Optimal Allocation of Capacitor for Iraqi Distribution Network using FLC-PSO Controller

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ABSTRACT
The aim of this work is obtaining the optimal power flow for the Iraqi distribution network represented by Al-RUSTAMIYA_Feeder09, through adding the capacitors to the system in order to reach the best improvement of voltage profile and power losses reduction. . A Fuzzy Logic (FLC)-Particle Swarm Optimization (PSO) controller was proposed to detect the optimal location and size of the capacitor banks in electrical distribution system. Three load variation levels were considered during the study those are 60%, 80%, and 100% load variation. From the obtained results it was very clear that the proposed intelligent algorithm was very accurate and efficient for obtaining the optimal location and size of the capacitors in the system.

Keywords
Reactive power control; Capacitor Placement and Sizing; FLC-PSO Approach, Iraqi distribution network

1. INTRODUCTION
The power supplied from electrical distribution system is composed of both active and reactive components. Overhead lines, transformers and loads consume the reactive power. The distribution network is always suffering from load demand growing; this lead to increase the burden on the power system and reduces the voltage levels. In order to improve the efficiency of any power system, the losses at the distribution level must be reduced. The reactive power control will improve the voltage profile, reduces the system losses and improves the system efficiency.

Many solutions have been used to reduce these losses and improves the voltage profiles such as network reconfiguration, installing shunt capacitor, voltage regulators placement, etc. In this work, locating the optimal location and size of capacitors were considered for achieving voltage profile improvement and losses reduction in the distribution system.

Even though considerable amount of research work was done in the area of optimal capacitor placement [2 to 13], there is still a need to develop more suitable and effective methods for the optimal capacitor placement.

In this work, a controller combining two intelligent algorithms FLC-PSO was proposed. The FLC algorithm provides a remedy for any lack of uncertainty in the data. It has the advantage of including heuristics and representing engineering judgments into the optimal capacitor placement problem, so the solutions from this approach can be easily analyzed to determine optimal capacitor locations. On the other hand, PSO algorithm is more useful in obtaining the optimal capacitor sizes. The proposed FLC-PSO controller was implemented on Iraq practical rural 62-node distribution system. Fixed capacitors were used because they are already installed in Iraqi distribution system.

2. PROBLEM FORMULATION
Shunt capacitor banks connected to a power system are the most economical source to meet the reactive power requirement of inductive loads and transmission lines operating at lagging power factor. By using shunt capacitor, the magnitude of the source current can be reduced; the power factor improved, and reduce the voltage drop between the sending end and the load end. The main problem of capacitor placement is to determine the location, type, and size of capacitors to be placed on a system, the problem includes the following inserting constraints:

1. Bus Voltage Limits:

The bus voltage magnitudes are to be kept within acceptable operating limits throughout the optimization process:

$$V_{min.} \leq |V_i| \leq V_{max.} \quad \text{…..…………..(1)}$$

2. The number and sizes of permissible capacitor banks constraint:

The number of capacitor banks can be expressed to satisfy the following expression:

$$\sum_{i=1}^{m} Q_c \leq Q_t \quad \text{………………..……..…(2)}$$

3. The line current (I) should be less than the line rated current (Irated).

$$\mathrm{I} \leq \mathrm{I_{rated}} \quad \text{…………………………………..(3)}$$

4. Power losses after the capacitor placement must less or equal to Power losses before the capacitor placement

$$\mathrm{P_{loss\,(q+1)}} \leq \mathrm{P_{loss\,(q)}} \quad \text{…………………….(4)}$$

Where:

