International Journal of Soft Computing 1 (1) : 8-16, 2006

A New Fuzzy Power Factor Improvement and Voltage Limit Violation Minimization Technique for Electrical Power Distribution System

[1]K. Manjunath and [2]M.R. Mohan,
Department of Electrical and Electronics Engineering,
Anna University, Guindy, Chennai 600 025, India

Abstract: The growing demand of electrical power needs proper attention of power distribution engineer/distribution substation operator to maintain good quality distribution of electrical power in the Electrical Power Distribution Systems (EPDS). The exercise of power distribution engineers/distribution system substation operator to add/remove the capacitor banks to improve the power factor and also to minimize the worst voltage drop in radial feeders leads to more voltage fluctuations in distribution system. The technique employed for voltage violation minimization and reactive power compensation in distribution systems should take care of various constraints like minimization of capacitor switching operations, improving the power factor to the optimal value and restoring voltage changes to the permissible value. So the power factor improvement and voltage limit violation minimization problem for efficient operation of EPDS is treated as a non-linear, non-differential and multi-objective optimization problem. Hence, in this paper a New Fuzzy Based Non-linear Control Technique for Power Factor (PF) improvement and Voltage Limit Violation Minimization (VLVM) in efficient operation of EPDS is presented. This new technique has been tested on 26-Bus, 28-Bus, 33-Bus and 69-Bus practical EPDS. The results shows that it is a highly suitable technique for PF improvement and minimization of voltage limit violations in efficient operation of EPDS. Hence this new technique can be used in EPDS for supplying good quality electrical power to the utilities in developing/developed countries.

Key words: Distribution systems, fuzzy logic, power factor improvement, voltage control and forward substitution method load flow analysis

INTRODUCTION

The performance of distribution systems and quality of service provided are measured in terms of freedom from interruptions and maintenance of satisfactory voltage levels at the customers premises which is within limits appropriate for this type of service. Based on the power engineers experience, too high steady voltage causes reduces light bulb life, reduced life of the electronic devices and premature failure of some type of the apparatus. On the other hand, too low voltages causes lower illumination levels, shrinking of TV pictures, slow heating of heating devices, difficulties in motor starting, and overheating and/or burning out of motors. These over-voltage and under-voltage variations can be minimized by means of disconnecting or connecting the capacitor banks at the appropriate nodes in the distribution network which suffers from the voltage problem[1]. These capacitor switching operations, some time leads to further voltage fluctuations. Hence, the minimization of capacitor switching operations, improving the operating power factor to the optimal value, besides minimizing voltage limit violations is an urgent need for distribution system substation operators/power distribution engineers.

Several methods[2-4] have emerged in the literature to solve this part of the complex problem[5]. In the past non linear programming approaches were proposed, however, these approaches may suffer from convergence problem and difficulties in evaluating the system losses. The New fuzzy approach for load balancing for distribution systems[6] does not consider the power factor and voltage profile in efficient operation of the distribution systems. The use of fuzzy logic based non-linear control technique, helps to make best decision for the connection/disconnection of the proper capacitor bank with the consideration of power factor and voltage limit violations.

Fuzzy sets were first proposed in the early 1960s by Zadeh[7] as general model of uncertainty encountered in engineering systems. His approach emphasized modeling uncertainties that arise commonly in human

---

Corresponding Author: K. Manjunath, Department of Electrical and Electronics Engineering, Anna University, Guindy, Chennai 600 025, India

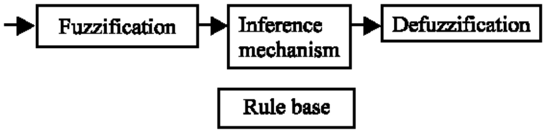

Fig. 1: Component of fuzzy control

thought processes. Bellman and Zadeh write: " Much of the decision making in the world takes place in an environment in the which goals, constraints and the consequences of possible actions are not known precisely[8]. Uncertainty in the fuzzy logic typically arises in the form of vagueness and/or conflicts, which are not represented naturally within the probabilistic frame work. To be sure, uncertainty[9] in reasoning may arise in a variety of ways. Consider the most common sort of discourse about a system among experts, and say to be more specific, a statement relevant to voltage quality disruption in EPDS.

Fuzzy logic, membership fucntions and fuzzy controllers: Fuzzy Logic is basically a multi valued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, etc. Fuzzy logic is superset of conventional Boolean logic. In fuzzy logic it is possible to have partial truth values. The components of fuzzy control is shown in the (Fig. 1).

