Fuzzy Control of Centrifugal Pumps Flow

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Abstract - **Electronic variable-speed drives can produce large energy and environmental savings in variable-load variable-speed applications when compared with other conventional technologies. There are a very large number of applications which would benefit, both in terms of process improvement and energy savings, through the use of speed control. Previous studies have shown that the variable-flow fluid motion applications (pumps, fans, and compressors) have the largest savings potential. Combined application of inverters and water pumps brings us not only good energy-saving benefits but some new problems, such as inverters configuration and overload etc. In systems with high static head the system curve does not follow the curves of constant efficiency. Using the Affinity Laws to calculate energy saving in system with static head is a mistake because it can also lead to major errors. From this element of uncertainty, the thought that we can try a fuzzy approach. This paper presents a theoretical study of use fuzzy logic to control the operation of a variable speed centrifugal pumps. A mathematical model has been realized and a Matlab simulation scheme was attached to it. Based on the mathmatical model of puming systems with or without static head, the article discusses some issues in detail, such as pressure and flow rate regulation. The fuzzy model can be successfully used for the variable speed control of hydraulic systems, when the Affinity Lows not observe exactly.**

Keywords: *variable speed, mathematical model of pump, controller, fuzzy logic approach.*

I. INTRODUCTION

When a pump is installed in a system, the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect (Fig.1) [1]-[3].

Many pumping systems require a variation of flow or pressure. Either the system curve or the pump curve must be changed to get a different operating point. Where a single pump has been installed for a range of duties, it will have been sized to meet the greatest output demand. It will therefore usually be oversized, and will be operating inefficiently for other duties.

Consequently, there is an opportunity to achieve an energy cost savings by using control methods, such as variable speed, which reduce the power to drive the pump during the periods of reduced demand.

For systems where friction loss predominates, reducing pump speed moves the intersection point on the system curve along a line of constant efficiency.

The operating point of the pump, relative to its best efficiency point, remains constant and the pump continues to operate in its ideal region.

The Affinity Laws are obeyed, which means that there is a substantial reduction in power absorbed accompanyng the reduction. in flow and head, making variable speed the ideal control method.

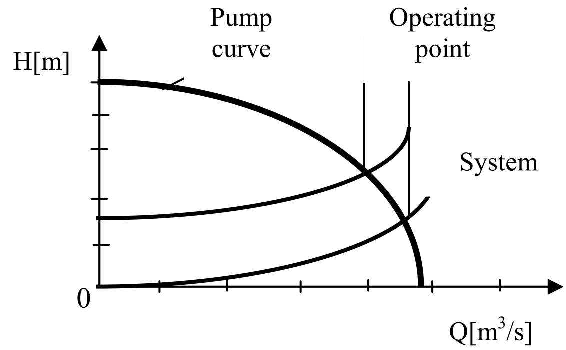

Fig.1. System curve, with and without static head.

However, in systems with high static head, the system curve does not start from the origin but at some non-zero value on the y-axis corresponding to the static head (Fig.1).

Hence, the system curve does not follow the curves of constant efficiency. The reduction in flow is no longer proportional to speed; a small turn down in speed greatly reduces flow rate and pump efficiency. A common mistake is to also use the Affinity Laws to calculate energy saving in system with static head. Although this may be done as an approximation, it can also lead to major errors.

II. THE PROBLEM FORMULATION

The internal characteristic of a centrifugal pump can be described through the following equation:

$$H_1 = 3.7Q^2 - 0.17Q - 3 \quad (1)$$

The characteristic of the pipe network is a parabolic curve such as:

$$H_2 = 1.2 + 2.75Q^2 \quad (2)$$

In the operating point of the pump the following relationship must be fulfilled:

$$H_1 = H_2 \quad (3)$$

Hence:

$$3.7Q^2 - 0.17Q - 3 = 1.2 + 2.75Q^2 \quad (4)$$

The answer is Q_F=2.1m^3/s. For this flow rate the head in operating point is H_F=14.45m.

Now consider the system requires a lower flow rate by 25%. The easiest way to achieve this is to use a static frequency converter. Ander the Affinity Law [4]-[5]:

$$\frac{f_F}{f_{G\,2}} = \sqrt{\frac{H_F}{H_G}} \quad (5)$$

where:

$f_F = 50Hz; H_F = 14.4m; H_G = 11m$.

Solving equation (5), frequency value is found f_G=43.7Hz. Considering the Affinity Law:

$$\frac{f_F}{f_G} = \frac{Q_F}{Q_G} \quad (6)$$

Results Q_G=1.91m^3/s. Substituting this value in equation (2), is found H_2=11.274m, was not 11m as system demand.