$\mathrm{P_{loss\,(q+1)}}$: Power losses after the capacitor placement

$\mathrm{P_{loss\,(q)}}$: Power losses before the capacitor placement

The total $\mathrm{I^2R}$ losses (PL) for a distribution system with n number of branches is given by:

$$P_L=\sum_{i=1}^{n} I_i^2\, R_i \quad \text{…….5}$$

Where I_i is the magnitude of the branch current. R_i is the resistance of the i^{th} branch . Since the branch current has two components I_a and I_r, then the losses of the active and reactive components of the current can be calculated as:

$$P_{La}=\sum_{i=1}^{n} I_{ai}^2\, R_i \quad \text{…….6}$$

$P_{Lr} = \sum_{i=1}^{n} I_{ri}^{2} R_i \quad ....7$

Where PLa associated with the active component of branch currents, PLa cannot be reduced because all active power must be supplied by the source at the root bus, supplying part of the reactive power demand locally can minimize the loss PLr associated with the reactive component of branch currents. The estimation of candidate nodes to place the capacitors helps in reduction in the search space for the optimization procedure, Power Losses Indices method is used for capacitors placement.

Capacitors can be placed on the nodes with the highest suitability. A load flow solution for the original system is required to obtain the initial real and reactive power losses. By compensating the total reactive load at every node of the distribution system, the power loss reduction is obtained using the load flow program. The loss reductions are then, linearly normalized into a (0-1) range with the largest loss reduction having a value of 1 and the smallest one having a value of 0,

The power Loss Index value for nth node was calculated using the equation:

$$PLI(n) = \frac{(Losses\ reduction(n) - Losses\ reduction(min))}{(Losses\ reduction(max) - Losses\ reduction(min))} \ldots (8)$$

3. THE PROPOSED INTELLIGENT CONTROLLER

The main benefit of the intelligent methods is their flexibility for handling different qualitative limitation. These methods can obtain several optimal solutions by doing a single simulation run. Therefore, they are relatively suitable for overcoming optimization problems. The techniques are in general based on biologically inspired strategies for solving problems. In this work, a combined FL-PSO controller is used to obtain optimal placement and sizing for the Iraqi distribution system. Figure (1) shows a block diagram for the proposed FLC-PSO.

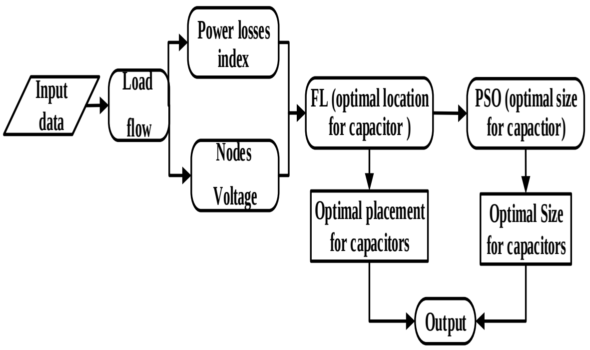

Figure (1) Block diagram of intelligent FL-PSO approach

As shown from the figure, the controller contains two parts, the FLC and the PSO part. Two objectives are considered in designing the FLC approach for identifying the optimal capacitor locations, those are: (i) minimize the real power loss. (ii) Maintain the voltage within the permissible limits.

The voltages and the power loss indices of the system nodes under consideration are modeled by fuzzy membership functions. The set of rules are then used to determine the capacitor placement suitability of each node in the distribution system.

The power loss reduction indices along with the p.u. nodal voltages were the inputs for the FLC, which determines the suitable node for capacitor installation. Two input and one output variables are selected. The first input variable is the power loss index (PLI) and the second one is the per unit nodal voltage (V).The output variable is the Capacitor suitability Index (CSI). Power Loss Index range varies from 0 to 1, P.U. nodal voltage range varies from 0.88 to 1.1 and Capacitor Suitability Index range varies from 0 to 1.

Five membership functions are selected for PLI. Those are: L, LM, M, HM and H. All the five membership functions are triangular as shown in Figure (2), for the selected voltage: L, LN, N, HN and H. These membership functions are trapezoidal and triangular as shown in Figure (3) and for the CSI are: L, LM, M, HM and H, the membership functions are triangular also. See figure (4)

For determining the suitability of capacitor placement at a particular node, a set of multiple-antecedent fuzzy rules has been established. The rules are summarized in the fuzzy decision matrix in Table-1. The consequents of the rules. Optimal capacitor locations are identified based on the highest Capacitor Suitability Index values.

