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A Study on Capacitor Placement in Radial Distribution Systems for Loss Reduction using Fuzzy Logic

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Abstract: ***A simple and efficient method for solving radial distribution networks is presented. The proposed method involves only the evaluation of a simple algebraic expression of receiving-end voltages. Computationally, the proposed method using fuzzy logic is very efficient. The effectiveness of the proposed method is demonstrated using some examples.***

Keywords: Distribution Systems, capacitor placement, FES(Fuzzy expert system), PLI(power loss index), nodal voltage, CSI (capacitor suitability index), Fuzzy Logic, Voltage Profiles

1. Introduction

Radial distribution systems are typically spread over large areas and are responsible for a significant portion of total power losses. Reduction of total power loss in distribution system is very essential to improve the overall efficiency of power delivery. This can be achieved by placing the optimal value of capacitors at proper locations in radial distribution systems. Capacitors are installed at strategic locations to reduce the losses and to maintain the voltages within the acceptable limits.

Application of shunt capacitors to the primary distribution feeders is a common practice in most of the countries. The advantages anticipated include boosting the load level of the feeder so that additional loads can be carried by the feeder for the same maximum voltage drop, releasing a certain kVA at the substation that can be used to feed additional loads along other feeders and reducing power and energy losses in the feeder.

Objective

The objective of the capacitor placement problem is to determine the locations and sizes of the capacitors so that the power loss is minimized and annual savings are maximized.

Although some of these methods to solve capacitor allocation problem are efficient, their efficiency relies entirely on the goodness of the data used. Fuzzy logic provides a remedy for any lack of uncertainty in the data. Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the capacitor allocation optimization process.

2. General description of Distribution System

Distribution system is that part of the electric power system which connects the high voltage transmission network to the low voltage consumer service point. In any distribution system the power is distributed to various uses through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity which carry the current in bulk to the feeding points. Distributors are conductors from which the current is tapped of for the supply to the consumer premises.

3. Basic Distribution Systems

There are two basic structures for distribution system namely
(i) Radial distribution system
(ii) Ring main distribution system

(i) Radial distribution system:
If the distributor is connected to the supply system on one end only then is system is said to be a radial distribution system. In such a case the end of the distributor nearest to the generating station would be heavily loaded and the consumers at the distance end of the distributor would be subjected to large voltage variations as the load varies. The consumer is dependent upon a single feeder so that a fault on any feeder or distributor cuts off the supply to the consumers who are on the side of fault away from the station.

(ii) Ring Main Distribution System:
Ring main employs a feeder which covers the whole area of supply finally returns to the generating station. The feeder is closed on itself. This arrangement is similar to two feeders in parallel on different buses.

3.1 Distribution System Losses

It has been established that 70% of the total losses occur in the primary and secondary distribution system, while transmission and sub transmission lines account for only 30% of the total losses. Distribution losses are 15.5% of the generation capacity and target level is 7.5%. Therefore the primary and secondary distribution must be properly planned to ensure losses within the acceptability limits.

3.2 Factors Effecting Distribution System Losses

1) Inadequate size of conductor,
2) Feeder Length,

3) Location of Distribution Transformers,
4) Low Voltage,
5) Use of over rated Distribution transformers,
6) Poor workmanship in fittings,
7) Low Power Factor

3.3 Reduction of line losses

The losses in Indian power system are on the higher side. So, the government of India has decided to reduce the line losses and set a target for reduction of T&D losses by 1% per annum in order to realize an overall reduction of 5% in the national average.

3.4 Methods for the reduction of line losses:

The following methods are adopted for reduction of distribution losses.
(1) HV distribution system,
(2) Feeder reconfiguration,
(3) Reinforcement of the feeder
(4) Grading of conductor,
(5) Construction of new substation,
(6) Reactive power compensation
(7) Installing Voltage regulators.