The fuzzy set theory is considered as a generalization of the traditional probability set theory. The idea is to replace the concept that a variable has a degree of membership assigned to each possible value that the variable can take.

If X = {x} is given as a set of objects or alternatives, a fuzzy set C in X is defined as a set of ordered pairs:

$$C = \{(x, \mu_c(x)) \mid x \in X\} \qquad (1)$$

where $\mu_c(x)$ is the membership function of x in C.

A higher value of $\mu_c(x)$ implies that it is more likely that x belongs to C.

The value of $\mu_c(x)$ is in [0,1], however if $\mu_c(x)$ is limited to either 0 or 1 then C becomes a crisp (non-fuzzy) set. For two fuzzy sets A and B with membership functions $\mu_A(x)$ and $\mu_B(x)$, respectively, the membership function of C = AB is defined as ,

$$\mu_c(x) = \max[\mu_A(x), \mu_B(x)] \qquad (2)$$

In addition, the membership function of C = AB is defined as,

$$\mu_c(x) = \min[\mu_A(x), \mu_B(x)] \qquad (3)$$

basically, given the concept of fuzzy set and the definition of union and intersection, it is possible to fuzzify any domain of mathematical reasoning based on set theory.

Lemma: Let $\mu_{ci}(x)$, i = 1, 2, 3…., m, be the membership functions of constraints in X, defining the decision space and $\mu_{Gj}(x)$, j = 1, 2, 3…., n, the membership functions of the objective functions or goals in X. A decision is then defined by its membership function

$$\mu_D = F(\mu_{c1}, \mu_{c2}, \ldots, \mu_{cm}, \mu_{G1}, \mu_{G2}, \ldots, \mu_{Gn}) \qquad (4)$$

where F denotes an operator for considering the membership functions of constraints and objective functions. Let M be the set of points $x \in X$ for which $\mu_D(x)$ attains maximum, then M is called the maximizing decision. If $\mu_D(x)$ has a unique maximum at x_M, then the maximizing decision is a uniquely defined crisp decision which can be interpreted as the action that belongs to all fuzzy sets representing either constraints or goals with the highest possible degree of membership.

According the definitions of the intersection and union, the min operator will be used to find the intersection the memberships describing the constraints and the objectives, and the max operator will be used to find the optimal solution or the highest possible degree of satisfaction.

Degree of satisfaction in selection of the number of capacitors: One of the objectives of minimizing the voltage fluctuations is to minimize the number of capacitor switching operations in the power distribution network. Hence the membership function for selection of number of capacitors μ_{SNC} is defined as in Fig. 2. which decreases with an increase in the number of capacitor switching operations. Each capacitor switching operation requires minimum one operation, i.e, to connect or disconnect the capacitor to that node in the distribution systems which suffers from low voltage problem.

$$\mu_{SNC} = 1.0 \text{ ; for } ns \le 1 \qquad (5)$$

$$= (1 - CS)/CS_{max} \text{ ; for } 1 \le ns \le CS_{max} \qquad (6)$$

It is noted that, in fuzzy set rotation, a high membership value indicates a desirable situation. For example, the degree of satisfaction for single capacitor switching operation is a highly desirable situation and is assigned a value equal to unity. A larger number of switching operations is given a lower membership value[5].