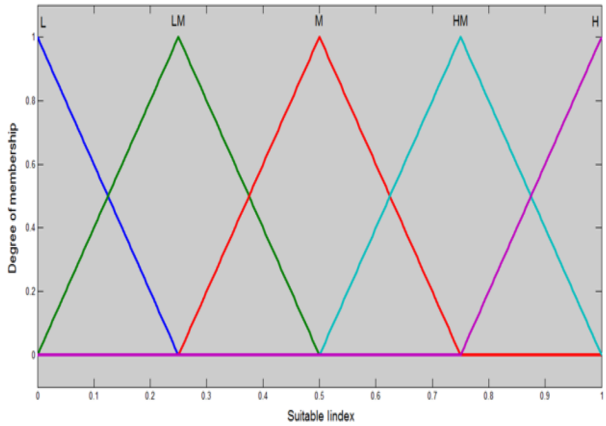

Figure-2. Membership function plot for P.L.I

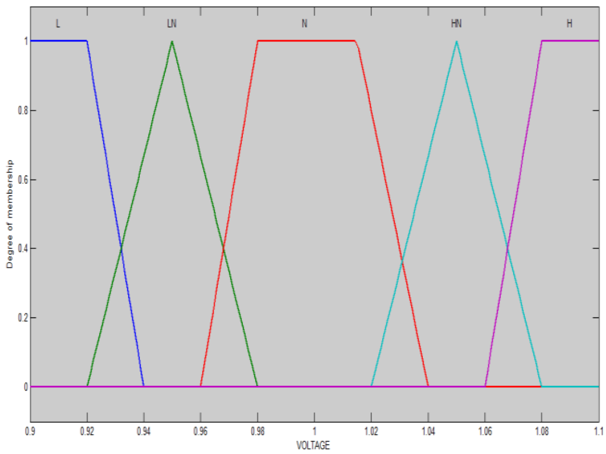

Figure-3. Membership function plot for p.u. nodal voltage

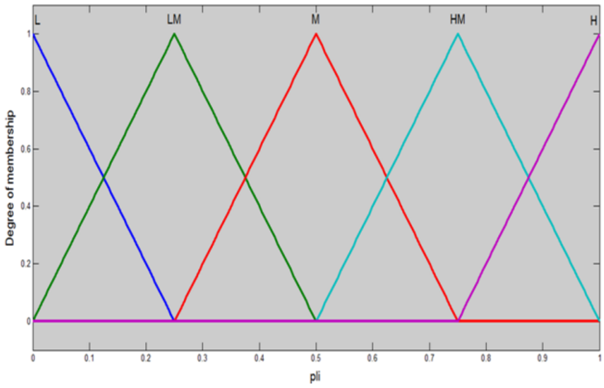

Figure-4. Membership function plot for C.S.I.

Table-1. Decision matrix for determining the optimal capacitor locations.

		L	**LN**	**N**	**HN**	**H**
PLI	**L**	**LM**	**LM**	**L**	**L**	**L**
	LM	**M**	**LM**	**LM**	**L**	**L**
	M	**HM**	**M**	**LM**	**L**	**L**
	HM	**HM**	**HM**	**M**	**LM**	**L**
	H	**H**	**HM**	**M**	**LM**	**LM**

For calculating the optimal size of the inserted capacitor, the PSO was used were the swarm consists of individuals called particles. Each particle in the swarm represents a potential solution of the optimization problem. Each particle moves through a D-dimensional search space at a random velocity. Each particle updates its velocity and position according to the following equations:

$$v^{i}_{j+1} = v^{i}_{j} + c_1 r_1 (p^{i}_{j} - x^{i}_{j}) + c_2 r_2 (p^{g}_{j} - x^{i}_{j}) \quad j=1,..n \quad \ldots 9$$

$$x^{i}_{j+1} = x^{i}_{j} + v^{i}_{j+1} \quad j=1,\ldots,n \quad \ldots .10$$

Where

c_1 and c_2 are acceleration constants;

r_1 and r_2 are uniformly distributed random numbers In the range 0 and 1.