It is universally acknowledged that the voltage reactive power control function plays a vital role in the distribution automation. The problem of reactive power compensation can be attempted by providing static capacitors. The present practice to compensate reactive power component is to increase reactive power by increasing the terminal voltage of the generator or by increasing the field current of the synchronous machine in condenser mode at generating stations. An alternate method for compensating the reactive power is the use capacitors in distribution systems at customer points.

There are two methods in capacitor compensation. They are
1. Series compensation. (Capacitors are placed in series with line)
2. Shunt compensation. (Capacitors are placed in parallel with load)

The fundamental function of capacitors whether they are in series or in shunt in a power system is to generate reactive power to improve power factor and voltage, thereby enhancing the system capacity and reducing losses. In series capacitors the reactive power is proportional to the square of the load current where as in shunt capacitors it is proportional to the square of the voltage.

For the capacitor placement problem, approximate reasoning is employed in this manner:

For example: It is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors; whereas a low loss section with good voltage is not. Note that the terms, *high* and *low* are linguistic descriptors which cannot be used to define rules in a conventional ES.

4. Framework of Approach

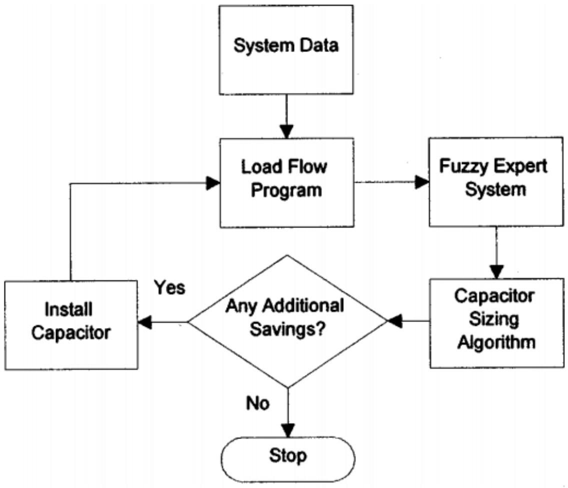


Figure: Framework of Fuzzy Allocation System

4.1. FES Implementation

The FES contains a set of rules which are developed from qualitative descriptions. In a FES, rules may be fired with some degree using fuzzy inferencing; whereas, in a conventional ES, a rule is either fired or not fired. For the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the following form:

IF premise (antecedent), THEN conclusion (consequent)

For determining the suitability of capacitor placement at a particular node, a set of multiple-antecedent fuzzy rules have been established. The inputs to the rules are the voltage and power loss indices, and the output consequent is the suitability of capacitor placement. The rules are summarized in the fuzzy decision matrix.

4.2 Selection of buses for capacitor placement using fuzzy

By invoking the instruction fuzzy we got display of the fuzzy inference system (FIS) at the top of window which shows the inputs, outputs and a central fuzzy rule processor. In this case, the inputs are
1. Power Loss Index (PLI)
2. Nodal Voltage

The central fuzzy rule processor contains the rules. The output is capacitor suitability index (CSI) which indicates the location suitability for capacitor placement.

4.3 The input calculations

1. PLI: The power losses at all buses are calculated and normalized between 0 and 1 such that, minimum power loss is zero and max power loss is 1.

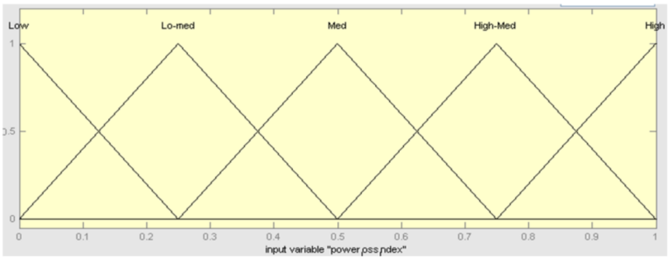
The formula is

$$PLI = \frac{\text{CURRENT LOSS REDUCTION-MINIMUM LOSS REDUCTION}}{\text{MAXIMUM LOSS REDUCTION -MINIMUM LOSS REDUCTION}}$$

