Power Factor Correction of Electrical Distribution Systems

Using Fuzzy Logic Technique

تصحيح معامل القدرة في نظم التوزيع الكهربائية باستخدام تقنية المنطق المبهم

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Abstract:-

This paper presents a study of the power factor and is impacts on distribution networks of electric power. Using remove the bad effects of low power factor on the network. Applying mathematical model using same equations. Apply Fuzzy Logic Technique (FLT) to improve the power factor by using MATLAB program to determine the shunt capacitor size and sensitive nodes (down power factor and high power losses) in the network and know the size needed for the purpose of improving power factor. The nine nodes network is implemented and applies the Fuzzy logic technique on the networks. The result performance of the electrical network improve the power factor , reduces power losses , improve the voltage profile and control adding shunt capacitor in the excel locations as needed to the network This results in finding best economical costs saving , and speeding the work , for possible on-line implementation in distribution network .

Kay word: Power factor, Voltage drop, Fuzzy logic.

1. Introduction

Capacitors are widely used in distribution system for reactive power compensation to achieve power and energy loss reduction, regulation, and system capacity release Reference [1],S.F Mekhamer , M.E Elawary, S. A Soliman , M. A Moustafa and

M. Mansour .The Artificial Intelligence-based techniques can solve the capacitor allocation problem in distribution system for power factor correction . Fuzzy logic technique are used methods to solve the capacitor allocation problem have various merits. However their efficiency relies entirely on the goodness of the data used. Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the capacitor allocation optimization process. The advantages of fuzzy logic technique are verified by the application to test feeders Reference [7] H.C Chin,[8] H N. Ng M.M.A Salama, A Y. Chickani,Therefore, the capacitor placement problem in distribution feeders consists of determining the place (number and location), type, size, and control scheme of capacitors to be installed such that the benefits mention above is weighted against the fixed and running costs of the capacitors and their accessories. When the active power transmission in improved by means of reactive power injection the electric power system can operate too near its limits. Reference [9] H.S Barbuy, A.R Luiz Augusto ,P Fernades and G C Guimoraes.

The installation of shunt capacitors on radial distribution systems is essential for many reasons, some of these reasons arc power flow control improving system stability , power factor correction, Voltage profile management and losses minimization, there for, it is important to find the optimal size and location of shunt capacitor required to minimize feeder power losses and the suitable time to switch on and off the capacitor. Effects of low power factor increase of investment costs for generators, transformers, on the transmission lines and distribution lines (6).Reference [7] H.C Chin used Fuzzy Set Theory and assigned three membership functions to describe power loss, bus voltage deviation, and harmonic distortion. A decision variable to determine nodes for capacitor placement is then calculated by taking the intersection of the three membership functions for each node in the distribution system. The node with the greatest decision values are selected for capacitor installation.

Mathematical optimization procedure is given in Reference [7] H.C Chin It shows method of calculating capacitor size to be placed in .the nodes selected by the fuzzy procedure .Reference [8] H N. Ng M.M.A Salama, A Y. Chickani.Applied Fuzzy Set Theory(FST) to the capacitor placement problem by using fuzzy approximate reasoning Voltage and power loss indices of the distribution system nodes are modeled by membership functions and fuzzy expert system containing a set of heuristic rules performs the inference to determine a capacitor placement suitability index of each node. Capacitors are placed on the can also account to unceI1ainty in the parameters used. All of the above Ai methods can be implemented using commercially-available AI development shells or be hard coded using any programming language with relative ease For techniques using Genetic Algorithm's.

2. Problem formulation and application of Fuzzy logic for power factor correction in radial distribution feeders.

In a three phase radial distribution feeder with (n) number of nodes.

$$S_j = P_j + Q_j \qquad j = 1, \ldots\ldots, n \tag{1}$$

$$P_{(j+1)} = P_j - R_{(j+1)}(P_j^2 + Q_j^2)/V_j^2 - P_{L(j+1)} \tag{2}$$

$$Q_{(j+1)} = Q_j - X_{(j+1)}(P_j^2 + Q_j^2)/V_j^2 - Q_{L(j+1)} \tag{3}$$

$$Pf_j = \frac{P_j}{\sqrt{P_j^2 + Q_j^2}} \tag{4}$$

$$V_{(j+1)} = V_j - 2(R_{(j+1)}P_j + X_{(j+1)}Q_j) + (R_{(j+1)}{}^2 + X_{(j+1)}{}^2) \times (P_j{}^2 + Q_j{}^2)/V_j{}^2 \tag{5}$$