p^{i}_{j} Best position ever visited by the Particle at the *i*th iteration;

p^{g}_{j} Global best position in the entire swarm;

4. THE STRUCTURE OF THE PROPOSED PROGRAM

Step1: schedule PLI for capacitor and Voltage in per unit.
Step2: Set the PLI as input1 and the per-unit voltage as input2

Step3: Fuzzified the inputs at Fuzzification unit.

Step4: Fuzzified Inputs process at Fuzzy logic-reasoning unit
Step5: deffuzzified Fuzzy controller outputs to classify the suitable Index (SI). The nodes, which have the greatest value of CSI, will be appropriate for placing the capacitor. Output of FLC is input for PSO determine the optimal size.

Step6: Read capacitors standard sizes.

Step 7: Generate particle swarm.

Step 8: Define the fitness of each particle swarm as the minimum total losses in the system.

Step 9: Check and modernize personal and global bests according to the Optimal size of capacitors that satisfy the objective function of minimum losses and voltage improvement.

Step 10: Update each individual velocity and position.

Step 11: Check stopping criteria, which are:

1. Voltage limits.
2. QT < QC.
3. Line losses after adding capacitor < line losses before adding capacitor.

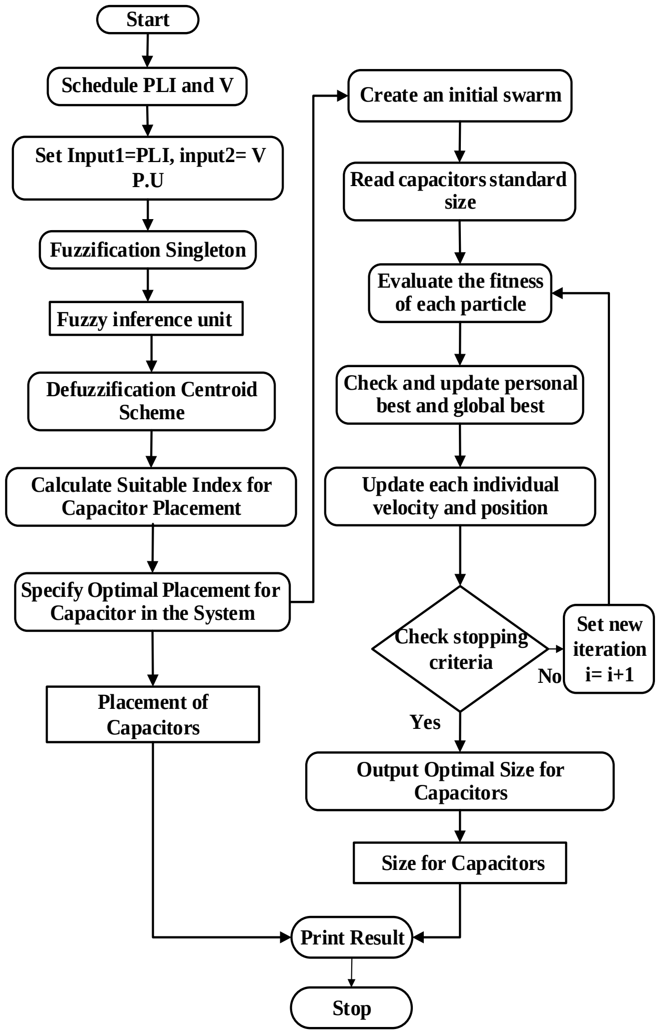

Figure (5) the flow chart of the proposed algorithm

5. RESULT AND DISCUSSION

The proposed intelligent FLC-PSO controller was implemented on the Iraqi distribution system represented by Al- RUSTAMIYA_Feeder09, 11kv, 50Hz, 62 nodes single source, figure (6) shows the one line diagram of the distribution system under consideration. The voltage limits were selected as Vmin = 0.95 pu and Vmax = 1.05 pu. Three load variation were considered in this study 60, 80 and 100 % and since the 80% load variation covers the longest period of the load cure of the system under consideration, then it was considered in the calculations of the optimal location and size of capacitors for the system. The input data represents the annual load curve for the system for the year 2014. See the appendix A.

