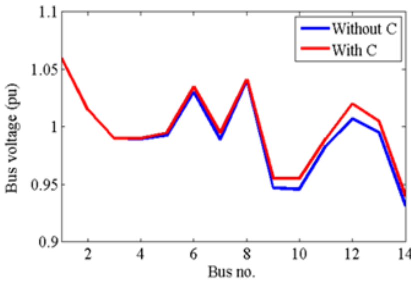

Fig. 9(a) Comparison of voltage profile before and after capacitor placement at bus no. 9.

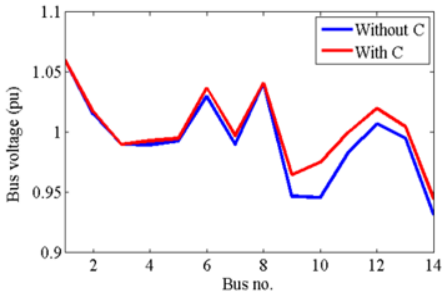

Fig. 9(b) Comparison of voltage profile before and after capacitor placement at bus no. 10.

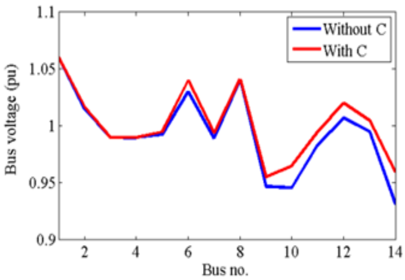

Fig. 9(c) Comparison of voltage profile before and after capacitor placement at bus no. 14.

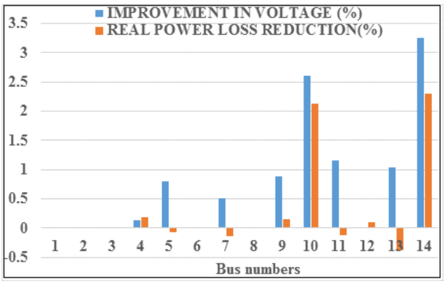

Fig. 10. Average voltage profile improvement and power loss reduction after capacitor placement.

4.3. Case-III: 30 bus system

Similarly, the proposed method is tested on a 30-bus system. The size of the capacitor to be installed at a bus is calculated. The voltage profile is found for both before and after the placement of capacitors in the system, compared and presented in Figs. 11 and 12. Table 8 represents the values of voltages at each node, PLIs and the corresponding SIs. The value of capacitor placed and the location is shown in Table 9. The percentage measure of average voltage profile improvement and average reduction in total real power loss attained after placing the capacitor of calculated size (Qck) at the respective nodes is noted down in Table 10. Figure 13 shows the voltage profile improvement and power loss reduction with respect to capacitor placed at respective nodes.

Table 8. Determination of suitable capacitor position (30-bus system).

Bus No.	Voltage (pu)	PLI	SI
1	1.06	0	0.08
2	1.013	0	0.0832
3	0.9904	0.869	0.75
4	0.9754	1	0.75
5	0.9800	0	0.25
6	0.9764	0.0933	0.25
7	0.9733	0.2855	0.298
8	0.9800	0	0.25
9	1.0096	0.1433	0.226
10	0.9908	0.7224	0.714

11	1.0620	0	0.08
12	1.0068	0.3094	0.25
13	1.0410	0	0.08
14	0.9885	0	0.25
15	0.9830	0.2252	0.25
16	0.9929	0.1285	0.25
17	0.9860	0.3743	0.374
18	0.9729	0.149	0.25
19	0.9702	0.3424	0.371
20	0.9746	0.3424	0.349
21	0.9750	0.9613	0.75
22	0.9817	0.0842	0.25
23	0.9747	0.0489	0.25
24	0.9693	0.1138	0.3
25	0.9671	0.0477	0.35
26	0.9484	0.4152	0.742
27	0.9746	0.1024	0.25
28	0.9739	0.0955	0.25
29	0.9395	0.4732	0.87
30	0.9361	0.3663	0.778

Table 9. Capacitor location and capacitor value.

