FUZZY LOGIC APPROACH TO REACTIVE POWER CONTROL IN UTILITY SYSTEM

Mr. C. Ramesh
(Corresponding author)
Research Scholar, Anna University of Technology,
Coimbatore, Tamil Nadu, India
Mobile No: +91 8861950333
Fax: +91 4259 236070
crameshpandian@rediffmail.com

Dr. M. Rajaram
Vice-Chancellor,
Anna University of Technology
Tirunelveli, Tamil Nadu, India
Mobile No: +91 9942227799
Office: +91 4622 554255
rajaramgct@rediffmail.com

Dr. S. Chenthur Pandian
Principal, Dr. Mahalingam College of Engineering and Technology, Tamil Nadu, India
Mobile No: +91 98423 04203   Fax: +91 4259 236070   chenthur@rediffmail.com

Abstract: The reactive power control has become particularly important concern for maintaining the voltage level for utility transmitting power over long distances. To maintain the voltage level at various buses either the reactive power is injected or absorbed. In this paper the 'load' and the 'voltage level' are considered as two inputs and the 'reactive power' is taken as an output. The input variable 'load' has been divided into five triangular membership functions. Another input variable 'voltage' has been divided into three triangular membership functions. The required 'reactive power' value as an output has been divided into five triangular membership functions. Case studies have been performed for State Electricity System (SES) which is known as the utility system in this paper. For this SES four generating stations have been considered in this paper. For all these cases the reactive power requirement are calculated by using fuzzy logic approach. This fuzzy based reactive power requirement values are compared with the conventional controller values. It is observed that the reactive power requirement by fuzzy approach is lower than the conventional method. Practical calculation and results are taken for simulation which has been performed by using the developed software in MATLAB package.

1. Introduction

The quality of power supply is decided by the level of voltage and frequency. Maintenance of the voltage in various buses within the tolerable range is an important aspects in the power systems. The voltage level is maintained by using suitable reactive compensating devices and UPFC at the desired location. The voltage controllers are connected on line so that we can program the voltage controller / reactive power controller setting according to daily reactive power dispatch schedules. The reactive power / voltage control should be fast for on line application, flexible for charging systems conditions and easy to comply with operator's decision making logic.

Fuzzy logic technology has achieved impressive success in diverse engineering applications ranging from mass market consumer product to sophisticated decision and control problems. Uncertainty in fuzzy logic typically arises in the form of vagueness and / or conflicts, which are not represented naturally within the probabilistic frame work. Emphasis is placed on understanding the types of uncertainties in power system problem that are well represented by fuzzy methods. There are many uncertainties in various power system problems because power systems are large, complex, geographically widely distributed system and influenced by unexpected events [1]. These facts make it difficult to effectively deal with many power

systems problems through strict mathematical formulations alone [2]. Therefore the fuzzy logic approach is chosen as one of its area of artificial intelligence approach for the reactive power control for the State Electricity System (SES) which is the utility system.

2. The Need for Reactive Power Control in Power System

The ideal ac power should have constant voltage and frequency, should be free from harmonics and the power factor should be nearly unity. The voltage profile of an elective power system could be constantly affected either by the variations of load or by the change of network configurations. The power systems are equipped with a number of voltage controlling devices such as capacitors, tap settings in transformers, UPFC and compensators [3].
The control of reactive power will maintain the level of voltage nearly constant or within the specified tolerance limits. The voltage control should be carried out on line against a possible disturbance, particularly in a heavily loaded system. The objectives are to minimize real power losses and to improve the voltage profile of the given system. The purpose of reactive power / voltage control in a distribution substation is to control the reactive power flow over the main transformer and the voltage on the low voltage bus. It is evident that sufficient reactive power reserve is required to maintain terminal voltage at the load bus. The objectives of reactive power control in power system are to minimize the real power which will reduce the operative cost and improve the voltage profile [4]. In addition to the voltage control the other effects of providing reactive power compensating devices at the load bus are:

- Reduction in supply side reactive burden
- Reduction of system copper loss due to reduction of reactive current
- Decrease in KVA loading of alternators
- Reduction in investment per kW of load supplied
- Improvement in the system power factor
- UPFC Design