$$P_{loss(j+1)} = R_{j+1}(P_j^2 + Q_j^2)/V_j^2 \tag{6}$$

$$Q_{LOSS\,(j+1)} = X_{j+1}(p_j^2 + Q_j^2)/V_j^2 \tag{7}$$

$$P = \sum_{j=0}^{n-1}(P_{loss(j+1)}) \tag{8}$$

$$Q_{\max} = L \times Q_c \tag{9}$$

Where: L is an integer. Then at each selected location there are L sizes to choose from. Let K_{1c} , K_{2c}, …. K_{Lc} be the corresponding capital invested per kVAR assuming

that only capacitor banks are used voltage excursions, the cost function S can be selected as

$$Cost = Kp \times P_{loss\ new} + \sum_{j-1}^{k} Kc_j Qc_J \quad (10)$$

$$Q_{cj} = P_j(\tan\varnothing_j - \tan\varnothing_{jnew}) \quad (11)$$

$$\varnothing_{jnew} = \tan^{-1}\left(\frac{P_j \tan\varnothing_j - Q_{cj}}{P_j}\right) \quad (12)$$

$$Pf_{new} = \cos\varnothing_{jnew} \quad (13)$$

Where: Kp : is cost per power losses ($ / kW / year) , assume

Kp = 200$/KW/Year [7] .

j = 1, 2, …….. k represents the selected buses. The objective function is to be minimized as $V_{min} \leq V_j \leq V_{max}$

j = 1, 2,3, ………….., n

kjc = cost of additional capacitors

Pf_{new} : is power factor after compensation

Q_{cj} : KVAR compensation

Kcj :Cost of KVAR ($/KVAR)

Fuzzification is to make a crisp quantity fuzzy. This process recognizes the quantity that carries considerable uncertainty. So the variable is fuzzy and can be presented by membership function.

The main difference between crisp sets and fuzzy sets is that the first one deals with binary logic (0, 1) providing two membership functions either "true" or "false", mathematically for a set A

MA (X) = 1 if $A \in X$ - MA (X) = 0 if $A \notin X$

But in a fuzzy set variables are allowed to have a degree of truth in the interval (0, 1). The most popular shapes and membership functions used in fuzzy applications are triangle shapes.

Table (1) The rule base of Fuzzy system operation for two membership function inputs, power losses and power factor

		Power factor				
And		**Low**	**low/med**	**medium**	**high/medium**	**high**
Power losses	**low**	low medium	Low medium	low	low	low
	low medium	medium	Low medium	low medium	low	low
	medium	high medium	Medium	low medium	low	low
	high medium	high medium	high medium	medium	low medium	low
	high	high	high medium	medium	low medium	low

3. Case study

The IEEE, nine-bus radial distribution feeder of REF (1) rated voltage is 23 KV . the system is show in Fig (1) and the input data is given in Table (1) .

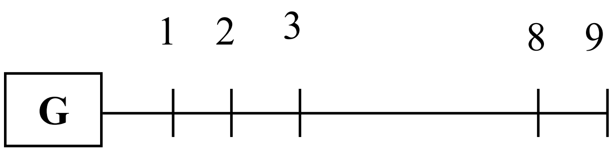

Fig 1 case study of nine bus system

Table (2) Input data of first case study nine-bus system

Section Feeder No.		R (Ohm)	X (Ohm)	P(kW)	Q(KVAR)
0	1	0.1233	0.4127	1840	460
1	2	0.0140	0.6051	980	340
2	3	0.7463	1.2050	1790	446
3	4	0.6984	0.6084	1598	1840
4	5	1.9831	1.7276	1610	600
5	6	0.9053	0.7886	780	110
6	7	2.0552	1.1640	1150	60
7	8	4.7953	2.7160	980	130
8	9	5.3434	3.0264	164	200

4. Proposed Solution

When storing fuzzy logic technique operation, finds suitability index at each node of distribution system. The maximum value of suitability index represents sensitive node depending on the value of reactive power and power loses in his this node. The high value of Q_{old} and power losses have a high suitability index.

The program chooses the value of shunt capacitor that must be added in this node This test is carried out when the power factor at each sensitive node is less than 0.94 The Solution algorithm can be summarized as follows :

1. Input system data shown in table (2) .
2. Perform the load flow program using equation (1 to 13) calculate bus voltages, power losses and power factor using numerical method .
3. Find the membership functions of power losses and power factor and decision for the fuzzy sets of power losses and power factor decision .

