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Fuzzy Based Tariff

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In deregulated and smart grid system, time based tariff is implemented using complex communication system. This time based tariff depending on market clearing price initiates demand management. Moreover, the consumer supporting the utility by adopting demand management technique is not benefited directly by the utility. In this paper, tariff is locally decided by the smart meter based on change in frequency and change in demand using Fuzzy logic. Based on the relation between change in frequency and change in demand with tariff, fuzzy rules are developed. On implementing fuzzy based tariff, the consumers supporting utility by doing demand management gets more benefited without using the complex communication network.

Keywords: Fuzzy logic, demand management, smart meter, time based tariff

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1. Introduction

Abridging the gap between the generation and demand is one of the major problems faced by developing countries. This gap can be reduced by applying supply side management [1- 3]. Costly, insufficient fuel production and unmanageable complex system makes adoption of supply side policy unfeasible [4 - 6]. Thus authorities are forced to implement load shedding in various sectors during most of the seasons. Load shedding disconnects one or more radial feeders originating from a substation by means of Under Frequency Relays (UFR) [7- 8], so that all loads fed from these feeders are disconnected. This causes inconvenience to the consumer. This problem can be overcome by deploying Demand Side Management (DSM) [4][6][9- 12].

DSM programs are implemented by the utility through tariff to control the energy consumption by the consumer with an objective to reduce the peak load demand [13- 14]. DSM adopts different pricing mechanism namely Incentive Based Program and Time Based Tariff. Incentive based program includes Direct Load Control (DLC), Interruptible Load program (IL) and demand bidding. In the time based tariff [15-17], the utility will increase the cost of the electric power when the system is facing peak load condition. Similarly the tariff will be less during off peak load condition. This time based tariff information will be provided to the customer energy meter using complex communication system [18-21].

On seeing the high or less tariff, the customer will decrease or increase his power consumption directly in person or by using an automatic control scheme based on his priority. The Control actions performed by the consumer is referred as Demand

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Management (DM). A number of researches have been carried out in the area of DM for managing various controllable loads [18].

However, time based tariff provides no incentives to the consumers taking part in DM program. He will not be paying more money for his non consumption. The utility will not give any incentive for his demand management. Hence, the consumers hardly react to the tariff rise. In addition, both time and incentive based pricing mechanisms require communication system [12][18][19- 21] to inform consumer about tariff. Wireless networks play a key role time based tariff. Implementing such a wireless based demand management system introduces congestion in the network and also makes the existing communication network further complex.

In this paper, Fuzzy Logic is used to solve the problem of complex communication systems requirement and providing incentive to the consumers involved in demand management. Moreover, non-price tools [18][22 - 24] like change in frequency and change in power demand are used by the fuzzy Logic to fix tariff. This fuzzy based tariff is locally decided in the energy meter will avoid communication system and will fix less tariff to the consumers involved in demand management.

Section 2, explains the tariff decision based on Fuzzy. From the knowledge on non price tool, the rule base for tariff is developed and explained in detail. Section 3 presents the simulation of the proposed technique in MATLAB and PROTEUS and discussions are made on the results obtained. Conclusion is finally presented in section 4.

2. Fuzzy Based Tariff

Frequency is the indirect quantity which defines the power balance in power system. Demand management can be done based on frequency. If the frequency is high, the consumers should be encouraged to connect loads. Connecting loads is to be discouraged when frequency is low. This control action supports the utility to maintain frequency. The consumers supporting the utility by involving himself in this control should be benefited in tariff.

This can be accomplished by some specific knowledge like, when frequency is high; tariff can be low, irrespective of change in demand. This less tariff will trigger the consumer to consume more power. When frequency is low, the tariff for consumer doing load management should be medium. This will give financial benefit to the consumer who supports utility. Similarly, the tariff should be high for the consumer who increases the load, when the system is suffering from low frequency. This will penalize the consumer and avoid him loading further. These ideas can be implemented in smart meter with the support of fuzzy in tariff decision making.