3. Reactive Power Control

One of the important operative tasks of power utilities is to keep voltage within an allowable range for high quality customer services. Electric power load varies from hour to hour and voltage can be varied by change of the power load. To maintain constant voltage profile, the reactive power control is needed. If the voltage of the bus is more than the specified level then the reactive power from that particular bus is to be absorbed. On the other hand if the voltage level is lower than the required level then the reactive power has to be injected to that bus. This is known as the reactive power control, which is needed to maintain the voltage profile by minimizing bus voltage variations. Power utility operators in control centers handle various equipment such as generators, transformers, static condenser, shunt reactor UPFC, so that they can inject reactive power and control voltage directly in target power system in order to follow the load change. The purpose of reactive power/voltage control in a distribution substation is to control the reactive power flow over the main transformer and the voltage on the low voltage bus. The ON / OFF status of the capacitor and tap positions for the LTC at each hour in the next day can be determined in order to keep the reactive power flow over the main transformer as small as possible and to maintain secondary bus voltage as close to the specified value a possible at all hours in the day [3]-[5].

4. Fuzzy Logic Implementation

Fuzzy logic allows a convenient way to incorporate the knowledge of human experts into the expert system using qualitative and natural language like expressions. The empirical establishment of the membership functions and the rule base allow one to incorporate available human knowledge and heuristics. The approach of this paper is to develop tools specifically designed for real-time operation instead of adapting planning tools for this purpose. In this case, the objective is to integrate Artificial Intelligence with traditional techniques for a more realistic formulation of the problem while maintaining a high computation efficiency [6]-[8].

The fuzzy set theory provides an excellent framework for this type of integration. The objective is to have optimal control of reactive power and to minimize real power losses and to improve the voltage profile of a system. Voltage constraints are also represented as fuzzy sets to reflect a more practical behaviour in this optimization problem. In this paper the optimal reactive power control problem will become that of maximizing this intersection, uncertainties in load and generations are modeled as fuzzy members. The approach by using the fuzzy sets aims at the enhancement of voltage security. In this modeling, two linguistic variables are applied to

measure the proximity of a given quantity to a certain condition to be satisfied [9]. The two linguistic variables are used as two inputs; they are Load in MW (Input 1) and the voltage level in KV (Input 2). The output is the reactive power requirement in MVAR.

For load (input 1) the intervals are divided into five triangular membership functions as:
* Very Low (V.LOW)   * Low (LOW)
* Medium (MEDIUM)   * High (HIGH)
* Very high (V.HIGH)

The triangular membership function in shown below in fig.1.
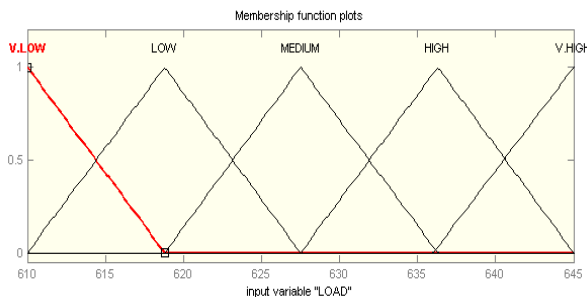
Fig. 1. Triangular Membership function for load.

The intervals for voltage level (Input 2) are divided into three triangular membership functions as:
*Low(LOW) *Medium(MEDIUM) *High(HIGH)

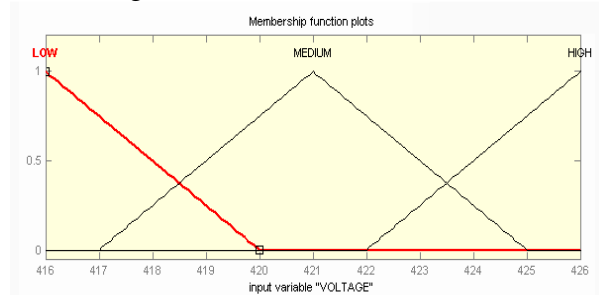The Triangular Membership function is shown below in fig.2

Fig. 2. Triangular Membership function for voltage

The intervals for the Reactive Power (output) are divided into five triangular membership functions as:

* Very Low (V.LOW)   * Low (LOW)
* Medium (MEDIUM)   * High (HIGH)
* Very high (V.HIGH)

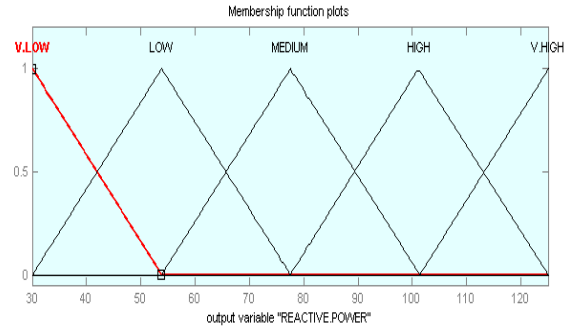The triangular Membership function is shown below in Figure3.