From this element of uncertainty, the thought that we can try a fuzzy approach. Control applications, such as temperature control, traffic control, or process control, are the most prevalent of current fuzzy logic applications.

III. The Fuzzy Model

Equations (1) and (2) are now considered as representing two fuzzy sets on the *H* (head) universe of discourse.

Further, there are defined the membership functions μ_1 and μ_2 representing the degree of membership of H_1 and H_2 in H.

The resulting stress is then given by (7) [6]:

$$H = \mu_1 H_1 + \mu_2 H_2 \,[\mathrm{m}] \quad (7)$$

The values of membership functions are given in Table 1.

Values of μ_1 and μ_2 in Table I were obtained by choosing of two interpenetrating fuzzy sets H_1 and H_2 spanning the range from 1.00 to 2.20 m^3/s for flow rate and rated speed.

The uncertainty in the laboratory test data indicates that H_1 and H_2 can be partitioned into four fuzzy sets each, as is illustrated in Fig.2 and 3 [7], [9]-[10].

Accordind to pump specifications the rated head (corresponding to maximum efficiency) is H_1=12.8m. The correspondent of this value in Fig. 2 gives the membership values for the LM and HM fuzzy sets of μ_{LM}=0.4 and μ_{HM}=0.26.

The logic sentence is:

IF	H_1	THEN	H_2	μ	CONCLUSION
	HM		LM	06	0.6LM
	LM		HM	0.4	0.4HM

The aggregate conclusion is the union of the above partial conclusions.

TABLE I.
Membership Values and Transition Head Values

Q[m^3/s]	μ_1	μ_2	H_1[m]	H_2 [m]	H[m]
1.00	1.00	0.00	0.53	3.95	0.53
1.15	0.80	0.20	1.69	4.83	2.31
1.30	0.60	0.40	3.03	5.84	4.15
1.45	0.47	0.53	4.53	6.98	5.82
1.60	0.42	0.58	6.20	8.24	7.38
1.75	0.34	0.66	8.03	9.62	9.08
1.90	0.28	0.72	10.03	11.12	10.81
2.05	0.08	0.92	12.20	12.75	12.70
2.20	0.00	1.00	14.53	14.51	14.51

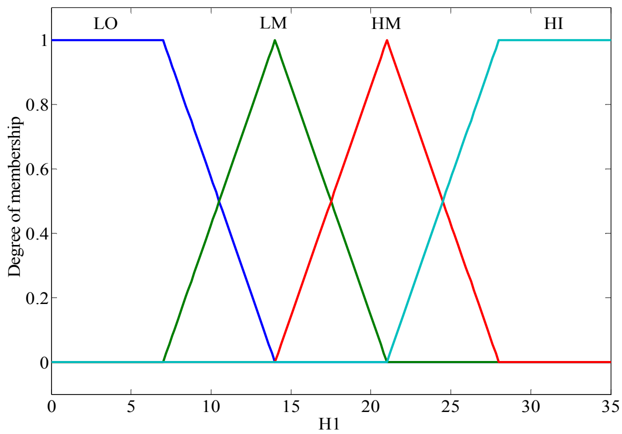

Fig. 2. Partitioning of the H_1 universes of discourse

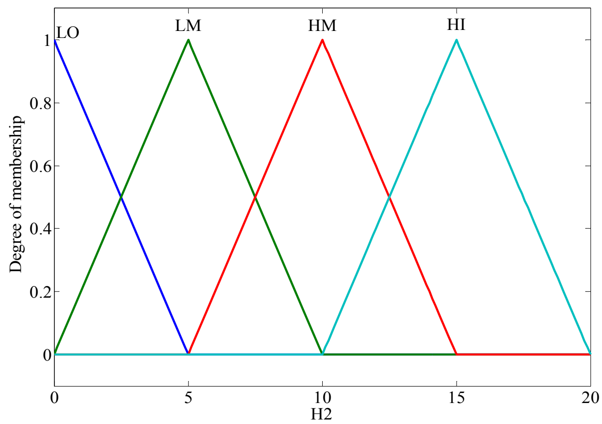

Fig. 3. Partitioning of the H_2 universes of discourse

The corresponding rule base reflecting opposite tendencies in H_1 and H_2 is shown in Table 2.