4. Identify the candidate node at the bus with the lowest membership function Ms (bus k) .
5. Install a capacitor at bus (k) with size varying in integer steps select Qc that has the lowest cost without violating the constraints from table (6) .
6. Add this Qc at bus (k) and perform the load flow again If power factor is corrected and power losses reduced go to steps 3, otherwise end t e program .
7. Assuming that (n) busses have been chosen for placing new capacitors, adjust the first capacitor (i = 1) in integer steps while keeping others fixed select Qc for the first one that has the lowest cost without violation Repeat for (i =2 ... n) .
8. Repeat step 7 if the cost function still decreases.

Table (3) size and location of shunt capacitor

sensitive nodes selected=	4	5	9
Q_c std (KVAR) =	1200	600	150

Table (4) Power factor ,power losses and cost with and without compensation of 9-bus system

Section feeder No.		PF old	PF new	Ploss old (kW)	Ploss new (kW)	Cost-old ($)	Cost-new ($)
0	1	0.9700	0.9701	34.2400	22.9110	6848	4582.300
1	2	0.9440	0.9443	2.7663	1.7014	553.260	340.280
2	3	0.9700	0.9708	119.0560	68.7400	23811.200	13748.000
3	4	0.6550	0.9288	71.1615	34.8200	14232.300	7168
4	5	0.9370	0.9999	90.1799	79.1827	18035.980	15968.540

5	6	0.9902	0.9902	17.376	16.3598	3475.340	3271.960
6	7	0.9986	0.9987	22.3555	20.6262	4471.100	4125.240
7	8	0.9913	0.9914	14.1010	12.0422	2820.200	2408.440
8	9	0.6340	0.9560	0.6757	0.2717	135.14	129.340

Table (5) Voltage profile, voltage drop, and VPu with and without compensation of 9-bus system

Section feeder No.		VP old (V)	VD old (V)	VPu-old	VP-new (V)	VD-new (V)	VPu-new
0	1	22773	226.98	0.9900	22814	185.67	0.9919
1	2	22500	269.00	0.9784	22603	210.99	0.9828
2	3	21938	566.12	0.9538	22173	430.184	0.9640
3	4	21642	295.65	0.9410	21966	206.828	0.9551
4	5	21081	560.85	0.9166	21441	525.546	0.9322
5	6	20915	166.33	0.9090	21274	161.396	0.924
6	7	20669	246.33	0.8986	21028	236.619	0.9138
7	8	20370	298.84	0.8856	20729	276.173	0.9018
8	9	20301	69.00	0.8826	20660	43.787	0.8999