Fig. 3. Triangular Membership function for reactive power**.**

The proposed approach is simple and straight forward which defines the membership function of the two linguistic variables ingeniously, so that the merits of fuzzy techniques are brought into play. In this modeling, control heuristics are expressed by IF…THEN…Fuzzy rules, where the premises are given by the inguistic variables, measuring the proximity of a given input to a certain condition to be satisfied as the grade of membership in fuzzy sets. Every premise include in a rule has a numerical value rather than true or false, which enables in relaxed pattern matching and flexible application of known numerical model in the consequence, reflecting the relation between input and output [6], [8]. The flowchart for the voltage-reactive power control based on fuzzy modeling is shown in Fig. 4.

5. Case Study

Case study has been carried out for State Electricity System (SES) in India which is considered as the utility system in this paper. The different types of generation system have been considered. Here station A consists of Thermal stations, station B consists of Hydro-Irrigation Stations and Station C means hydro non-Irrigation and Station D means the Diesel generation stations. The various values of load MW, Reactive power in MVAR and the voltage levels in KV are shown below in Table 1 for all the four stations (Stations A,B,C,D). The case study is carried out for a particular day. Simulations of results are carried out in 'MATLAB' simulation package. The fuzzy membership functions for the inputs and output, three-dimensional surface views for these four stations are shown in Fig. 5, 6, 7 and 8(a) & (b) respectively.

Table 1. State Electricity System (SES) Real (Re) Power in MW, Reactive Power, Conventional (Con) and Fuzzy (Fuz) in MVAR, Voltage in KV for a particular day.

Time (Hrs)	Station A			Station B			Station C			Station D			Voltage in KV		
	Re MW	Con MVAR	Fuz MVAR	Re MW	Con MVAR	Fuz MVAR	Re MW	Con MVAR	Fuz MVAR	Re MW	Con MVAR	Fuz MVAR	B, D 110	C 230	A 400
1	635	55	49.6	15	12	9.96	30	12	10.9	2	44	42	111	231	426
2	640	65	58.6	15	12	9.96	30	12	10.9	2	50	42	111	231	424
3	610	50	38.0	15	12	9.96	30	12	10.8	2	48	42	111	230	425
4	640	65	58.6	15	12	10.5	30	12	10.8	2	50	42	110	230	424
5	640	80	62.5	46	22	16.3	30	12	10.8	2	48	42	110	230	423
6	640	80	62.2	90	44	40.5	105	40	37.4	2	48	42	110	230	420
7	645	90	79.7	90	44	41.0	105	40	37.4	2	56	42	109	227	418
8	645	125	81.8	90	44	40.5	105	40	37.1	2	52	42	110	227	416
9	645	110	81.5	90	44	41.0	105	40	37.4	2	48	42	109	229	417
10	645	90	79.7	90	44	41.0	105	40	37.4	2	44	42	109	230	418
11	645	90	81.8	90	44	41.0	105	40	37.1	2	56	42	109	230	416
12	645	50	38.0	90	44	41.0	105	40	37.1	2	52	42	109	232	420
13	640	85	76.9	85	44	40.5	105	40	37.1	2	48	42	110	231	418
14	640	85	76.2	85	44	40.9	105	40	37.1	2	46	42	111	232	417
15	640	80	62.2	85	44	40.9	105	40	37.1	2	52	42	112	231	420
16	640	85	76.9	85	44	40.9	105	40	37.1	2	52	42	111	231	418
17	640	90	71.0	85	44	40.5	105	40	37.1	2	42	42	110	229	419
18	640	90	71.0	85	44	40.5	105	40	37.4	2	43	42	110	230	419
19	640	120	76.2	85	44	40.5	105	40	37.4	2	44	42	110	230	417
20	640	85	76.9	85	44	40.5	105	40	37.4	2	44	42	110	230	418
21	640	80	62.2	85	44	40.5	105	40	37.4	2	48	42	110	233	421
22	640	80	62.5	15	12	9.96	105	40	37.1	2	50	42	111	231	423
23	640	70	62.5	15	12	9.96	15	12	10.9	2	46	42	111	232	423
24	640	70	62.2	15	12	9.96	15	12	10.9	2	45	42	111	232	421