TABLE II.
RULE BASE FOR H_1 AND H_2

Rule's number	Rule's enunciation
1	IF H_1 IS LO THEN H_2 IS HI
2	IF H_1 IS LM THEN H_2 IS HM
3	IF H_1 IS HM THEN H_2 IS LM
4	IF H_1 IS HI THEN H_2 IS LO

where:

LO – low; LM – low medium; HM – high medium; HI – high.

The first controller is shown in Figure 4. Expressing the conclusion in discrete form gives a fuzzy value of H:

$$H = 0//2.5 + 0.2//3.4 + 0.2//8.62 + 0.5//10 + 0.8//10.8 + 0.8//12 + 0.5//15 + 0//17.54$$

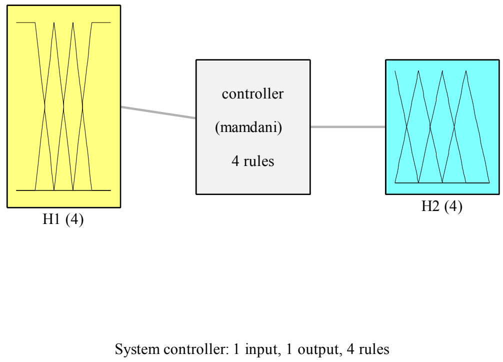

Fig.4. Head of pump controller.

The fuzzy value H may be defuzzified using:

$$H = \left(\sum_{i=1}^{n} H_i x_i \right) / \sum_{i=1}^{n} H_i . \qquad (8)$$

Fig. 5. Final output of H.

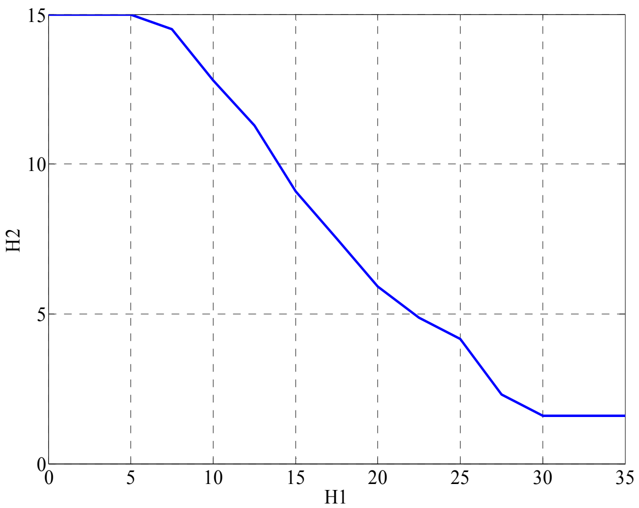

Fig. 6. The first control surface.

Next, determine the frequency corresponding to H=11.04m. H and f can be partitioned into five fuzzy sets each, as is illustrated in Fig.7 and 8.

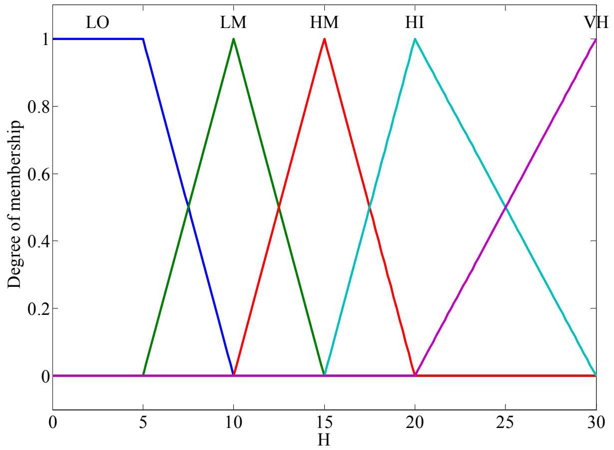

Fig. 7 Partitioning of the H universes of discourse.

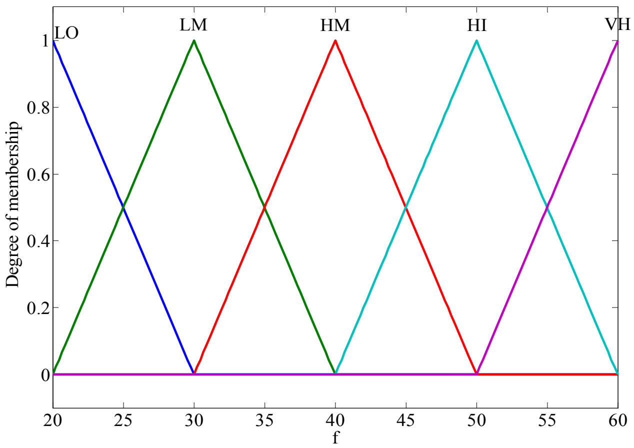

Fig. 8 Partitioning of the *f* universes of discourse.

