# Control of Flow and Pressure in the Cooling Water Circuit of a Thermal Power Plant Using Fuzzy Logic

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***Abstract* - Optimum operation of cooling water systems means minimum use of water while maintaining proper temperatures to limit algae growth and cool all equipment properly. Combined, the application of inverters and cooling water pumps brings us not only good energy-saving benefits but some new problems, such as inverter configuration and overload etc. The objective of this paper is to find a suitable solution by designing the intelligent controller for frequency control of cooling water systems, such as fuzzy logic and to investigate the controllability of this model under various changes of static head system. Based on the mathmatical model of puming systems with or without static head, the paper discusses some issues in detail, such as pressure and flow rate regulation. In fuzzy logic control, Mamdani model is used to control the system. The suggested system uses the concept of fuzzy logic system where the fuzzy rule base consists of a collection of fuzzy IF–THEN rules. The fuzzy inference engine uses these fuzzy IF–THEN rules to determine a mapping from fuzzy sets in the input universe of discourse to fuzzy sets in the output universe of discourse based on fuzzy logic principles. The fuzzy model can be successfully used for the variable speed control of hydraulic systems, when the Affinity Lows not observe exactly.**

**Cuvinte cheie:** *sistem de răcire cu apă, turație variabilă, model matematic, pompă, controler fuzzy.*

**Keywords:** *cooling water system, variable speed, mathematical model, pump, fuzzy logic controller.*

## I. INTRODUCTION

In the present paper we intend to analyze the operation of electropumps in the cooling water circuit of an energy group, equipped with variable speed drives.

Energy savings achieved through energy efficiency is the cheapest and most environmentally friendly resource compared to renewable energy or fossil fuels.

Energy prices are on the rise, many companies are forced to find new solutions to save energy and get lower prices for the final product. One of the economic solutions found and with high efficiency is the use of frequency converters for speed regulation.

This technology contributes to meeting local and international agreements in the field of energy saving and carbon dioxide emissions. Due to their high savings potential and lower costs, these technologies have become more attractive. Thus, it is not a new idea to use frequency converters for speed control in volumetric equipment such as pumps, compressors and fans.

We have taken into account the possibilities of variable speed drives to reduce energy consumption, which are currently supported in the technical literature. Cooling water is the one that evacuates the heat to the cold source, as well as from various points of the boiler.

The main cooling water consumers are: turbine condenser, generator coolers, turbine oil coolers, technology cooling circuits for internal service equipment.

The cooling water supply systems can be made in open circuit, closed circuit or mixed circuit.

Cooling water pumps are used for supplying heat exchangers with cooling water [1]. Their flow rate varies depending on the heat flow to be dissipated.

The required head is determined by the type of cooling system. The flow rate depends on the cooling process, the characteristics of the heat exchanger and on whether the pump is to be installed in a fossil-fuelled or a nuclear power station (Fig. 1).

Cooling water pumps can be controlled in various ways:

a) Closing a throttling element (valve) in the discharge line ( pump system) increases the head of the system and decreases the flow rate. Throttling generates the highest losses. Its use is generally confined to very small units. Throttling is not common in today's modern power stations.

b) Speed control is used for adjusting the rotational speed of the pump [2]. As a result, the head, flow rate and pump input power are adjusted in accordance with the affinity laws. However, the greater the static component of the system head, the more the operating point deviates from its optimum at reduced speed. In other words, it shifts toward low-flow operation and, hence, toward the cut-off point.

c) On late fuzzy logic control has become very popular over the conventional control logic (CCL), mainly the process of FLC is simply to put the realization of human control strategy, where CCL heavily relies on the mathematical formulations. The motivation behind this research is to find an improved method and a new technique of control by exploring the fuzzy system in the area of speed cooling water pump control [3].

The methodology for making a fuzzy controller contains the following steps: building the rule base, fuzzyfication, making the decision, defuzzyfication.

The main advantages of fuzzy systems are:

- It can work with imprecise terms like cold / hot / hot, near / far, fast / slow, which are difficult and arbitrarily measurable, even for human beings. In hard terms, this means that fuzzy systems do not require accurate analog / digital converters to acquire the signals.

- They are able to control the mechanical systems very smoothly, as comfortable as possible.

Fuzzy technology has been applied in many of the traditional issues and has recently been applied in areas such as information technology, telecommunications, traffic control and, last but not least, energy systems.

Fuzzy logic is, in most cases, the best way, because in almost all cases, the same product is obtained (as by other methods) but faster and cheaper.