Re- Real Power;   Con – Conventional Controller; Fuz – Fuzzy Controller

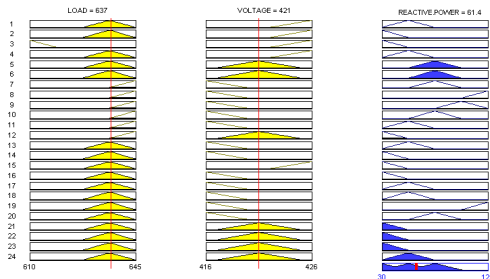Reactive Power for SES (State Electricity System)
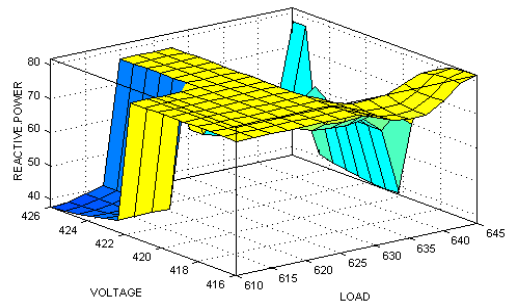Station A

Fig. 5(a) Inputs and Output

Fig.5 (b): Three Dimensional Surface views

START

INPUT SYSTEM DATA

INPUT BUS VOLTAGE DATA

CALCULATE LOAD FLOW

BUS VOLTAGES VIOLATE CONSTRAINTS

No

Yes

DETERMINE VOLTAGE CONTROL BY APPROXIMATE REASONING

ESTIMATE CONTROL EFFECT

WILL VOLTAGE BE RESTORED TO NORMAL?
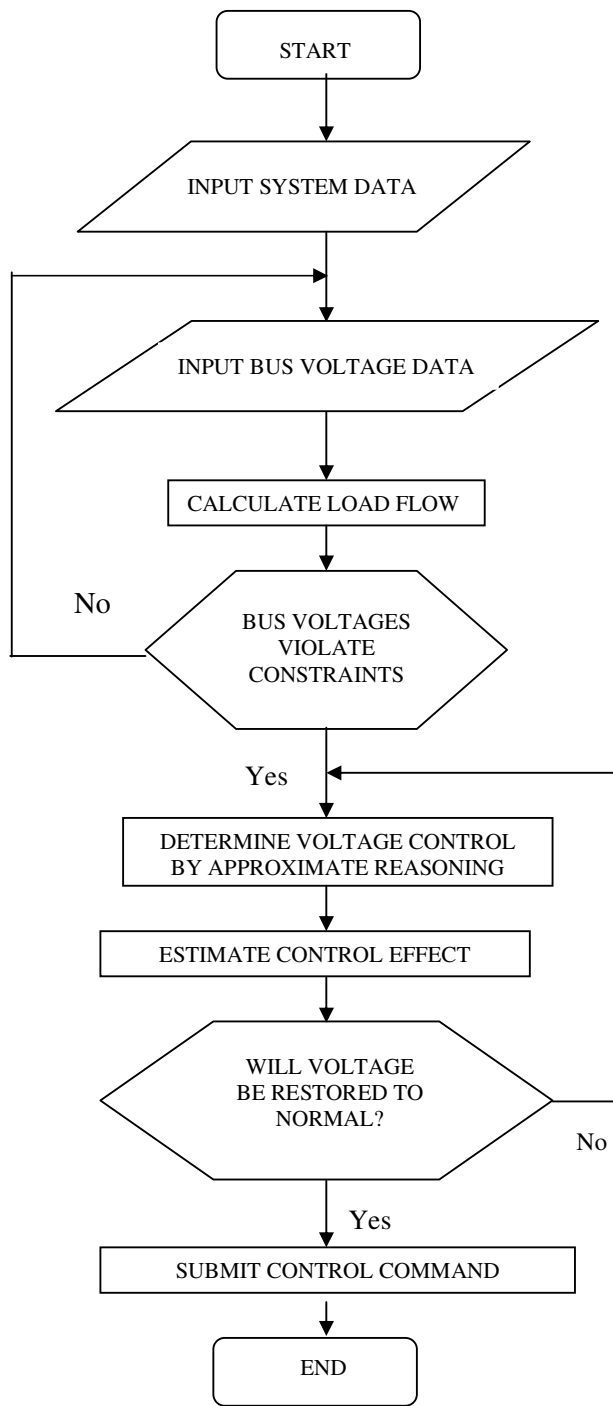
No

Yes

SUBMIT CONTROL COMMAND

END

Fig. 4.   Flow Chart for voltage fuzzy based voltage-reactive power control

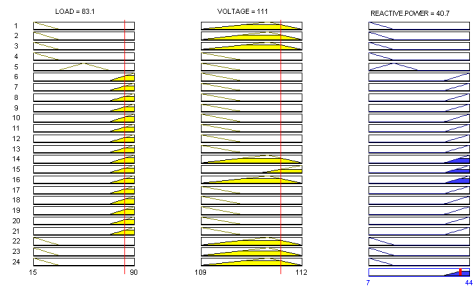Reactive Power for SES (State Electricity System) Station B
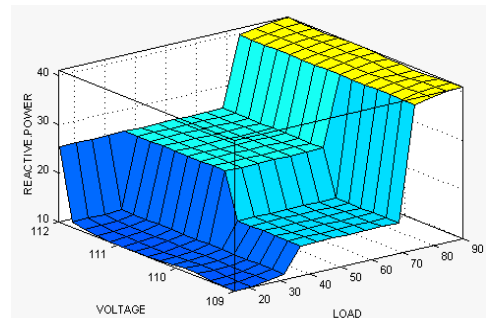

Figure 6(a) Inputs and Output

Fig.6 (b): Three Dimensional Surface views