Sl. No.	Capacitor location (bus no.)	Capacitor value (MVar)
1	3	11.3
2	4	12.6
3	10	7.3
4	21	12.5
5	26	3.38
6	29	3
7	30	2.74

Table 10. Determination of capacitor size.

Bus no.	Capacitor size (MVar)	Improvement in voltage (%)	Real power loss reduction (%)
3	11.3	0.68	0.48
4	12.6	0.53	0.5
6	2.7	0.06	0.07
7	8	0.9	0.12
10	7.3	0.82	0.24
12	8.7	1.25	-0.05
14	0.56	0.12	0.014
15	2.75	0.36	0.14
16	1.88	0.34	0.078
17	3.75	0.58	0.22
18	1.6	0.4	0.12
19	3.1	0.8	0.24
20	3.18	0.76	0.23
21	12.5	2.42	0.92
22	1.08	0.223	0.07
23	0.7	0.112	0.063
24	1.16	0.26	0.106
25	0.67	0.237	0.067
26	3.38	2.27	0.343
27	5.02	1.75	0.205
28	2.9	0.17	0.08
29	3	2.15	0.47
30	2.74	2.12	0.34

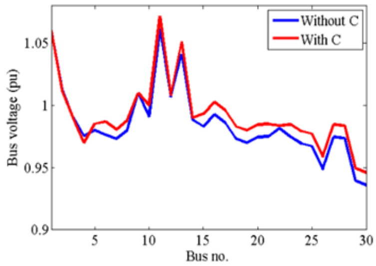

Fig. 11(a) Comparison of voltage profile before and after capacitor placement at bus no. 3.

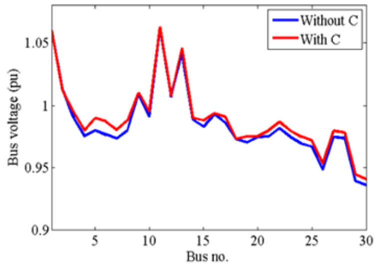

Fig. 11(b) Comparison of voltage profile before and after capacitor placement at bus no. 4.

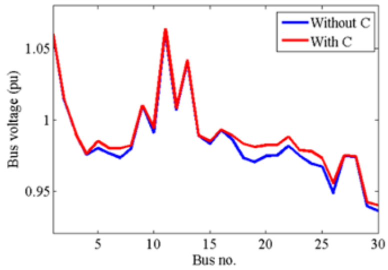

Fig. 11(c) Comparison of voltage profile before and after capacitor placement at bus no. 10.

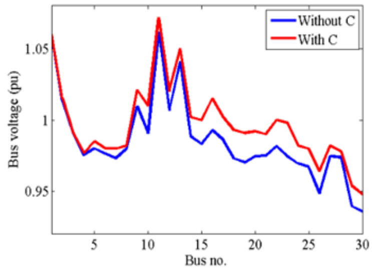

Fig. 11(d) Comparison of voltage profile before and after capacitor placement at bus no. 21.

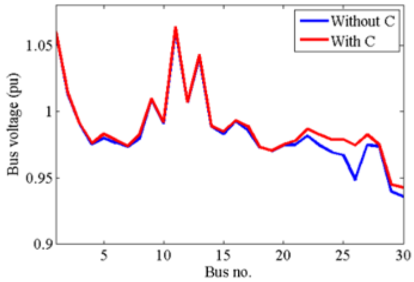

Fig. 12(a) Comparison of voltage profile before and after capacitor placement at bus no. 26.

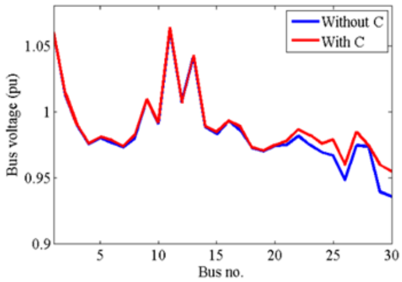

Fig. 12(b) Comparison of voltage profile before and after capacitor placement at bus no. 29.

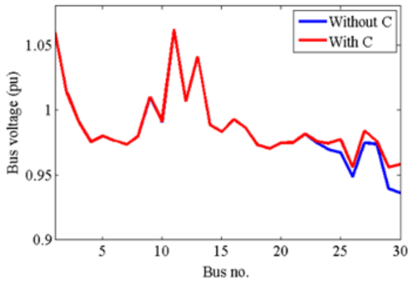

Fig. 12(c) Comparison of voltage profile before and after capacitor placement at bus no. 30.