In this paper, tariff is determined by fuzzy, based on change in frequency (Δf) and change in demand (ΔP) [24]. The block diagram representation of the system is shown in Figure 1.

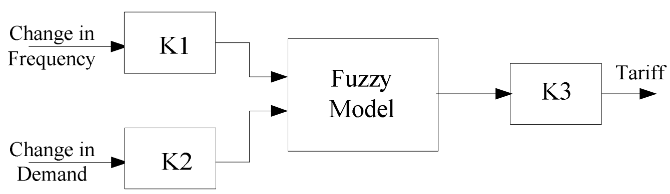

Figure 1: Block diagram of basic fuzzy model

In Figure 1, K1, K2, K3 are the scaling factors for change in frequency, change in demand and tariff respectively. In this work, K1, K2 and K3 are considered to be 1, 1/1000 and 5 respectively. K1 is decided by the utility based on frequency specification. K2 is based on the consumer and K3 is decided by the utility depending on profit margin and type of consumer. K3 factor will be large for large industrial consumers and will be less for small domestic consumers. The fuzzification of inputs, change in demand and change in frequency are done as per the membership function furnished in Figure 2. The universe of change in frequency and change in demand is classified into 3 linguistic variables namely, Negative (N), Zero (Z) and Positive (P) ranging from [-1.0 to 1.0] as shown in Figure 2. For N and P, trapezoidal membership function is considered whereas, Z is triangular. The constants K1 and K2 are used for normalizing the inputs like change in frequency and change in demand respectively within the membership range of -1 and +1.

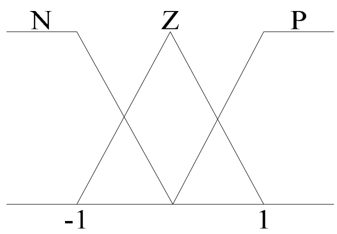

Figure 2: Input membership function

Fuzzy based tariff is developed in both Mamdani and Sugeno models. For Mamdani and Sugeno model, the input membership functions remain the same, whereas, the output representation is different. The output membership functions for both the models have 5 linguistic variables namely Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH) ranging from [0 to 1.0]. In Mamdani model, the linguistic variables L, M and H are triangular, and VL and VH are trapezoidal as shown in Figure 3. In Sugeno model, all the linguistic variables are constants as shown in Figure 4.

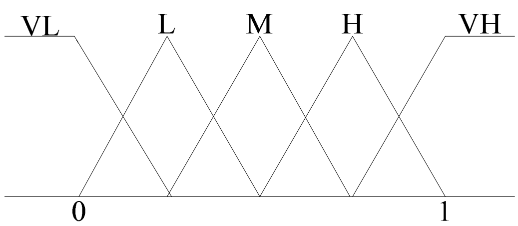

Figure 3: Output membership function-Mamdani model

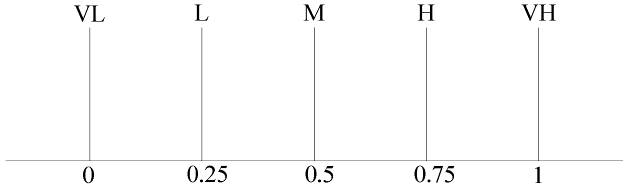

Figure 4: Output membership function-Sugeno model

When the change in frequency is positive, the tariff should be low so that consumers will consume more power and will bring down the frequency. When the change in frequency is negative and consumer involved in demand reduction, the tariff should be medium. Similarly, when the change in frequency is negative and the consumer increases his consumption, the tariff should be high. Based on these knowledge, the rule base for Fuzzy based tariff is developed and presented in Table 1.

Table 1: Fuzzy rules

Δf, ΔP	N	Z	P
N	L	H	VH
Z	M	M	H
P	L	L	VL

The rule 3 states, IF the change in frequency is N AND the change in demand is P, THEN tariff is VH. In Mamdani model, Centroid method is used for defuzzification. Weighted average method is used for defuzzification in Sugeno model. The developed rules will give an optimum tariff depending on the input variables. The fuzzy model explained in this section is to be simulated and tested for various input conditions.