Reactive Power for SES (State Electricity System) Station C
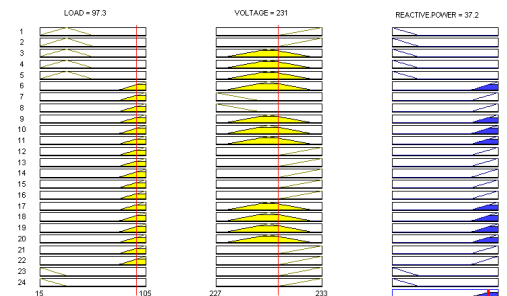
Figure 7(a) Inputs and Output
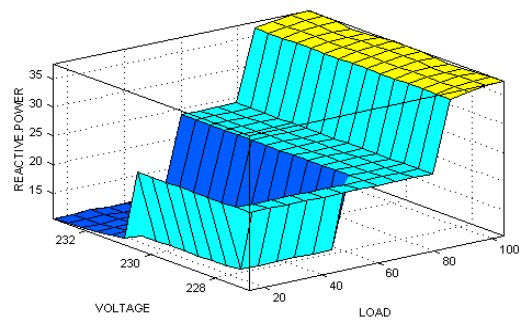
Figure 7 (b): Three Dimensional Surface views
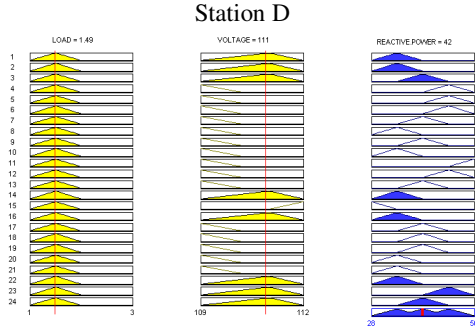
Reactive Power for SES (State Electricity System)
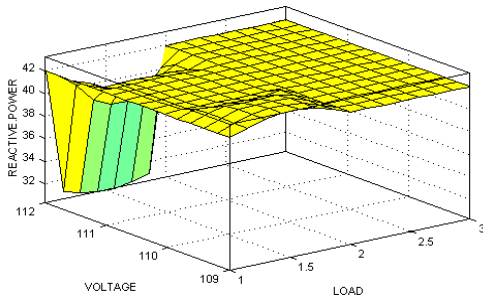Station D

Figure 8(a) Inputs and Output

Figure 8 (b): Three Dimensional Surface views

6. Result Analysis

The fuzzy rule approach is designed to closely describe the input, output relationship of the actual problem by using linguistic terms. Fuzzy logic membership functions and fuzzy rules are designed to provide a simple technique to directly implement experience and intuition into a computer program. This approach is much closer to people's decision making process in real life that we consider the preference around the environments before making final decision.