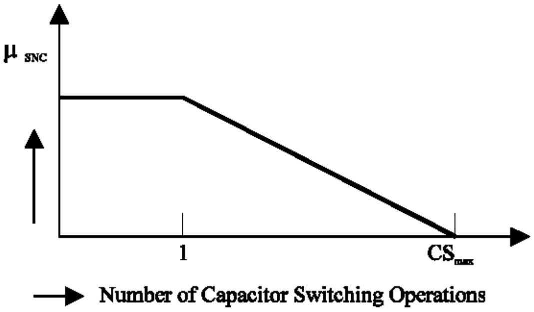

Fig. 2: Membership function for the capacitor switching operation

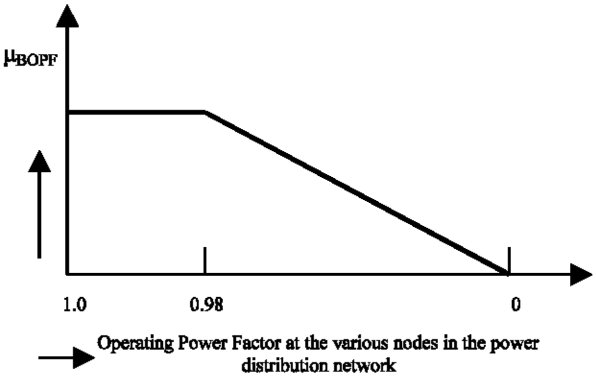

Fig. 3: Membership function for the choice of best operating power factor

Degree of satisfaction in choice of best operating power factor: One of the objectives of minimizing the low voltage problem is to reduce the low power factor problem. Normally the power factor of 0.98 is considered to be the best operating power factor in the distribution system. The low power factor problem can be minimized by means elimination of low voltage problem in respective node or the nearby node which also, suffers from the low voltage problem. Hence the membership function for selection of best operating power factor μ_{BOPF} is defined as in Fig. 3, which decreases with an decrease in power factor at the various nodes in distribution system.

$$\mu_{BOPF} = 1.0 \qquad \text{for } 0.98 \leq PF \leq 1 \tag{7}$$

$$= (1 - PF)/PF_{max} \qquad \text{for } PF < 0.98 \tag{8}$$

Degree of satisfaction for the minimization of voltage limit violations: The maximum change in voltage is given by $\Delta V_i^{max} = V_i^{max} - V_i^{(0)}$ and the minimum change in the voltage is $\Delta V_i^{max} = V_i^{max} - V_i^{(0)}$,where $V_i^{(0)}$ is the current operating value of the voltage. Each voltage is represented by the two linear constraints for the minimum and maximum limits as shown in Fig.4.

$$\mu(\Delta V_i) = \begin{cases} 1 & i \quad \Delta V_i \rangle \Delta V_i^{mi} \\ 1 & i \quad \Delta V_i \langle \Delta V_i^{ma} \\ 1 + \dfrac{\Delta V_i^{mi} - \Delta V_i}{d_i} & i \quad \Delta V_i^{mi} - d_i \leq \Delta V_i \leq \Delta V_i^{mi} \\ 0 & i \quad \Delta V_i \leq \Delta V_i^{mi} - d_i \\ 1 + \dfrac{\Delta V_i^{ma} - \Delta V_i}{d_i} & i \quad \Delta V_i^{mi} \leq \Delta V_i \leq \Delta V_i^{ma} + d_i \\ 0 & i \quad \Delta V_i \geq \Delta V_i^{ma} + d_i \end{cases}$$

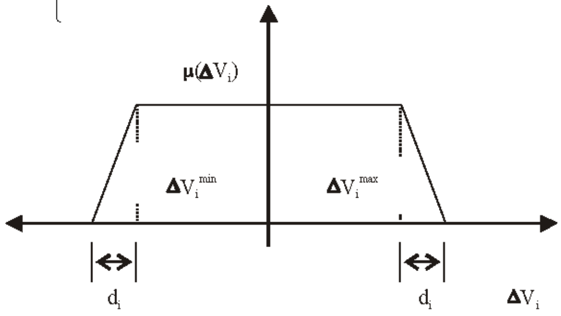

Fig. 4: Fuzzy membership functions for the bus voltage increament

Operating constraints: The distribution system is subjected to inequality and equality constraints which are described as:

$$Q_i^{min} \leq Q_i \leq Q_i^{max} \qquad I = 1, 2, 3, \ldots\ldots, m$$

$$V_j^{min} \leq V_j \leq V_j^{max} \qquad Vlj = 1, 2, 3, \ldots\ldots, n$$

$$Q_k = QD_k \qquad k = 1, 2, 3, \ldots\ldots, l$$

There are m + n + l constraints. The first m constraints are for reactive power sources and tap changing transformer terminals. The next n constraints are the bus voltage constraints. The last l equality constraints are for loads and junction buses that are not connected to the transformer terminals.

Fuzzy controllers: The traditional control design paradigm is to form a system model and develop control laws from analysis of this model. The controller may be modified based on results of testing and experience. Due to difficulties of analysis, many such controllers are linear. The fuzzy controller approach is to somewhat reversed. General control rules that are relevant to a particular system based on experience are introduced and analysis or modeling considerations come later. For example, consider the following general control law for a positioning system

If error is small and positive
and error change is large and negative
then control output is small and negative

