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FIS based Optimization and Selection of Capacitor Placement in Distribution System

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ABSTRACT

Power sectors are currently facing power shortage due to high distribution losses. This paper proposes loss reduction method by fuzzy inference system for a radial distribution system. Proper sizes of shunt capacitors in radial distribution systems can reduce some portion of this loss and tends to improve the efficiency of the system. To validate the proposed method is try out on 10 bus radial distribution system. Power flow of 10 bus system is executed on power world simulator. Concept of power factor has been introduced to develop a fuzzy controller to select a proper location and size of capacitor to be added across the load. Aim of this paper is to study and discuss the result of this method to reduce maximum power loss to improve the efficiency of system. Fuzzy techniques are simple, flexible cheaper to develop and gives fast results with few computations only. The propose method can be applied to higher bus distribution system. The results of sensitivity analysis and fuzzy inference system are compared show the effectiveness and robustness of the proposed approach.

Keywords: *Capacitor Placement Suitability Index (CPSI), Power loss reduction index (PLRI), Fuzzy Inference System (FIS), Optimal Power Flow (OPF).*

1. INTRODUCTION

In the present scenario, Power is delivering to the consumer via large and complex distribution network. As the efficiency of the power supply system largely depends on the distribution system, losses are the major problem in distribution system [1]. To diminish the power losses in distribution network, shunt compensations employed in the system. In a distribution system, shunt capacitor is widely used to reduce power losses as it will enhance voltage and power factor too. Capacitor placement is also upgrading the system stability and voltage regulation so the overall system efficiency is increased [2]. The placement of capacitor in proper manner and at proper voltage level will leads to minimize the losses at lower cost. For the proper voltage rating (for proper size) and placement of capacitor at proper location, sensitivity analysis and alpha co efficient method is to be preferred. Capacitor placement and its sizing is done using loss sensitivity factor and α-coefficient method respectively [3]. But this method is complex, more time consuming and gives less loss reduction. Here fuzzy inference system (FIS) is introduced to find optimum location of capacitor and size of capacitor [4]. Fuzzy expert system which uses set of linguistic variable would be prefer to use for minimizing losses in power system by placing capacitor at suitable nodes with optimum size [5]. PLRI (power loss reduction index), VI (voltage index), CPSI (capacitor placement suitability index) of distribution system are developed by fuzzy membership functions. FIS system uses power loss reduction index and voltage index to determine capacitor location using CPSI for each bus on radial distribution system [6]. It is new methodology to determine size, type, number and location of capacitor in a proper way. Power factor and power demand are modeled by fuzzy membership function for capacitor sizing. FES is more reliable, less time consuming and gives better results than sensitivity analysis and α coefficient method [7]. Innumerable researches are introduced the optimal locations of capacitors by two stage methodology including sensitivity analysis and capacitor sizing implemented by various optimization techniques [8]. Although this paper introduces two fuzzy models for better location and selection of optimal size of capacitor. Performance of these models depends on proper selection of rule base and membership functions.

2. POWER FLOW ANALYSIS

Distribution of power must be done at minimum cost and maximum efficiency which involves real and reactive power adjustment in proper way to minimize overall operating cost. Power world simulator employs linear programming method for finding an optimal solution [9]. To determine the location and size of capacitor, Optimum Power flow (OPF) analysis is done in power world simulator.

The three phase balanced 10 buses radial distribution system is considered as a test system. The data of system are obtained from [1].Shunt capacitors (fixed) are used to be placed at suitable nodes as reactive power injection [3].Fig. 1 shows 10 bus system implemented in power world simulation software for analysing performance of distributed system.

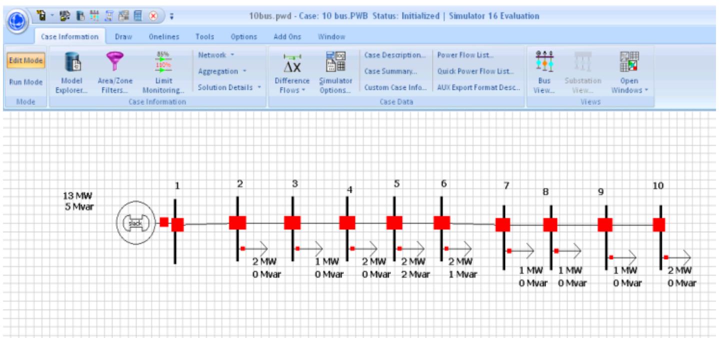

Fig. 1. 10 bus systems in power world simulator

With the help power world simulator power flow can be done within very less time. It is very useful software for analysis of power flow dynamics compare to other tools like ETAP, PSAT etc.