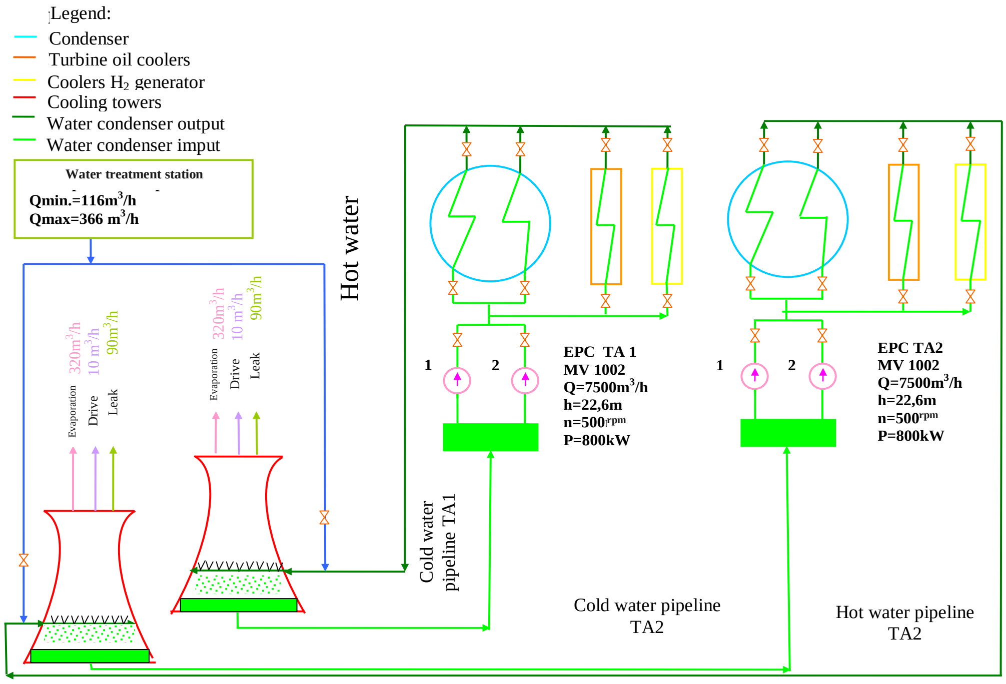


Fig. 1. Cooling circuit diagram from S.E. Craiova II.

## II. The Problem Formulation

The operation and control of the energy systems is performed on systems in operation, whose parameters and structure fluctuate constantly. These changes and fluctuations require rapid responses to offset the deviations and to provide stability to the energy system. The nature of fluctuations and the response of the system is unpredictable, so the management and planning of the energy system is confronted with uncertainty over energy demand, limited access to data, as well as changes in economic, political and social conditions.

Managers and engineers of these systems need to increase the efficiency of electricity production in a variable environment, the behavior of which is difficult to predict in the absence of reliable data. This problem can be solved by applications of intelligent driving methodologies. Applications based on expert systems, neural networks and fuzzy sets can be used in the control, operation and management of energy systems under the new conditions.

The theory of fuzzy sets is recognized by numerous researchers and engineers as a method that can provide modern tools in solving many problems of the energy system, particularly in the case of unknown system structure and parameter fluctuations. It is also a promising technique for unknown processes in the absence of reliable data.

The curves of the pipe network and the analyzed centrifugal pump are presented in Fig.2.

At the operating point the head and the flow have the following values: $H_F$=17m, $Q_F$=3m$^3$/s.

Now considering the system requires a lower flow rate by 25%, meaning $Q_G$=2.25m$^3$/s. The simple solution for achieving this flow is to use a static frequency converter and Affinity Laws [4]

$$\frac{f_F}{f_G} = \frac{Q_F}{Q_G} \tag{1}$$

$$\frac{f_F}{f_G}_2 = \sqrt{\frac{H_F}{H_G}} \tag{2}$$

where: $f_F$=50Hz, $Q_F$=3m$^3$/s and $H_F$=17m.

Solving equation (1) the frequency value is found $f_G$=37.5Hz. Substituting this value in equation (2), is found $H_G$=9.56m, was not 13.5m as system demand.

Therefore, the curve of the static head system (the curve of the network does not start from the origin but from a value other than zero on the y-axis, which corresponds to the static head) does not follow the constant efficiency curves.

Reduction of flow is no longer proportional to speed; A small variation in speed significantly reduces pump flow and efficiency. In this case, it is a mistake to use Affinity Laws to calculate energy savings [5].

From this element of uncertainty, the thought that we can try a fuzzy approach.