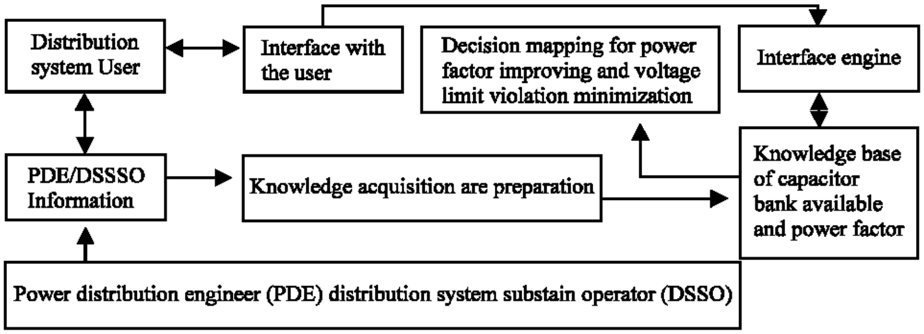

Fig. 5: The proposed distribution system information logical structure for power factor improvement and voltage violation minimization for efficient operation of electrical power distribution system

This rule implements a control concept for anticipating the desired position and reducing the control level before the set point is reached in order to avoid overshoot. The quantities small and large are fuzzy quantities. A full control design requires developing a set of control rules based on available inputs and designing a method of combining all rule conclusions. The precise fuzzy membership functions depend on the valid range of inputs and the general response characteristics of the system. Within power systems, fuzzy logic controllers have been proposed primarily for stabilization control.

Fuzzy decision-making and optimization: The broadest class of problems within power system planning and operation is decision-making and optimization, which includes transmission planning, security analysis, optimal power flow, state estimation, and unit commitment, among others. These general areas have received great attention in the research community with some notable successes; however, most utilities still rely more heavily on experts than on sophisticated optimization algorithms. The problem arises from attempting to fit practical problems into rigid models of the system that can be optimized. This results in reduction in information either in the form of simplified constraints or objectives. The simplifications of the system model and subjectivity of the objectives may often be represented as uncertainties in the fuzzy model. Consider optimal power flow. Objectives could be cost minimization, minimal control adjustments, minimal emission of pollutants or maximization of adequate security margins. Physical constraints must include

generator and load bus voltage levels, line flow limits and reserve margins.

In practice, none of these constraints or objectives are well defined. Still, a compromise is needed among these various considerations in order to achieve an acceptable solution. Fuzzy mathematics provides a mathematical framework for these considerations. The applications in this category are an attempt to model such compromises.

The fuzzy based information logical structure for efficient operation of EPDS is shown in Fig. 3. The researched scheme of the distribution system is presented by structured objects. The dispatcher has access to supplemental information like substation number, state of the bus switches, outgoing feeders, rated currents of transformer primary winding, capacitor ratings and their availability and type of loads when appealing to the menu sub-point. The practical interaction of the distribution system user with the program is realized by dialog.

Fast computation of real power losses and loss reduction: The necessary details about the pre / post fault configuration of PDN have been obtained from the developed New Network Connectivity Method[10]. If EPDS has 'n' number of the feeders connected to the 'n' root nodes, then the voltages at the root nodes is taken as 1.0 p.u.

The unscheduled bus voltages in the input data of the load flow analysis are called state variables or dependent variables since their values, which describe the state of the system, depend on the quantities specified at all the buses. Hence the Distribution System Load Flow Problem is to:

Determine the Voltages at all the Buses in all the phases of the PDN that is,

$$|V_{abc\,(I)}| \qquad i = 2, 3, \ldots .nbus.$$

Subject to the following constraints

- $|V_{(abc)min}| = |V_{(abc)}| = |V_{(abc)max}|$
- $PLL_{(abc)min} = PLL_{(abc)} = PLL_{(abc)max}$
- $QLL_{(abc)min} = QLL_{(abc)} = QLL_{(abc)max}$