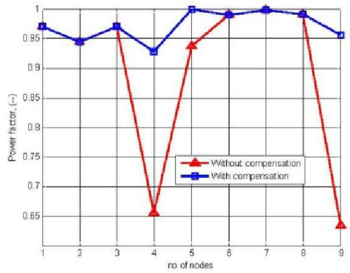

Fig 2 Power factor with and without compensation of 9-bus system

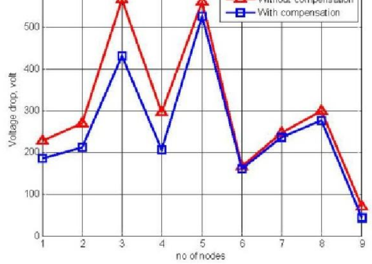

Fig 3 Voltage drop with and without compensation of 9-bus system

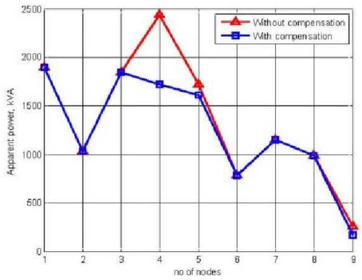

Fig 4 Apparent power with and without compensation of 9-bus system

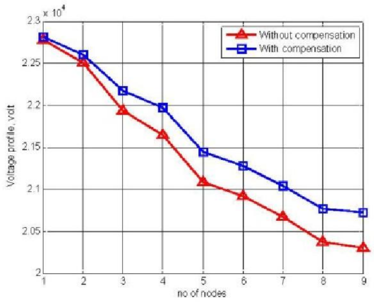

Fig 5 Voltage profile with and with out compensation of 9-bus system

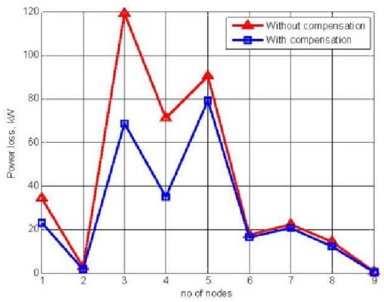

Fig 6 Power loss with and without compensation of 9-bus system

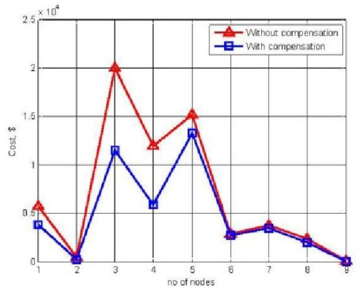

Fig 7 Cost with and without compensation of 9-bus system

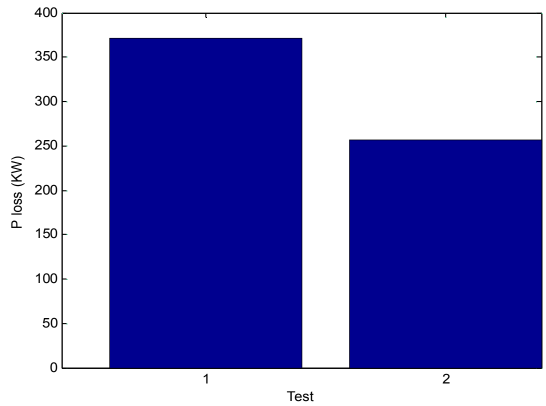

Fig 8 Total power loses (1) with and (2) without compensation

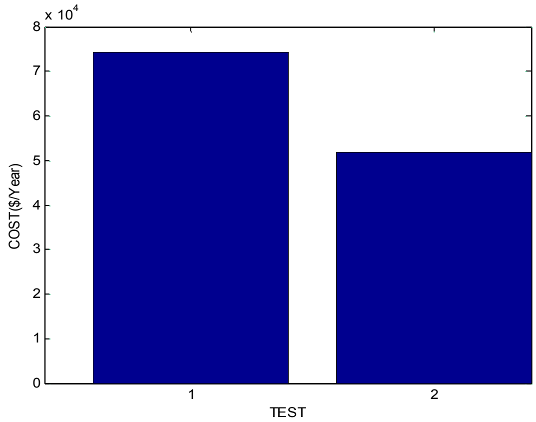

Fig 9 Total cost (1) with and (2) without compensation

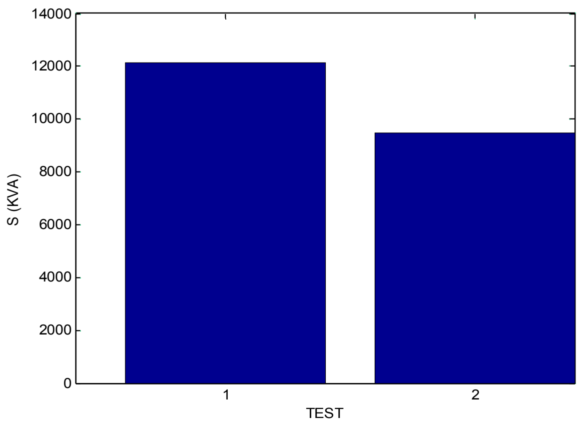

Fig 10 Total apparent power (1) with and (2) without compensation

Fig (2,3,4,5,6,7) shows the comparison between the performance of network before{without compensation) and after(with compensation) correction power factor. Fig (8,9,10) shows the comparison between total power losses, total cost and total apparent power with (new) and without (old) compensation.

The numerical method had been used to calculate the load flow and find the values of the network by the improving power factor and voltage as shown in Table (4,5) and used Fuzzy Logic technique to find size which are chosen from Table (6) according to the calculated value of shunt capacitor and location for improving power factor.

The MATLAB program closer the value of shunt capacitor was calculation to the nearest values in Table (6) to find optimal value of shunt capacitor as shown Table(3).The results finds sensitive nod and value of shunt capacitor. The power factor equal(0.655) at node (4)when addition 1200K V AR shunt capacitor the power factor improved to (0.928), at node (5) the power factor equal (0.937) when addition 600KV AR shunt capacitor the power factor improved to (0.999) and at nod (9) the power factor equal (0,634) when addition 150KV AR shunt capacitor the power factor improved to (0.956).Table(4,5)shows the values from system with and without compensation and improved performance of this system .