The rule views are presented in figure 5 and the control surface in Figure 6 (representing all solutions).

The correspondent of H=11.04m in Fig. 7 gives the membership values for the LM and HM fuzzy sets of μ_{LM}=0.815 and μ_{HM}=0.185.

The logic sentence is:

IF	H	THEN	f	μ	CONCLUSION
	LM		HM	0.815	0.815HM
	HM		HI	0.185	0.185HI

The aggregate conclusion is the union of the above partial conclusions.

The corresponding rule base reflecting opposite tendencies in H and f is shown in Table 3.

TABLE III.
RULE BASE FOR *H–F* RELATIONSHIP

Rule's number	Rule's enunciation
1	IF *H* IS LO THEN *f* IS LM
2	IF *H* IS LM THEN *f* IS HM
3	IF *H* IS HM THEN *f* IS HI
4	IF *H* IS HI THEN *f* IS VH

The second controller is shown in Figure 9.

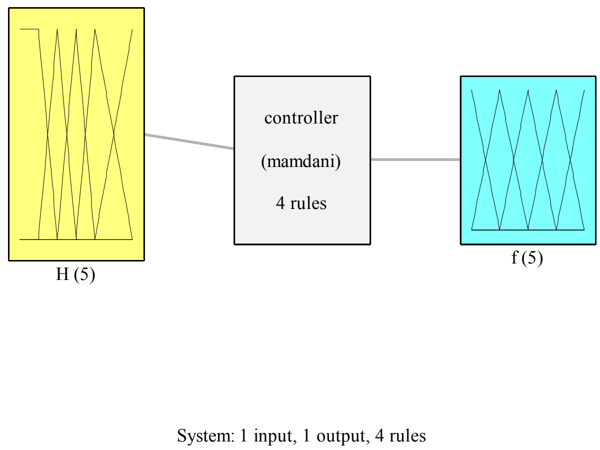

Fig. 9. The frequency controller.

The conclusion is given as following:

$$f = 0//30 + 0.5//55 + 0.815//37 + +0.815//43 + 0.5//45 + \\ +0.185//48 + +0.185//53 + 0//60$$

Defuzzifying gives the following value, according to Figure 10:

$$\sum_{i=1}^{8} f_i x_i = 0.5(35+45) + 0.815(37+43) + \\ +0.185(48+53) = 123.885$$

The conclusion is illustrated in Figure 10 and 11 is presented the control surface (representing all solutions).

$$\sum_{i=1}^{8} f_i = 0 + 2\cdot 0.2 + 2\cdot 0.5 + 2\cdot 0.8 = 3.$$

there results:

$$f = \frac{123.885}{3} = 41.295 Hz.$$

Comparing this value to that date of Affinity Law, f_g=43.7Hz, it is found that the difference is not great, but fuzzy controller helps you obtain precision required to achieve system load, even for the system with static head, when Affinity Laws no longer observe exactly.