where

nbus = Total Number of buses in the EPDS
nbch = Total number of branches in the EPDS
V_{abc} = Vector of Phase Voltages of size (3(nbus – 1) x 1)
$V_{abc} = [\ V_a \quad V_b \quad V_c\ ]^T$
$V_a = [\ V_{a(2)} \quad V_{a(3)} \ V_{a(4)} \ldots\ldots \quad V_{a(nbus)}]^T$
$V_b = [\ V_{b(2)} \quad V_{b(3} \ V_{b(4)} \ldots\ldots \quad V_{b(nbus)}]^T$
$V_c = [\ V_{c(2)} \quad V_{c(3)} \ V_{c(4)} \ldots\ldots \quad V_{c(nbus)}]^T$
PLL = Vector of Real Power Transmission Loss of size (3nbch x 1)
$PLL_a = [\ PLL_{a(1)} \quad PLL_{a(2)} \quad PLL_{a(3)} \ldots\ldots \quad PLL_{a(nbch)}]^T$
$PLL_b = [\ PLL_{b(1)} \quad PLL_{b(2)} \quad PLL_{b(3)} \ldots\ldots \quad PLL_{b(nbch)}]^T$
$PLL_c = [\ PLL_{c(1)} \quad PLL_{c(2)} \quad PLL_{c(3)} \ldots\ldots \quad PLL_{c(nbch)}]^T$
QLL = Vector of Reactive Power Transmission Loss of size (3nbch x 1)
$QLL_a = [\ QLL_{a(1)} \quad QLL_{a(2)} \quad QLL_{a(3)} \ldots\ldots \quad QLL_{a(nbch)}]^T$
$QLL_b = [\ QLL_{b(1)} \quad QLL_{b(2)} \quad QLL_{b(3)} \ldots\ldots \quad QLL_{b(nbch)}]^T$
$QLL_c = [\ QLL_{c(1)} \quad QLL_{c(2)} \quad QLL_{c(3)} \ldots\ldots \quad QLL_{c(nbch)}]^T$
$PLL_{(abc)} = [\ PLL_a \quad PLL_b \quad PLL_c\ ]^T$
$QLL_{(abc)} = [\ QLL_a \ QLL_b \ QLL_c\ ]^T$

The Real and Reactive Power flows, Voltages at the buses in pre/post fault PDN are calculated using the following recursive equations. The lines are represented by impedances $Z_k = R_k + j\ X_k$, and the Real and Reactive Power Demands are represented as complex power sinks $S_L = PD_L + j\ QD_L$. The substation voltage / root branch voltage has, assumed as 1.0 p.u. The remaining node voltages are calculated using the Eq 13.

$$P_{i+1} = \sum_{j=i+1}^{nbus} P_i + \sum_{j=i+1}^{nbus-1} PLOS_i$$

$$Q_{i+1} = \sum_{j=i+1}^{nbus} Q_i + \sum_{j=i+1}^{nbus-1} QLOS_i \qquad (10)$$

for i = 1,2...(NB-2)

$$PLOS_{i+1} = R_i \ x \left[\frac{P_i^2 + Q_i^2}{V_i^2} \right] \qquad (11)$$

$$QLOS_{i+1} = X_i \ x \left[\frac{P_i^2 + Q_i^2}{V_i^2} \right] \qquad (12)$$

$$|V_{i+1}| = \sqrt{\left\{ \sqrt{\left[\left(P_{i+1} \times R_i + Q_{i+1} \times X_i - \frac{|V_i^2|}{2} \right)^2 - \left(R_i^2 + X_i^2\right) \times \left(P_{i+1}^2 + Q_{i+1}^2\right) \right]} - \left(P_{i+1} \times R_i + Q_{i+1} \times X_i - \frac{|V_i^2|}{2} \right) \right\}} \qquad (13)$$

The detailed formulation of the mathematical model is presented in[10-12]. The real and reactive power losses are calculated using the Eq 11 and 12.

Problem formulation: The main objective of the power factor improvement and voltage violation minimization problem is:

- To minimize the number of capacitor switching operations
- To improve the power factor to the optimal value of 0.98
- To minimize the voltage limit violations

Let X be the set of alternative set, i.e. various set of the capacitors connection/disconnection in the EPDS. The main objective in X is fuzzy subset <To minimize the number of capacitor switching operations>, < To improve the power factor to the optimal value of 0.98>, < To minimize the voltage limit violations> as described by goal H. If X is the alternative set then the simple representation ö: X > I, *x* X is the distribution system reaction on the effect of the capacitor switching. Then the main objective is subset H of reaction set I and H is described by membership function $\mu_H(x)$, which denotes the degree that *x* belongs to fuzzy subset H and is normally limited to values 0 and 1. A high value of $\mu_H(x)$ implies that it is very likely for *x* to be in H. The fuzzy alternative set μ_H providing the achievement of the goal H is a prototype of fuzzy set μ_G through representation ö, i.e.

$$\mu_H(x) = \mu_H(ö(x)), \ x \in X \qquad (14)$$

The more membership value of the alternative *x* to H, the more achievement degree of this goal through the alternative selection of *x* as the solution exists. Then this problem is considered as achievement problem of fuzzy goal μ_H under necessary fuzzy constraints.

Therefore, the fuzzy problem solution of fuzzy goal achievement is a fuzzy set intersection of main objective and constraints, i.e. the membership function is defined by

$$\mu_D(x) = \min\{\mu_H(x), w_1\,\mu_{SCSMIN}(x), w_2\,\mu_{SPFMAX}(x), w_3\,\mu_{SVLVM}(x)\} \qquad (18)$$

where w_i is the weight for ith constraint importance which is given by power distributionengineers/ distribution system substation operators.