From Table 1 it is observed that the voltage is maintained within tolerable limit of $\pm$ 5 %. It is noticed that the voltage is almost constant. The variations and fluctuations in the voltage level are negligible. The comparison of results by conventional control method and fuzzy control method is done for the State Electricity System (SES). The values are shown in Table I and the compared results are shown in Figures 9 (a), (b), (c) and (d) for stations A, B, C & D respectively.

From Figure 9 (a), (b), (c) and (d), it is observed that the reactive power requirement values by the fuzzy approach is lower than the conventional methods which is more economical and requires less number of capacitor or reactive power compensating devices. Hence the fuzzy approach is best suited for reactive power control / UPFC .
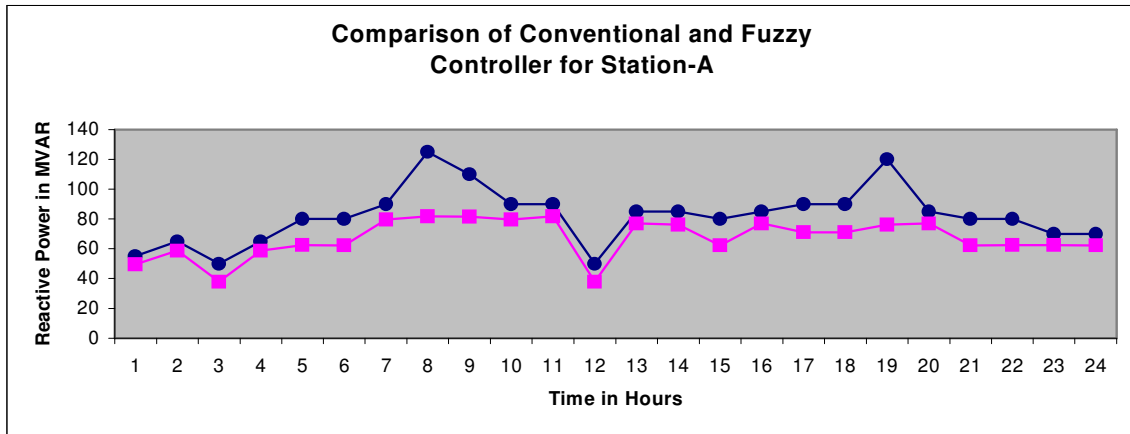

Fig. 9 (a) Comparison of Conventional and Fuzzy Controller for Station-A
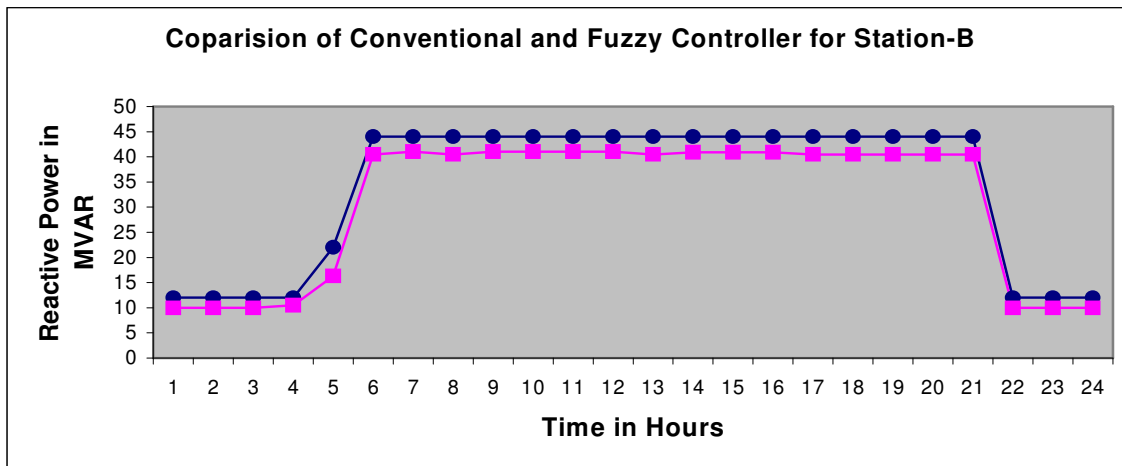
Dynamic   Fuzzy