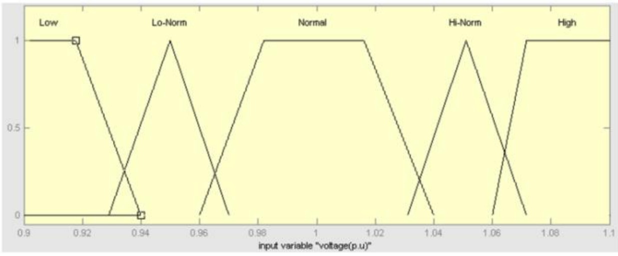
2. Nodal Voltage
The per-unit nodal voltage is calculated from the load flow problem. The voltages will be generally in range of 0.9 to 1.1.

4.3.1 Assigning of membership functions

1. PLI The range of this PLI is between 0 and 1. Triangular membership functions are assigned as shown below

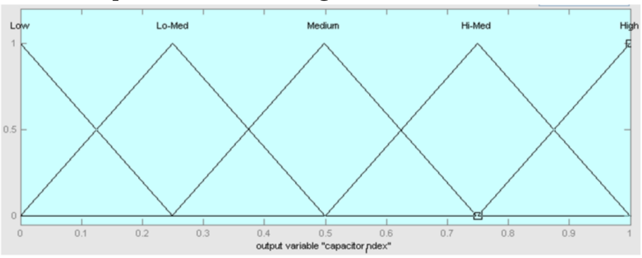


2. Nodal Voltage
The range of this is between 0.9 and 1.1. The combination of triangular and trapezoidal membership functions are selected as shown in the figure



3. The Output (CSI)

The range of this is between 0 and 1. Triangular membership functions are assigned shown below



4.3.2 Decision Matrix

AND		VOLTAGE				
		Low	Low-normal	Normal	High normal	High
POWER LOSS INDEX	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

4.3.3 Rule Base

The rules defined in the fuzzy decision matrix are:

1) If power loss is low and voltage is low then suitability is low- medium
2) If power loss is low and voltage is low normal then suitability is low medium. Etc.,

5. Case Study

Case Study Results of 15 Bus System Capacitor Locations using FUZZY LOGIC

Here the candidate buses are selected based on the CSI value. In this case CSI value is considered to be 0.75. Now the buses 4,6,7,11,15 are selected as the candidate buses for minimum losses.

BUS NO	PLI	VOLTAGE	CSI	Node Selected
2	0	0.9713	0.0940	---------
3	0.3205	0.9567	0.3318	---------
4	0.9602	0.9509	0.7500	4
5	0.1742	0.9499	0.2500	---------
6	0.8000	0.9582	0.7500	6
7	0.8353	0.9560	0.7500	7
8	0.3267	0.9570	0.3370	---------
9	0.1671	0.9680	0.2287	---------
10	0.0313	0.9669	0.1972	---------
11	0.9865	0.9500	0.7500	11
12	0.4612	0.9458	0.4505	---------
13	0.2255	0.9445	0.2500	---------
14	0.4119	0.9486	0.4051	---------
15	1.0000	0.9484	0.7500	15

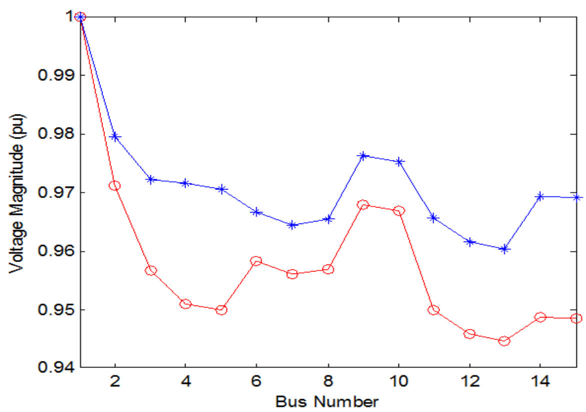
5.1 Optimal Sizing of Capacitors

By using this method the size of the capacitor, real power loss, and loss reduction obtained as shown