The system function is described by the state equation

$$P_{t+1} = x_{t+1} = f_1(x_t, V_t); \quad t = 0, 1, 2, \ldots\ldots, N\text{-}1 \qquad (19)$$
$$Q_{t+1} = x_{t+1} = f_2(x_t, V_t); \quad t = 0, 1, 2, \ldots\ldots, N\text{-}1 \qquad (20)$$

The load distribution between sections is changed under switching operations. Therefore the load changes as the single figure representation ö: U > I. At the random time t the controlled voltage value V_t must be submitted to given fuzzy main objective H under fuzzy constraints SCSMIN, SPFMAX and SVLVM described by fuzzy subsets of set V with membership function $\mu_t (V_t)$.

Consider this system control at the time interval from 0 to N-1. The problem solution is to select the equations of succession $V_0, V_1, V_2, \ldots\ldots, V_{N-1}$, which meets the fuzzy constraints SCSMIN, SPFMAX, SVLVM and provides for fuzzy main objective achievement H_N. The fuzzy solution of the problem is defined by

$$\mu_D (V_0, V_1, V_2, \ldots,, V_{N-1}) = \min \{\mu_0 (V_0), \ldots\ldots, \mu_{N-1} (V_{N-1}), \mu_{GN} (x_N)\} \tag{21}$$

The maximizing problem solution as control successive V_0, V_1, $V_{,2}$ ………, V_{N-1} which maximal membership degree of fuzzy solution D is

$$\mu_D (V_0, V_1, V_2, \ldots,V_{N-1}) = \max [\min \{\mu_0 (V_0), \ldots, \mu_{N-1} (V_{N-1}), \mu_{GN} (x_N)\}] \tag{22}$$

Finally the membership function for achieving the minimal number of capacitor switching operations, improving the power factor and minimization of voltage limit violations is given by

$$\mu_{GN-1} (x_{N-1}) = \max [\min \{\mu_{N-1} (V_{N-1}), \mu_{GN} (f (x_{N-1}, V_{N-1}\}] \tag{23}$$

The function $\mu_{GN-1} (x_{N-1})$ is the membership function of the main objective for control problem at the time interval from 0 to N-2 corresponding to the given control goal G_N at the time interval from 0 to N-1. The system transition from the state x_0 to the state x_{N-1} by the selection control $V_0, V_1, V_2, \ldots, V_{N-2}$ is defined by Eq 19 and 20. Then by selecting the control V_{N-1} we can get maximal achievement of the degree of main objective $\mu_{GN-1} (x_{N-1})$. Thus the maximal achievement of the degree of main objective G_N in the case when on V_{N-2} step system is in the x_{N-2} state.

Solution algorithm:

Step1: Read line resistances and reactance's, real and reactive power demands, substation voltage, convergence tolerance, transformer ratings and its tap ratio's.

Step2: Perform the load flow analysis using forward substitution method and then compute the power factor at the various nodes in the distribution network

Step3: Check whether voltage at all the nodes is within 0.95 and 1.05 p.u. If voltage at the particular node is less than 0.95 and p.f at that node is less than 0. 98 compute the optimal leading MVAr [9] to improve the p.f to 0.98 using the following equation.

$$\Delta Q_c = PD_i (\tan \varphi - \tan \theta) ; \quad i = 2,3,\ldots..NUV; \tag{24}$$

where

ΔQ_c = required capacitor size in MVAr,
PD_i = System demand at the i^{th} node

Table 1: Load flow results without power factor improvement and also without voltage limit violation minimization for the 28 Bus electrical power distribution system

Bus No	[v]in p.u	Power factor	Shunt capaciter in MVAr	Bus No	[v]in p.u	Power factor	Shunt capaciter in MVAr
1	1.0000	0.8753	0.0000	15	0.8406	0.8829	0.0000
2	0.9700	0.8737	0.0000	16	0.8341	0.8877	0.0000
3	0.9416	0.8769	0.0000	17	0.8284	0.8975	0.0000
4	0.9376	0.8782	0.0000	18	0.8264	0.9001	0.0000
5	0.9358	0.9092	0.0000	19	0.9627	0.8697	0.0000
6	0.9851	0.8992	0.0000	20	0.9608	0.8702	0.0000
7	0.9759	0.9121	0.0000	21	0.9582	0.8767	0.0000
8	0.9722	0.9114	0.0000	22	0.9562	0.8984	0.0000
9	0.9679	0.9099	0.0000	23	0.9358	0.8950	0.0000
10	0.9106	0.8823	0.0000	24	0.9324	0.9107	0.0000
11	0.8926	0.8814	0.0000	25	0.9290	0.8950	0.0000
12	0.8847	0.8854	0.0000	26	0.9819	0.8944	0.0000
13	0.8648	0.8815	0.0000	27	0.9809	0.8944	0.0000
14	0.8496	0.8809	0.0000	28	0.9803	0.8944	0.0000