3. Simulation and Discussion

The fuzzy based tariff which is explained in the previous chapter is developed in MATLAB/FIS environment. The fuzzy inference system is developed for both Mamdani and Sugeno model. The rule viewer of Mamdani model is shown in Figure 5.

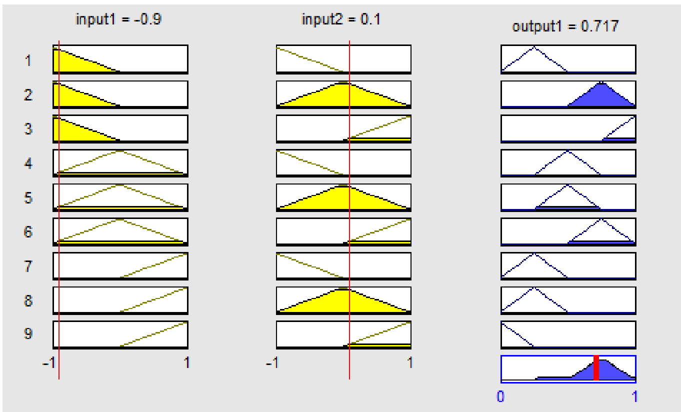

Figure 5: Rule viewer of Mamdani model

In the above Figure, change in frequency is considered to be -0.9Hz and change in demand as 100W. Since the K1 and K2 values are 1 and 1/1000 respectively, after scaling, change in frequency and change in demand becomes -0.9 and 0.1 respectively. The Mamdani model gives the output of 0.717 after implication, aggregation, and defuzzification. In this work, scaling factor of 5 is used for K3. The tariff obtained from the

Mamdani model after scaling is Rs. 3.59. The fuzzy based tariff is also developed using Sugeno fuzzy model which is presented in Figure 6.

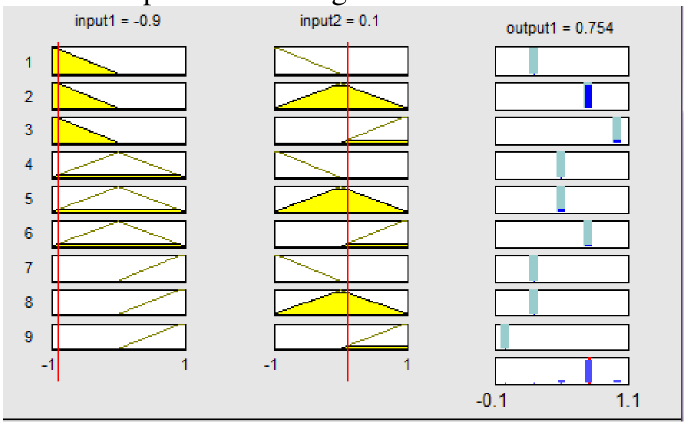

Figure 6: Rule viewer of Sugeno model

As in the Mamdani model, the same inputs are considered for the Sugeno model i.e., -0.9Hz (-0.9 after scaling) for change in frequency and 100W (0.1 after scaling) for change in demand. 0.754 is the value obtained after implication, aggregation, and defuzzification. The tariff is found to be Rs. 3.77 after scaling. Mamdani model is based on Centroid method for defuzzification and Sugeno model uses weighted average method for defuzzification. This creates small difference in the final solution.

The fuzzy model for tariff calculation is further developed in MATLAB / Simulink as furnished in Figure 7. The Sugeno model presented in Figure 6 is incorporated in the fuzzy logic controller block of Simulink model.