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Result of power flow done is given in table I.

Bus no	Voltage Magnitude(V)	Power loss(KW)
1	0.9929	46.7
2	0.9874	4
3	0.9635	177.3
4	0.9481	114.3
5	0.9173	190.1
6	0.9073	47.8
7	0.8890	75.7
8	0.8588	88.5
9	0.8376	39.3

Table I: Power flow solution of 10 bus radial system

3. CAPACITOR PLACEMENT USING FUZZY APPROACH

There are a lot of methods implemented for optimal capacitor placement problem [1]-[6].Fuzzy logic is a form of many-valued logic based on degree of truth in which the truth values of variables may be any real number between 0 and 1 including both. Fuzzy logic has the advantage of including heuristics and providing engineering estimation for optimization of capacitor allocation [7].The candidate buses for capacitor allocation are determined using fuzzy approach. Two major objectives are considered for these estimation processes for implementation of fuzzy logic in capacitor placement problem are:

1) To minimize the real power loss

2) To maintain voltage within its permissible limits.

For determining the suitability of capacitor placement at a particular bus, a set of multiple-antecedent fuzzy rules has been established [10].Voltage and power loss reduction index are modelled by fuzzy membership functions. A fuzzy inference system (FIS) made up of a set of rules is then used to determine the capacitor placement suitability of each bus in the distribution system. Capacitor placement can be done on buses with the highest suitability which can be identified by an experienced engineer by examining voltage levels and losses after power flow analysis. A bus having highest losses and lower voltage is suitable for the capacitor placement. First power flow solutions are required to obtain real power losses in the system. Again, Power flow solutions are required to obtain the power loss reduction by compensating the total reactive load at every bus of the distribution system. 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. Power Loss reduction Index value for nth bus can be obtained using

$$PLRI_n = \frac{(LR_{(n)} - LR_{(min)})}{(LR_{(max)} - LR_{(min)})} \quad (1)$$

Where,
$LR_{(n)}$: Loss reduction,

$LR_{(min)}$: Minimum reduction,

$LR_{(max)}$: Maximum reduction,

n: Number of bus

These power loss reduction indexes along with the p.u. bus voltages are the inputs to the fuzzy inference system. This system finds suitable location of capacitor. This system is developed using Fuzzy Logic Toolbox in MATLAB, which is used for finding the capacitor placement suitability index [CPSI].

Fuzzy rules are designed such that output based on input variables and made up by if-then rule which is given below.

IF premise (antecedent), **THEN conclusion** (consequent)

Outline of this fuzzy inference system is given by fuzzy decision matrix in Table II.

Power loss reduction index	Voltage index				
	Low	**Low-normal**	**Normal**	**High-normal**	**High**
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-medium

Table- II: Fuzzy decision matrix for suitability of capacitor placement.

The membership function of a fuzzy set is a generalization of the indicator function for classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. In proposed methodology, five triangular membership functions are selected for PLRI, VI and CPSI. They are Low, Low-Medium, Medium, High-Medium and High. All the five membership functions are as shown in figure 2, 3 and 4 respectively. Result obtained by fuzzy inference system develop by fuzzy decision matrix given in table III.As per logic CPSI will be maximum at critical buses. Those buses needs stability and require capacitor placement to balance the system.

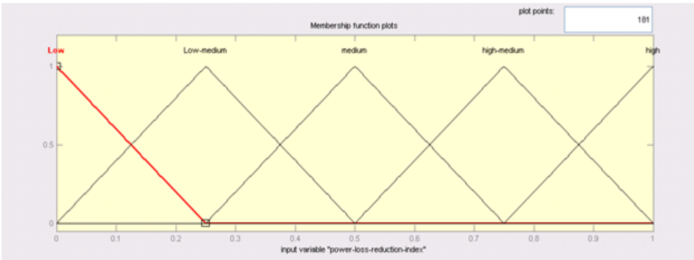

Fig. 2. Membership function for input variable PLRI

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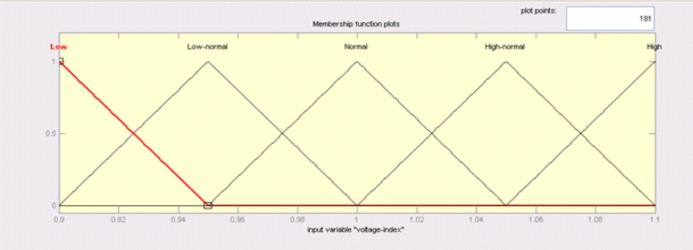