Total real power demand (PPLOAD) = 1900.00 Kw total real power (PL) = 179.4095 Kw

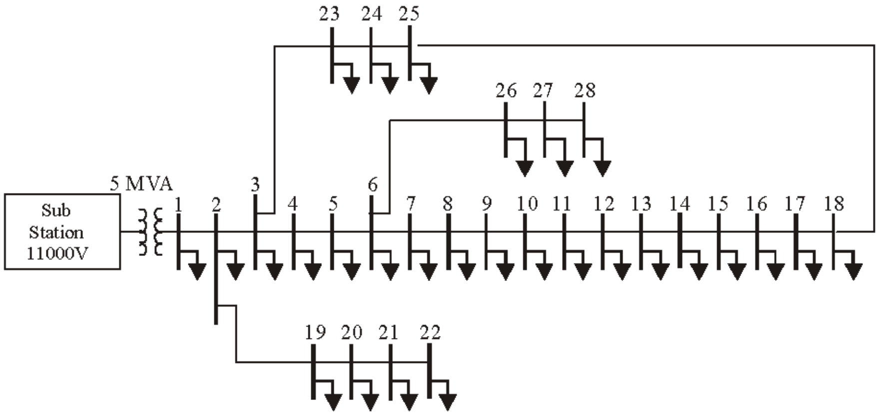

Fig. 6: 29 Bus practical electrical power distribution system

Table 2 : Fuzzy control rules for the minimization of capacitor switching operations and voltage limit violations

	Power factor						
Voltage	LN	mN	SN	ZE	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	ZE
MN	LP	MP	MP	MP	SP	ZE	SN
SN	LP	MP	SP	SP	ZE	SN	MN
ZE	MP	MP	SP	ZE	SN	MN	MN
SP	MP	SP	ZE	SN	SN	MN	LN
MP	SP	ZE	SN	MN	MN	MN	LN
LP	ZE	SN	MN	MN	LN	LN	LN

Total Real Power Demand (PPLOAD) = 1900.00 Kw

Number of Capacitor switching operations = 12

Total Real Power Loss PL = 135.7742 KwO

tan φ = tangent of original power factor angle

tan θ = tangent of economic power factor angle

NUV = number of nodes which suffers from low power factor problem

Step4: Using Fuzzy logic information structures obtain the optimal number of capacitors to connect / disconnect to improve the power factor and minimize the voltage limit violations.

Step5: If there is any change in load go Step 1, otherwise go to next Step.

Step6: Stop.

Table 3 : Load Flow results without power factor improvement and also without Voltage limit violation minimization for the 28 Bus Electrical Power Distribution Systems

Bus No	[v]in p.u	Power factor	shunt capaciter in MVAr	Bus No	[v]in p.u	Power factor	shunt capaciter in MVAr
1	1.0000	0.9792	350	15	0.8667	0.9397	0
2	0.9784	0.9760	350	16	0.8615	0.9995	0
3	0.9573	0.9913	350	17	0.8566	0.9974	100
4	0.9544	0.9992	200	18	0.8548	0.9853	0
5	0.9530	0.9842	0	19	0.9718	0.9727	25
6	0.9881	0.9999	0	20	0.9701	0.9940	0
7	0.9807	0.9993	0	21	0.9677	0.9327	50
8	0.9779	0.9967	100	22	0.9659	0.9914	0
9	0.9746	0.9933	0	23	0.9527	0.9708	0
10	0.9292	0.9604	100	24	0.9497	0.9989	25
11	0.9127	0.9487	0	25	0.9467	0.9863	0
12	0.9061	0.9983	0	26	0.9853	0.9991	0
13	0.8890	0.9961	200	27	0.9844	1.0000	50
14	0.8751	0.9682	0	28	0.9839	0.9701	0

Table 4: Comparison of Results of Proposed Method with the Basic Intuitive Method

Quantity	Basic intuitive method	Proposed method
Number of capacitor Switching operations	28	12
Total system losses in KW	156. 6253	135.7742
Computation time	250 s	8.26 s

RESULTS AND DISCUSSION

The validity of this new fuzzy based non-linear control technique has been tested on 26 Bus, 28 Bus, 33 Bus and 69 Bus practical distribution systems. The detailed explanation of this new proposed fuzzy based technique for the 28-Bus Practical distribution system of a rural area in Andhra Pradesh State (India) is presented. The Bus diagram of 28-Bus practical distribution system is shown in the Fig. 6. Table 1 gives the load flow results without power factor improvement and also without any shunt reactive power compensation in 11 KV distribution systems.