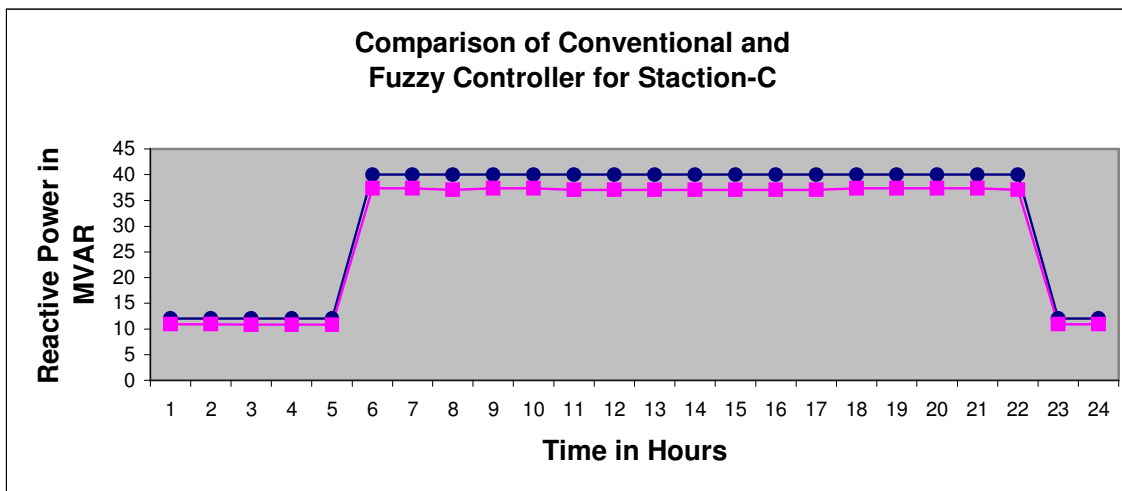Fig. 9 (b) Comparison of Conventional and Fuzzy Controller for Station-B

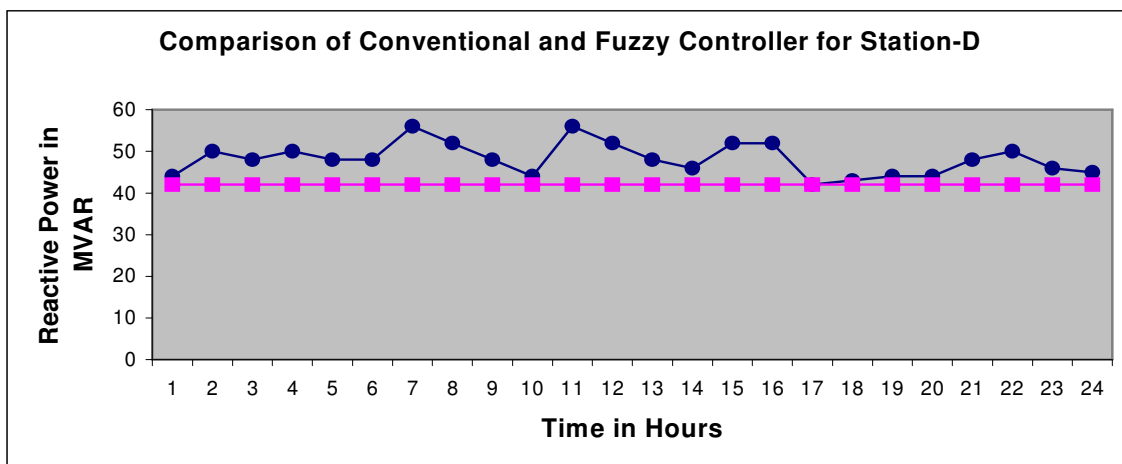Fig. 9 (c) Comparison of Conventional and Fuzzy Controller for Station-C

Fig. 9 (d) Comparison of Conventional and Fuzzy Controller for Station-D

7. Conclusion

Fuzzy logic allows a convenient way to incorporate the knowledge of human experts using qualitative and natural language like expressions. In this reactive power control two inputs such as load and the level of voltages are considered as fuzzy inputs. The reactive power requirements are formed out as output. By changing the value of reactive power the voltage profile is maintained constant. Voltage is the sole indicator of reactive power balance. By controlling the reactive power the real power losses are reduced. In SES for the different stations (A, B, C and D) the requirements of reactive power required have been found out by fuzzy approach. All these reactive power values are compared with the conventional controller. It is found out that the reactive power requirements calculated by the fuzzy approach are lower than the conventional controller. Hence, this fuzzy logic approach for reactive power control is a flexible approach to a coordinated control of voltage and reactive power in order to enhance voltage security of electric power systems. It is concluded that the fuzzy logic controller is better, effective, superior and much closer to people's decision-making process in real life.

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