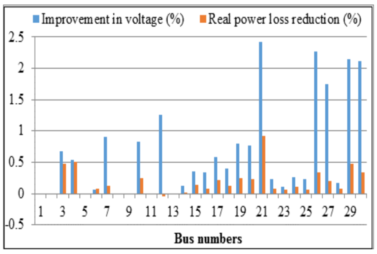

Fig. 13. Average voltage profile improvement and power loss reduction after capacitor placement.

5. Conclusions

In this paper, an approach incorporating fuzzy set theory for the determination of optimal size and location of the capacitor to be placed in the system has been presented. The paper attempts to introduce two indices, namely, power loss sensitivity (PLI) index and suitability index (SI).

The size of the capacitor is found out analytically and then the optimal size is found out using PLI. Fuzzy logic is used to estimate the optimal position by providing PLI and voltage at the individual node as the input to get SI as the output for placement of capacitor in the system for maximum minimization of transmission losses and improvement of voltage profile.

The proposed method is applied in three IEEE test bus systems to prove its effectiveness. It has been observed that by using the proposed approach, there is a significant improvement in the voltage profile and reduction of system losses. Hence, the presented method provides complete solution to problems like loss minimization, voltage profile improvement and cost minimization in capacitor allocation problems.

Nomenclatures

I_{ai}	Active part of current
I_{ck}	Capacitor current at node k
I_i	Current flowing in branch I
I_{ri}	Reactive part of current
Q_{ck}	Capacity of capacitor to installed at required node
TP_L	Total real power loss
TP_{La}	Power loss because of real current
TP_{Lr}	Power loss because of reactive current
V_k	Voltage at node k
$X(i)$	Loss reduction at node i
Y	Minimum reduction
Z	Maximum reduction

Greek Symbols

ΔTP_{Lk}	Total loss reduction

Abbreviations

FES	Fuzzy expert system
H	High
Hi-Norm	High normal
HM	High medium
L	Low
LM	Low medium
L-Norm	Low normal
M	Medium
MF	Membership function
Norm	Normal
PLI	Power loss indices
SI	Sensitivity index
V-Low	Very low

References

1. Grainger, J.J.; and Lee, S.H. (1981). Optimal size and location of shunt capacitors for reduction of losses in distribution feeders. *IEEE Transactions on Power Apparatus and Systems*, PAS-100, 1105-1118.
2. Santoso, N.I.; and Tan, O.T. (1989). Neural-net based real-time control of capacitors installed on distribution systems. *IEEE Transactions Power Delivery*, 5(1), 266-272.
3. Chiang, H.-D.; Wang, J.-C.; Cockings, O.; and Shin, H.-D. (1990). Optimal capacitor placements in distribution systems, Part I: A new formulation and the overall problem. *IEEE Transactions Power Delivery*, 5(2), 634-642.
4. Chiang, H.-D.; Wang, J.-C.; Cockings, O.; and Shin, H.-D. (1990). Optimal capacitor placement in distribution systems, Part II: Solution algorithms and numerical results. *IEEE Transactions Power Delivery*, 5(2), 643-649.
5. Baghzouz, Y.; and Ertem, S. (1990). Shunt capacitor sizing for radial distribution feeders with distorted substation voltage. *IEEE Transactions Power Delivery*, 5(2), 650-657.
6. Baghzouz, Y. (1991). Effects of nonlinear loads on optimal capacitor placement in radial feeders. *IEEE Transactions Power Delivery*, 6(1), 245-251.
7. Sundhararajan, S.; and Pahwa, A. (1994). Optimal selection of capacitors for radial distribution systems using a genetic algorithm. *IEEE Transactions on Power Systems*, 9, 1499-1507.
8. Miu, K.N.; Chiang, H.-D. and Darling, G. (1997). Capacitor placement, replacement and control in large-scale distribution systems by a GA-based two-stage algorithm. *IEEE Transactions on Power Systems*, 12(3), 1160-1166.
9. Gou, B.; and Abur, A. (1999). Optimal capacitor placement for improving power quality. IEEE Conference *Proceedings on Power Engineering Summer Meeting*, 1, 488-492.
10. Delfanti, M.; Granelli, G.P.; Marannino, P.; and Montagna, M. (2000). Optimal capacitor placement using deterministic and genetic algorithms. *IEEE Transactions on Power Systems*, 15(3), 1041-1046.
11. Levitin, G.; Kalyuzhny, A.; Shenkman, A. and Chertkov, M. (2000). Optimal capacitor allocation in distribution systems using a genetic algorithm and a fast energy loss computation technique. *IEEE Transactions Power Delivery*, 15(2), 623-628.
12. Mori, H.; and Ogita, Y. (2000). Parallel tabu search for capacitor placement in radial distribution systems. *IEEE Conference Proceedings on Power Engineering Society Winter Meeting*, 4, 2334-2339.
13. Chang, C.S.; and Lern, L.P. (2000). Application of tabu search strategy in solving non differentiable savings function for the calculation of optimum savings due to shunt capacitor installation in a radial distribution system. *IEEE Conference Proceedings on Power Engineering Society Winter Meeting*, 4, 2323-2328.
14. Ng, H.N.; Salama, M.M.A.; and Chikhani, A.Y. (2000). Capacitor allocation by approximate reasoning, fuzzy capacitor placement. *IEEE Transactions Power Delivery*, 15(1), 393-398.