The fuzzy control rules are given in Table 2. for example, If Voltage is Large Negative (i.e, too small or very less than 0.95 per unit) AND Power Factor is also Large Negative (i.e, less than 0.8), then the Capacitor to be placed at that node in the distribution network is Large Positive. The results with capacitor placement and also with power factor improvement are presented in the Table 3.

The results show that the real power loss has been reduced from 179.4095 Kw to 135.7742 Kw, i.e. with a reduction of 43.63 Kw. The losses has been found be reduced from 9.44 % to 7.14 % of the real power demand. The losses can further be reduced with reconfiguration of the power distribution network.

The results obtained by this proposed new fuzzy based non linear control technique are compared with the basic intuitive method[1] . These results of comparison are presented in the Table 4. The result shows that, the number of capacitor switching operations has been reduced from 28 to 12, with significant reduction in system losses. This considerable reduction of capacitor switching operations helps to minimize the voltage fluctuations in the distribution systems.

CONCLUSIONS

A new approach based on fuzzy reasoning for power factor improvement and voltage limit violation minimization for distribution systems is developed. This new technique has been tested on 26-Bus, 28-Bus, 33-Bus and 69-Bus practical distribution systems. In the proposed algorithm the power factor has been found to be improved and voltage limit violations are also minimized by minimizing the capacitor switching operations. The results obtained are same as that under practical testing conditions of Electrical Power Distribution Systems. The advantages of this fuzzy logic based non-linear control technique includes single iterative process and less time consuming, it reduces mathematical complexity, multiple security constraints can be taken into consideration, problem can be extended to multi-level objective functions. Hence this fuzzy based non-linear control technique can be used for efficient planning and operation of the Electrical Power Distribution Systems.

REFERENCES

1. Gonen, T., 1986. Electric Power Distribution System Engineering, McGraw-Hill Book Company, New York .
2. Zhou, Q., D. Sgrimohammadi and W.H. Edwin Liu, 1997. Dostribution feeder reconfiguration for operation cost reduction, IEEE Trans on Power Systems, 12: 730-735.
3. Borozan,V., B.R. Risto and Ackkovski, 1995. Improved method for loss minimization in distribution networks, IEEE Trans on Power Systems, 10: 1420-1425.
4. Manjunath, K. and M.R. Mohan, 2004. An Improved Technique for the estimation of service restoration time in power distribution systems. Intl. J. Power. Ener. Sys., Power Con Special Issue, pp: 64–70.
5. Shahidehpour, S.M. and N. Deeb, 1990. An overview of reactive power allocation in electric power systems. Electrical Machines and Power Systems, 18: 495 -518.
6. Naga Raj, B. and K.S. Prakasa Rao, 1995. A new fuzzy reasoning approach for load balancing in distribution system, IEEE Trans on Power Systems, 10: 1426–1432.
7. Zadeh, L. A., 1965. Fuzzy sets in information and control , 8: 1 338-353.
8. Bellman, R.B. and L.A. Zadeh, 1970. Decision making in a Fuzzy Environment, Management Science, 1: 7141-164.
9. Zimmermann, H.J., 1987. Fuzzy sets, decision making, and expert systems, kluwer academic publishers, Boston.

10. Manjunath, K. and M.R. Mohan, 2005. An improved multi-objective efficient operational planning technique for electric power distribution systems," IEE International Conference on Energy, Information Technology and Power Sector, Kolkata, India, PEITSICON, pp: 146-152.
11. Manjunath, K., M.R. Mohan, 2000. Distribution automation system and advanced load flow technique for balanced/unbalanced radial distribution main feeder, Proc. 11th National Power System Conference (India), NPSC, 2: 633-636.
12. Manjunath, K. and M.R. Mohan, 2002. A New Genetic Algorithm based loss minimization and service restoration technique for distribution feeder reconfiguration, Proc. IEEE National Conference ACE 41: 458-461.