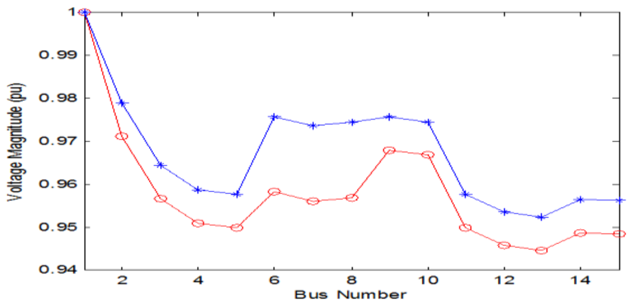
BUS NO.	Using ANALYTICAL METHOD		
	Capacitor Size (KVAR	Real Power Loss (KW)	Loss Reduction (KW)
4	855.6900	38.1356	23.6581
6	666.8327	45.3314	16.4623
7	551.4296	47.3714	14.4223
11	695.4039	41.7115	20.0822
15	666.9284	42.2454	19.5483

5.2 Voltage Profiles (before and after compensation) at the Candidate Buses

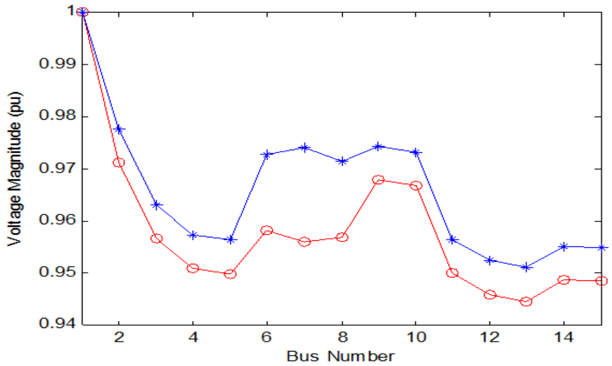
i) At Bus 4



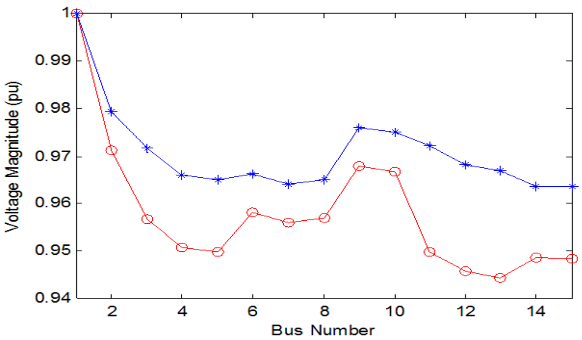
ii) At Bus 6



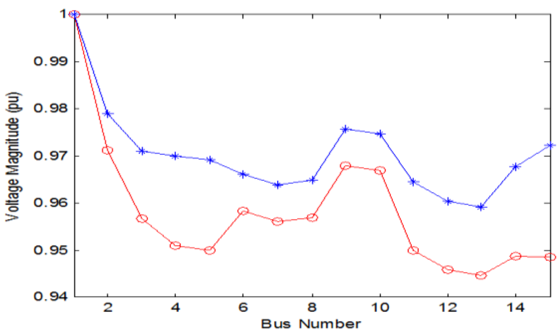
iii) At Bus 7



iv) At Bus 11



v) At Bus 15



6. Conclusions

By implementing fuzzy logic the optimal capacitor locations are determined for maximum loss reduction by using matlab program. For identifying the bus locations for maximum loss reduction and size of the capacitor are obtained using MATLAB in distribution systems. The results of the proposed methods are almost identical and even better results are obtained with these methods.

7. Future Scope

Regarding the future scope, these algorithms can be implemented and applied to a real practical system instead of IEEE test system. At the same time, the cost benefit of practical implementation can be analyzed. The capacitor ratings obtained in this method may not match with the practically available capacitor ratings. So these ratings can be rounded off to the nearest size of the capacitor based on the economical considerations. Here we have used single capacitor placement algorithms, which can be further extended to multiple capacitor placement for additional savings.

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