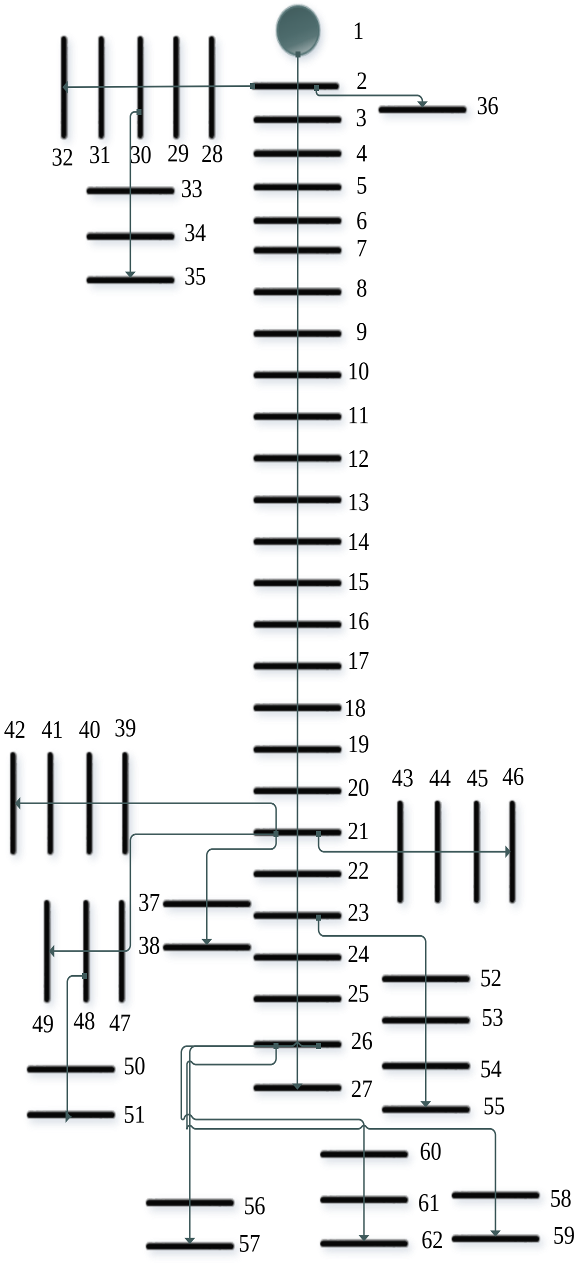

Figure (6) Al- RUSTAMIYA_Feeder09 distribution system

Table (2) shows the optimal locations of capacitor which have capacitor suitable index (CSI) more than 0.75 using FLC, and optimal size of capacitors using PSO. Table (3) show the real and reactive power losses before and after the installation for the Three-load variation.

Table (2) the optimal sizes of capacitor

Location by FES	Size by PSO-KVAR
24	1200
39	600
52	450
Total sizes	2250

Table (3) losses and voltage after and before capacitors

100%	**Before**	**After**	**Improve%**
KW loss	411.37	248.6174	39.563
KVAR loss	409.28	246.8701	39.681
Min voltage	0.88532	0.9318	5.25
80%	**Before**	**After**	
KW loss	250.6816	149.5314	40.35
KVAR loss	249.3294	148.6792	40.368
Min voltage	0.9104	0.9539	4.8
60%	**Before**	**After**	
KW loss	159.8883	98.6114	38.324
KVAR loss	158.9907	98.3128	38.164
Min voltage	0.9284	0.9699	4.47

Figures (7, 8. And 9) shown in appendix B show that the voltage, the real power losses, and the reactive power losses improvement at 80% load level respectively. The red curve represents the base case and the blue one represents the vales after adding the capacitors.