15. Ladjavardi, M.; and Masoum, M.A.S. (2008). Genetically Optimized Fuzzy placement and sizing of capacitor banks in distorted distribution networks. *IEEE Transactions Power Delivery*, 23(1), 449-456.
16. Ramadan, H.A.; Wahab, M.A.A.; El-Sayed, A.M.; and Hamada, M.M. (2014). A fuzzy based approach for optimal allocation and sizing of capacitor banks. *Electric Power Systems Research*, 106, 232-240.
17. Gonzalez, J.F.V.; Lyra, C.; and Usberti, F.L. (2012). A pseudo-polynomial algorithm for optimal capacitor placement on electric power distribution networks. *European Journal of Operational Research*, 222(1), 149-156.
18. Injeti, S.K.; Thunuguntla, V.K.; and Shareef, M. (2015). Optimal allocation of capacitor banks in radial distribution systems for minimization of real power loss and maximization of network savings using bio-inspired optimization algorithms. *International Journal of Electrical Power & Energy Systems*, 69, 441-455.
19. Duque, F.G.; de Oliveira, L.W.; de Oliveira, E.J.; Marcato, A.L.M.; and Silva, I.C. (2015). Allocation of capacitor banks in distribution systems through a modified monkey search optimization technique. *International Journal of Electrical Power & Energy Systems*, 73, 420-432.
20. Devabalaji, K.R.; Ravi, K.; and Kothari, D.P. (2015). Optimal location and sizing of capacitor placement in radial distribution system using Bacterial Foraging Optimization Algorithm. *International Journal of Electrical Power & Energy Systems*, 71, 383-390.
21. Vuletić, J.; and Todorovski, M. (2016). Optimal capacitor placement in distorted distribution networks with load models using Penalty Free Genetic Algorithm. *International Journal of Electrical Power & Energy Systems*, 78, 174-182.
22. Abou El-Ela, A.A.; El-Sehiemy, R.A.; Kinawy, A.-M.; and Mouwafi, M.T. (2016). Optimal capacitor placement in distribution systems for power loss reduction and voltage profile improvement. *IET Generation, Transmission & Distribution*, 10(5), 1209-1221.
23. Nezhad, M.E.Y.; and Hoseinzadeh, S. (2017). Mathematical modelling and simulation of a solar water heater for an aviculture unit using MATLAB/SIMULINK. *Journal of Renewable and Sustainable Energy*, 9(6), 10. 063702, 2017
24. Hoseinzadeh, S.; and Azadi, R. (2017). Simulation and optimization of a solar-assisted heating and cooling system for a house in Northern of Iran. *Journal of Renewable and Sustainable Energy*, 9(4), 045101-13, 2017.