Fig. 3. Membership function for input variable VI

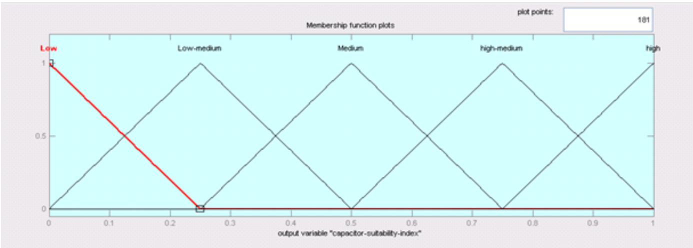

Fig.4. Membership function for output Capacitor Placement Suitability Index (CPSI)

Bus no.	PLRI	VI	CPSI
1	0.2202	0.9929	0.142
2	0	0.9874	0.173
3	1	0.9635	0.673
4	0.711	0.9481	0.701
5	0.5956	0.9173	0.654
6	0.1046	0.9073	0.359
7	0.1768	0.8890	0.418
8	0.2382	0.8588	0.483
9	0.0938	0.8376	0.35

Table III Location finding for capacitor placement using fuzzy logic

From above table we can conclude that bus no.3,4 and 5 are in urgent need of balancing for loss minimization and require to place a capacitor at particular node.

4.FUZZY LOGIC MODEL FOR SIZING OF CAPACITOR

The proposed technique aims at estimating the optimal size of capacitor. The main part of fuzzy inference system is Knowledge base, which is described by the linguistic rules. Linguistic rules leads to determine size of capacitor at particular node by fuzzy decision controller. Each fuzzy rule is basically a function of If and THEN rule statement .Fuzzification maps the crisp value of preprocessed input into fuzzy sets which act as membership function. Membership functions used in this technique is given below in figure 5, 6 and 7 respectively. Capacitor plays an important role in energy saving. It improves power factor of the system. Power factor varies as per the variation in power demand also. As per this relationship, for identification of size of capacitor two input variables are considered that is power factor and power demand.

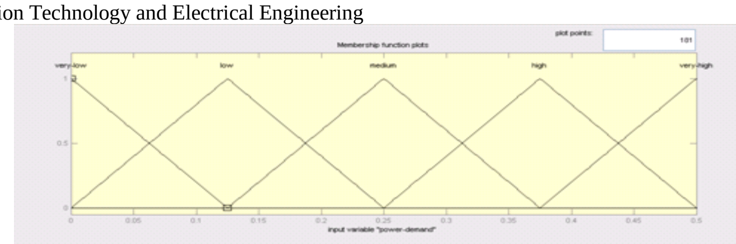

Fig. 5. Membership Function for Input Variable power demand

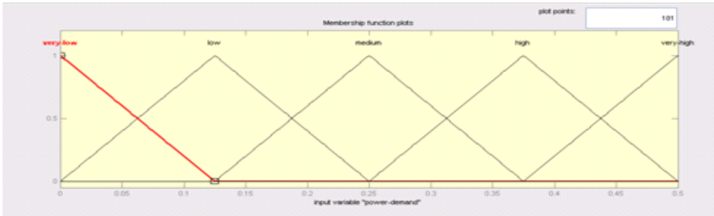

Fig. 6. Membership Function for Input Variable power factor

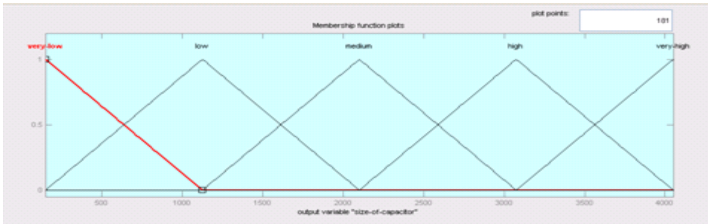

Fig. 7. Membership Function for Output size of capacitor

The fuzzy decision controller uses 25 rules to determine the value of Capacitor for given Power demand and power factor. The fuzzy rule base has been given in Table-IV.