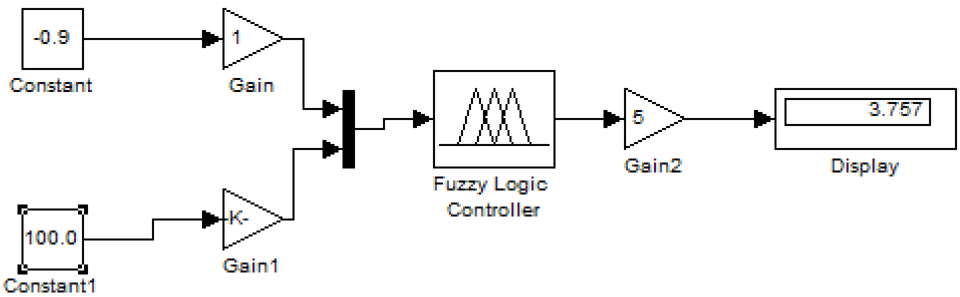

Figure 7: Simulink model of fuzzy based tariff

In the Figure 7, the scaling factor for change in frequency and change in demand is 1 and 0.001 respectively. Whereas the scaling factor for tariff is 5. For the change in frequency of -0.9Hz and the change in demand of 100W, the tariff is found to be Rs. 3.76. Since the MATLAB / Simulink yields required result, the fuzzy logic has been developed in MPLAB and programmed in the PIC using PROTEUS environment for practical development and testing. The Fuzzy based tariff in PROTEUS is shown in Figure 8.

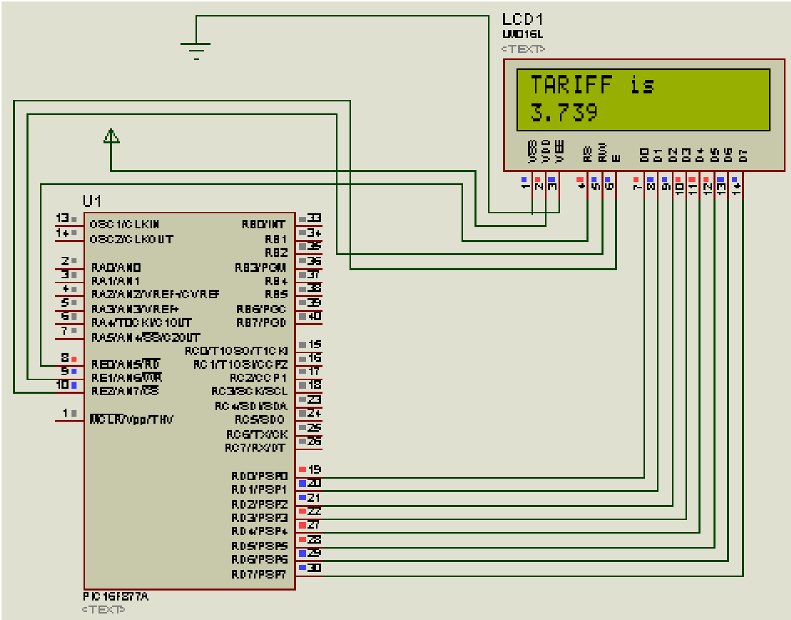

Figure 8: PROTEUS model of fuzzy based tariff

The Tariff has been calculated for all the possible combination as explained in the Table 1 of rule base. The results are tabulated in Table 2.

Table 2: Fuzzy calculated tariff for different combinations

Change in frequency (Hz)	**Change in demand (W)**	**Tariff (Rs.)**
-0.8(N)	-500(N)	2.458(L)
-0.8(N)	0(Z)	3.516(H)
-0.8(N)	500(P)	4.114(VH)
0(Z)	-500(N)	2.5(M)
0(Z)	0(Z)	2.5(M)
0(Z)	500(P)	3.151(H)
0.8(P)	-500(N)	1.484(L)
0.8(P)	0(Z)	1.484(L)
0.8(P)	500(P)	1.129(VL)

Table 2 clearly shows that the fuzzy model developed for tariff calculation based on change in frequency and change in demand is providing accurate results.

4. Conclusion

Fuzzy based tariff is developed in this paper. The tariff is decided based on the change in system frequency and change in demand. Fuzzy logic is used for deciding the tariff. The proposed method is an alternate for time based tariff which supports and triggers the consumers to involve in demand management by giving incentive in tariff. It also avoids the loading of communication networks. On testing, it is proved that fuzzy base tariff yields required results.

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