The execution time for FLC-PSO is 21.571947 seconds.

From the tables it is clear that adding the capacitors reduces the real losses, reactive losses and improves the voltage profile by (38.324% –to- 39.563%) (38.164% - 39.681%) and (4.47% - 5.25%) respectively for the three cases(60%-100%) of the load variation.

6. CONCLUSION

This paper introduced an intelligent FLC-PSO approach method to determine the optimal location and size of capacitors in Iraqi distribution power system. This combination reduced active power losses and improved the bus voltage levels in an efficient way .The main advantage of this approach was clarifying the robustness of intelligent systems over the conventional systems in flexibility, robustness of the complex combination problem, sure and fast convergence. The obtained results declared the effectiveness of the proposed method.

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8. APPENDIX A

V = 11 KV P.F. = 0.8								
LINE DATA								
Node data				**11kV Feeder data**				
	Node No.	Trans. Rating (kVA)		Feeder section	Kind of feeder	Length (km)	R (Ω)	X (Ω)
	2	-		s.s-2	3×150 UGC	2.133	0.29464	0.230703
	3	400		2-3	Al-95	0.1	0.04184	0.044302
	4	250		3-4	Al-95	0.216	0.03146	0.03331
	5	250		4-5	Al-95	0.216	0.06795	0.07194
	6	250		5-6	Al-95	0.15	0.06795	0.07194
	7	250		6-7	Al-95	0.15	0.04719	0.049965
	8	250		7-8	Al-95	0.066	0.04719	0.049965
Main feeder	9	250		8-9	Al-95	0.466	0.020763	0.021984
	10	250		9-10	Al-95	0.266	0.146603	0.155224
	11	250		10-11	Al-95	0.233	0.083683	0.088604
	12	250		11-12	Al-95	0.183	0.073301	0.077612
	13	250		12-13	Al-95	0.3	0.05757	0.06095
	14	250		13-14	Al-95	0.133	0.09438	0.09993
	15	250		14-15	Al-95	0.066	0.041841	0.044302
	16	250		15-16	Al-95	0.266	0.020763	0.02198
	17	250		16-17	Al-95	0.5	0.020763	0.02198
	18	250		17-18	Al-95	0.4	0.1573	0.16655
	19	250		18-19	Al-95	0.166	0.12584	0.13324

	18	250		17-18	Al-95	0.4	0.1573	0.16655
	19	250		18-19	Al-95	0.166	0.12584	0.13324
	20	250		19-20	Al-95	0.3	0.052223	0.055294
	21	250		20-21	Al-95	0.5	0.09438	0.09993
	22	250		21-22	Al-95	0.15	0.17303	0.183205
	23	250		22-23	Al-95	0.166	0.036493	0.038639
	24	630		23-24	Al-95	2.1	0.18876	0.19986
	25	250		24-25	Al-95	2.3	0.026111	0.027647
	26	400		25-26	Al-95	0.15	0.16768	0.177542
	27	250		26-27	Al-95	0.3	0.262061	0.277472
Lateral 1	28	630		2-28	Al-95	0.416	0.34718	0.28633
	29	250		28-29	Al-95	0.233	0.04719	0.049965
	30	250		29-30	Al-95	0.3	0.09438	0.088604
	31	250		30-31	Al-95	0.1	0.130873	0.138569
	32	250		31-32	Al-95	0.766	0.073301	0.077612
sub Lateral 1	33	250		30-33	Al-95	0.433	0.09438	0.09993
	34	250		33-34	Al-95	0.2	0.03146	0.03331
	35	250		34-35	Al-95	0.65	0.240983	0.255154
Lateral 2	36	250		2-36	Al-95	0.2	0.28426	0.21971
Lateral 3	37	250		21-37	Al-95	0.333	0.136221	0.144232
	38	250		37-38	Al-95	0.65	0.06292	0.06662
Lateral 4	39	630		21-39	Al-95	0.55	0.20449	0.216515
	40	400		39-40	Al-95	0.116	0.06292	0.06662
	41	250		40-41	Al-95	0.6	0.104762	0.110922
	42	400		41-42	Al-95	0.083	0.20449	0.216515
Lateral 5	43	250		22-43	Al-95	0.533	0.17303	0.183205
	44	250		43-44	Al-95	0.833	0.115143	0.121914
	45	250		44-45	Al-95	0.55	0.115143	0.121914
	46	250		45-46	Al-95	0.366	0.12584	0.13324
Lateral 6	47	630		21-47	Al-95	0.366	0.1573	0.16655
	48	400		47-48	Al-95	0.4	0.04719	0.049965
	49	250		48-49	Al-95	0.766	0.036493	0.038639
Sub lateral2	50	250		48-50	Al-95	0.6	0.240983	0.255154
	51	250		50-51	Al-95	0.766	0.18876	0.19986
	52	630		24-52	Al-95	0.466	0.240983	0.255154