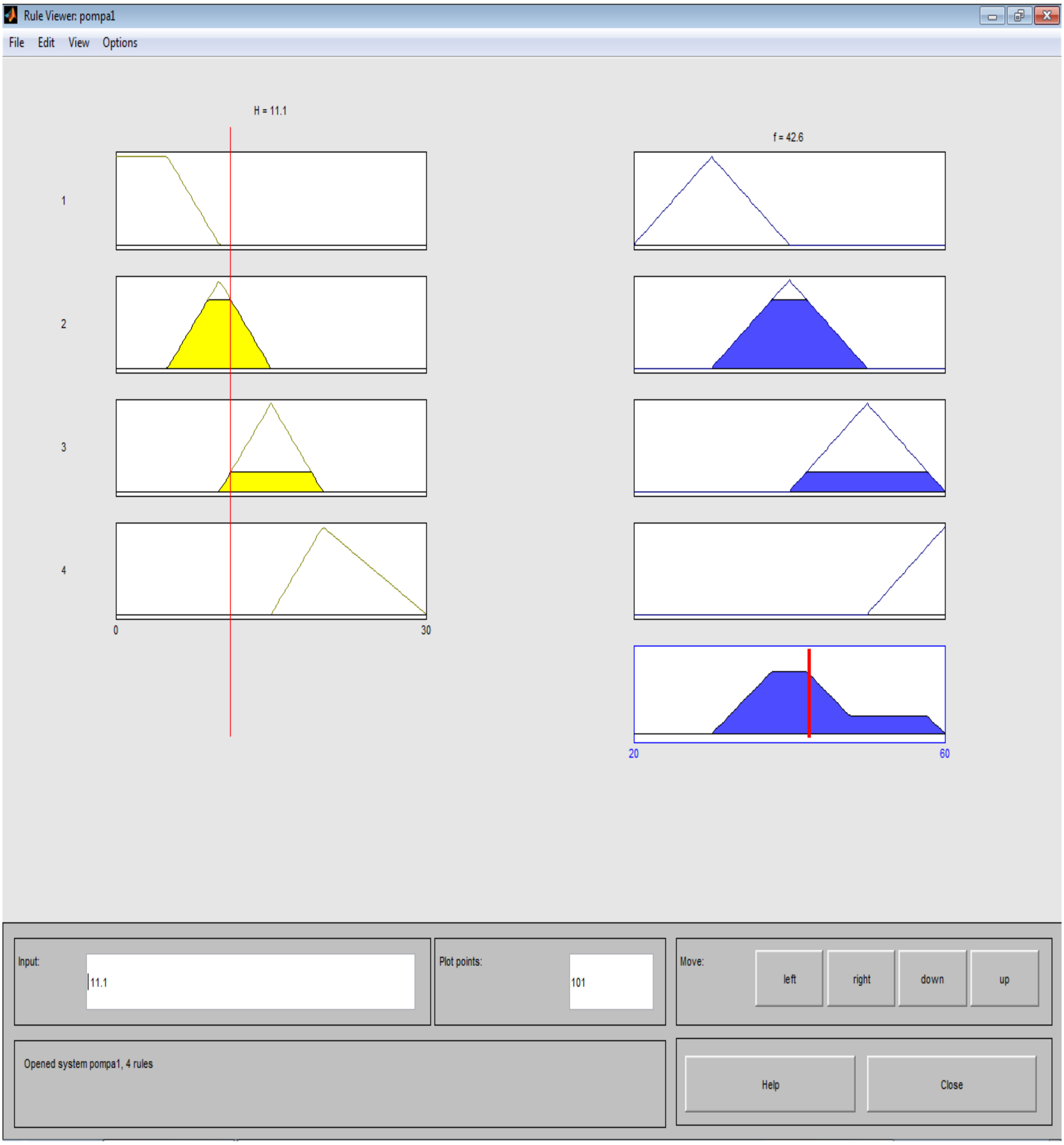

Fig.10. Final output f - H_2=11,1m and f=42.6Hz

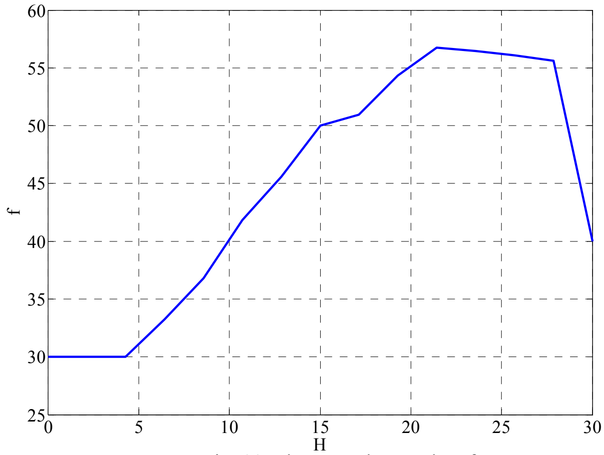

Fig. 11. The second control surface

IV. Conclusions

This paper is focused on the utility of fuzzy set theory and fuzzy logic as tools to improve our engineering and physical models.

Pump speed control is especially appropriate for systems that are largely dominated by friction head.

Pressure and flow rate regulation during pumping systems operation is a complex issue. In high power pumps with low energy losses (i.e. cost – effectiveness), variable – speed pump – controlled hydraulic systems are generally preferred in the drive systems of the contemporary machine systems.

However, there exist some critical problems such as the static head of the pipe network. For a system with static head, the dynamic behavior of hydraulic system becomes nonlinear.

Because of this, in practice there is usually significant uncertainty in forecasting frequency response of centrifugal pumps to their real in service conditions.

To achieve the control objectives in such systems, methodology used in this paper was fuzzy logic. Uncertainty or vagueness in the input data (i.e. influence still uncertain of the static head) is reflected in the conclusions in the form of membership fuzzy sets.

The fuzzy logic treatment of the case considered clearly show the frequency value for which to obtain the required head value, even when the Affinity Lows not observe exactly.

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