5. Conclusion

The previous study shows that the location and size of shunt capacitors have very important impact on the power factor correction problem. It is clear from the tests that (he accuracy of the appropriate sizes of the capacitors will affect the values of reactive power compensation added to reduce the power losses in electric power system, the possible value added to mitigate the loss of energy or increase it according to the added value of reactive power compensation. This value must be carefully chosen because it also affects the value of the voltage in the network so that it should not exceed the allowable value in the network .

The location and size of shunt capacitors must be selected on the basis of the point known variables and the reasons of the correction because the location has the possibility to be changed and the appropriate location provides us with different benefits and increases the saving power after power factor correction. The best investment cost could be obtained by finding the best size and location of shunt capacitors. The programs used have calculated all costs and chosen the optimal location and size of the shunt capacitor. The calculation of the economic saving.

3.

6. DISCUSSION

1. Fuzzy logic technique operation depends of IF -THEN of rule base.
2. The Fuzzy Logic Technique operation depend on tile number of membership function and rule base that selected by the user. l he number of rule base selected according to the relation between membership function and the number of input data .

Number of member ship function= (1, 3,5,7.. ..... n) .

Number of rule base = (number of membership function) power to the number of input data In this paper used two input data and fifth triangular membership functions. Input data is the power factor and power losses, output data is capacitor placement suitability. So the rule base written and application is 25 rule base.

3. The power factor improved the weak nodes and the previous nodes in less degree because less the reduction imaginary current passing in the network shown table (4 and 5) the program finish when the power factor improving according to the condition written. It can improve the voltage through increase

This improvement by introduction of third input, voltage power losses and powe factor, must be written 125 rule base

.Shows that the correction of power factor provides us with several benefits which are as follows:

1. Reduce active power losses
2. Decrease in investment costs in power plant.
3. Increase in the number of customers because the power is increased du to the power factor improving as increases saving costs.
4. Reduction in reactive power drawn from the network provides us with additional capacity to the network .
5. Improve the voltage profile by reducing the current passing through the network, and this leads to improve the performance of the networks.

Table 6 Standard KVAR and COST/KVAR

No.	Qc (KVAR)	Kc ($)
1	**5**	**0.8**
2	**15**	**0.75**
3	**30**	**0.7**
4	**50**	**0.65**
5	**100**	**0.6**
6	**150**	**0.5**
7	**300**	**0.35**
8	**450**	**0.253**
9	**600**	**0.22**
10	**750**	**0.276**
11	**900**	**0.183**
12	**1050**	**0.228**
13	**1200**	**0.17**
14	**1350**	**0.207**
15	**1500**	**0.201**
16	**1650**	**0.193**

17	1800	0.187
18	1950	0.211
19	2100	0.176
20	2250	0.197
21	2400	0.17
22	2550	0.189
23	2700	0.187
24	2850	0.183
25	3000	0.18
26	3150	0.195
27	3300	0.174
28	3450	0.188
29	3600	0.17
30	3750	0.183
31	3900	0.182
32	4050	0.179

الخلاصة:

يقدم البحث دراسة لمعامل القدرة وأسباب حدوثه وتأثيراته علي شبكات توزيع الطاقة الكهربائية والطرق المستخدمة لإزالة تأثيرات انخفاض معامل القدرة على الشبكة وقد تم تطبيق الطريقة الحسابية باستخدام بعض المعادلات لغرض استخدامها وتطبيق تقنيه المنطق المبهم لتحسين معامل القدرة وتطبيقها بالاستفادة من برنامج الماتلاب لمعرفة النقاط الحساسة والضعيفة (معامل القدرة منخفض والفقد في الطاقة عالي) في شبكات التوزيع الكهربائية ومعرفة سعة مكثفات التوازي اللازم إضافتها لغرض تحسين معامل القدرة وقد تمت دراسة شبكة تحتوي علي تسعة عقد كانت النتيجة معرفة أداء الشبكة وتحسين معامل القدرة وتقليل القدرة الضائعة وتحسين الفولتية المطبقة وكذلك تم التحكيم في إضافة مكثفات التوازي في أي موقع وحسب الحاجة وقد حصلنا

علي نتائج جيدة وسريعة في العمل وكذلك المحافظة علي القيم المسموح بها في الشبكة واستخدام هذه الطريقة بشكل مباشر (on-line) في شبكات التوزيع الكهربائية.

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