Lateral 7	53	400		52-53	Al-95	0.266	0.146603	0.155224
	54	250		53-54	Al-95	0.8333	0.083683	0.088605
	55	400		54-55	Al-95	1.033	0.262061	0.277472
Lateral 8	56	250		26-56	Al-95	0.1666	0.324981	0.344092
	57	250		56-57	Al-95	0.583	0.052223	0.055294
Lateral 9	58	630		26-58	Al-95	0.3	0.183411	0.194197
	59	250		58-59	Al-95	1.4	0.09438	0.09993
	60	250		26-60	Al-95	1.166	0.44044	0.46634
	61	400		60-61	Al-95	1.6	0.366823	0.388394
	62	250		61-62	Al-95	1.166	0.44054	0.46644

9. APPENDIX B

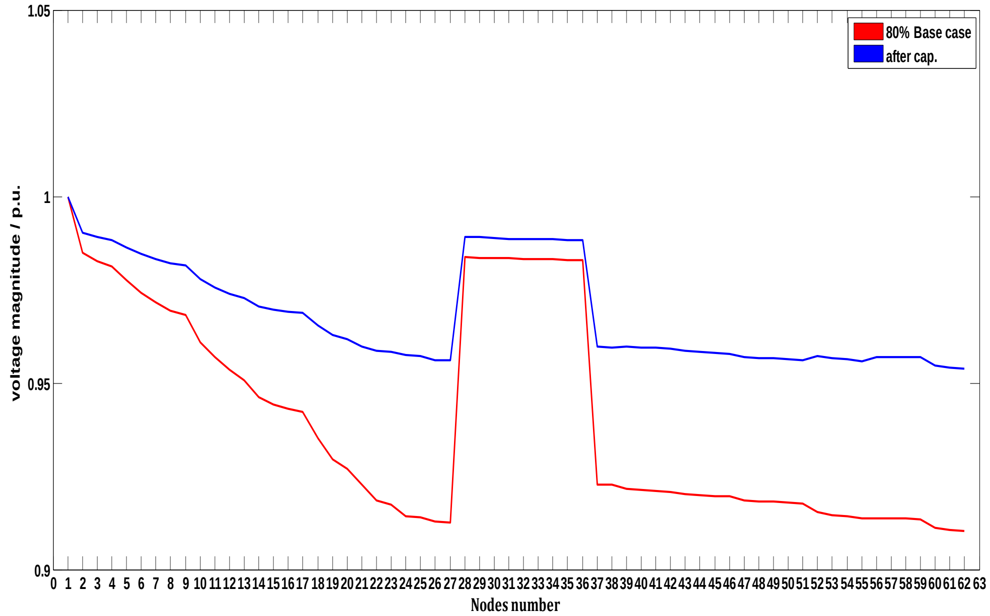

Figure (7) the voltage levels improvements

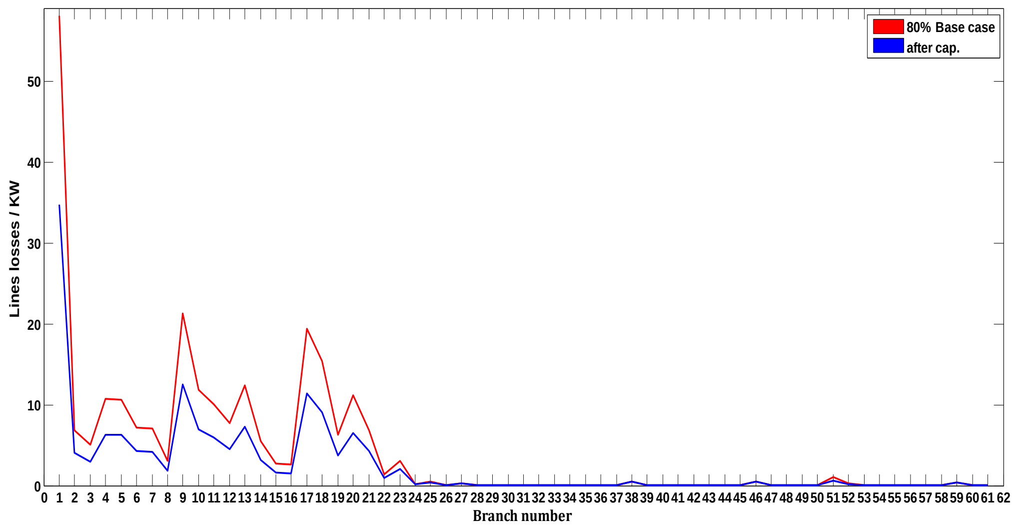

Figure (8) the active power losses improvements

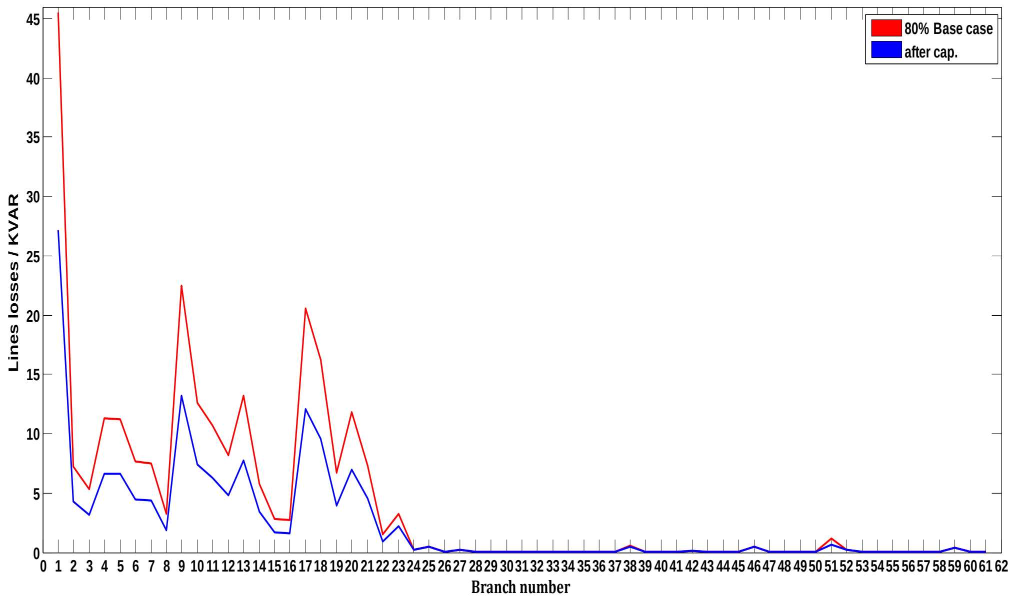

Figure (9) the reactive power losses improvements