Power demand	**Power factor**				
	Very-low	**Low**	**Medium**	**High**	**Very-high**
Very-low	Very-high	High	Medium	Low	Very-low
Low	High	Medium	Low	Very-low	Very-low
Medium	Medium	Low	Low	Very-low	Very-low
High	Low	Very-low	Very-low	Very-low	Very-low
Very-high	Very-low	Very-low	Very-low	Very-low	Very-low

Table VI Fuzzy decision matrix for suitability of capacitor placement

Interpretation of the entire fuzzy inference process can be

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done by rule viewer. Rule viewer can represent the shape of certain membership functions influences the overall result. Rule viewer of proposed techniques is shown below in figure 8.

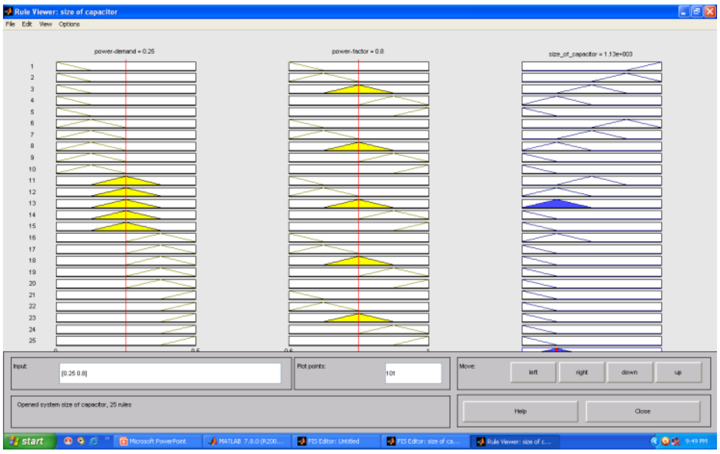

Fig. 8. Rule viewer for sizing of capacitor.

The result of capacitor sizing is given in Table-V. Capacitor size is decided by power demand and power factor at particular node using fuzzy technique.

Bus no.	Power factor	Power demand	Size of capacitor
3	0.9701	0.1193	583
4	0.6561	0.1065	2560
5	0.9372	0.1073	750

Table V Results of capacitor sizing using fuzzy

5.RESULTS

Evaluation of power loss can be done by performing load flow analysis for voltage analysis and loss calculation using equation (2).Performing load flow in power world simulator gives voltages and losses simultaneously, which reduces computation time and shown in table VI.

Bus no.	Before compensation		After compensation	
	Voltages	Losses	Voltages	Losses
1	0.9929	46.7	0.9958	40.4
2	0.9874	4	0.9946	3.4
3	0.9635	177.3	0.9795	149.1
4	0.9481	114.3	0.9681	94
5	0.9173	190.1	0.9404	174.7
6	0.9073	47.8	0.9307	45.2
7	0.8890	75.7	0.9130	71.5
8	0.8588	88.5	0.8836	83.3
9	0.8376	39.3	0.8631	37
Total losses	783.7 KW		699 KW	

Table VI Comparison of voltages and losses by performing load flow in power world simulator

The total reduction in the power losses is calculated manually as:

$$\Delta P_{LOSS} = P_{loss\ before\ capacitor} - P_{loss\ after\ capacitor} \qquad (2)$$

Table VII Indicates the loss reduction after capacitor placement implemented by fuzzy inference system.

	Before capacitor placement	After capacitor placement
Power loss	783.7 KW	699 KW
Loss reduction	84.7 KW	

Table VII Loss reduction after capacitor placement implementing FIS.

Power loss is reduced by 84.7 KW after placing capacitor by implementing fuzzy inference system for optimization and sizing. Hence, Efficiency of system improves as it is inversely proportional to the losses.

6.CONCLUSION

Loss reduction in distribution system is analysed using different techniques. Proposed technique tested on 10 bus radial system and power flow analysis is carried out with power world simulator for its easiness. Here, power factor and power demand played an important role to develop fuzzy model for sizing of capacitor. Proposed method provides higher accurate solutions with less computational effort and gives much more savings as it requires less number of capacitor. It has been found that maximum benefit can be obtained by placing the capacitors at highly sensitive nodes. As FIS is modeled for both location and sizing of capacitor and power world simulator is used for power flow, it gives better results within minimum time and computations than deterministic approach.

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AUTHOR PROFILE

Hetal C. Ejner is currently working as an Assistant professor in Department of Electrical Engineering at Government engineering college, Bharuch. Her research interest includes the field of Optimization and Control of Power System Network using AI and fuzzy logic.