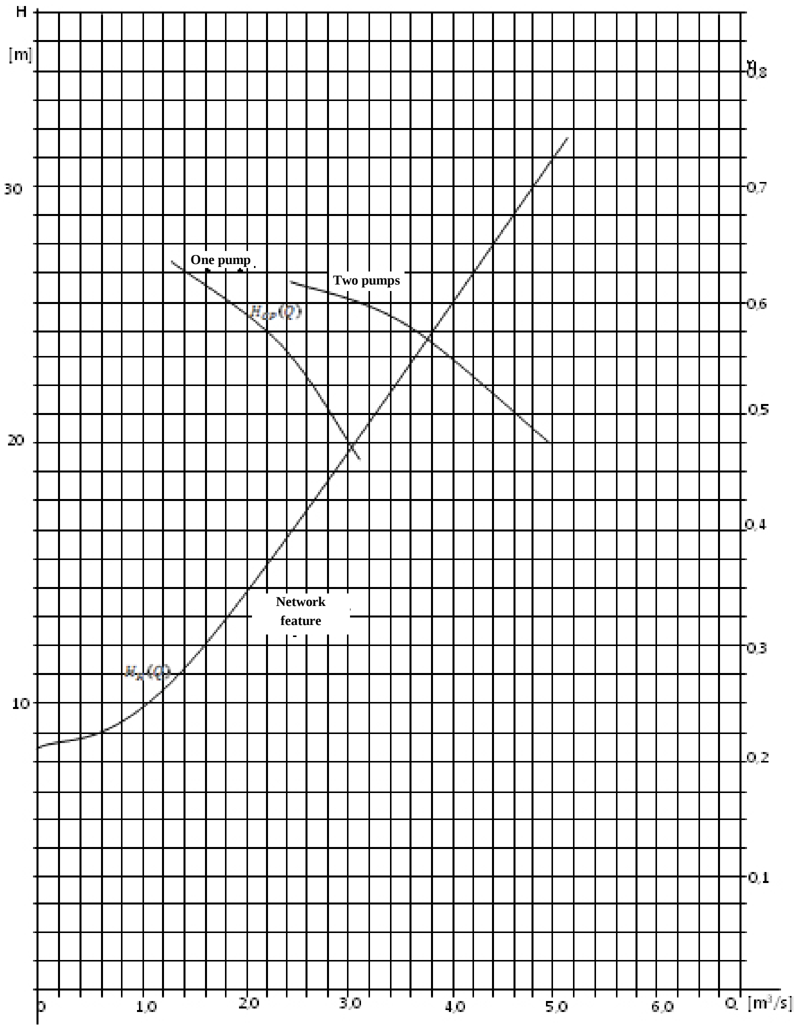


Fig. 2. The characteristic curves of the cooling water pumps.

## III. The Fuzzy Model

The internal characteristic of centrifugal pumps, resulting from the characteristic operation curves from Fig. 2, can be described by the following equation:

$$H_1 = 35.7 - 6.5Q - 0.2Q^2 \quad (3)$$

The pipeline network characteristic is a parabolic curve of equation:

$$H_2 = 8.2 + 1.42Q^2 \quad (4)$$

Equations (3) and (4) are now considered as representing two fuzzy sets on the *H* (head) universe of discourse. Further, there are defined the membership functions $\mu_1$ and $\mu_2$ representing the degree of membership of $H_1$ and $H_2$ in $H$. The resulting stress is then given by equation 5,[6]:

$$H = \mu_1 H_1 + \mu_2 H_2 \text{ [m].} \quad (5)$$

The values of membership functions are given in Table 1.

TABLE I.
MEMBERSHIP VALUES AND TRANSITION HEAD VALUES

| Q[m³/s] | $\mu_1$ | $\mu_2$ | $H_1$ [m] | $H_2$ [m] | H [m] |
|---|---|---|---|---|---|
| 1.00 | 1.00 | 0.00 | 27.5 | 9.5 | 27.5 |
| 1.50 | 0.90 | 0.10 | 25.5 | 10.5 | 24.0 |
| 2.00 | 0.80 | 0.20 | 22.8 | 12.0 | 20.6 |
| 2.50 | 0.70 | 0.30 | 19.5 | 14.0 | 17.8 |
| 3.00 | 0.50 | 0.50 | 16.5 | 16.5 | 16.5 |

Values of $\mu_1$ and $\mu_2$ in Table I were obtained by choosing of two interpenetrating fuzzy sets $H_1$ and $H_2$, spanning the range from 1.00 to 3.00 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.3 and Fig.4 [7].

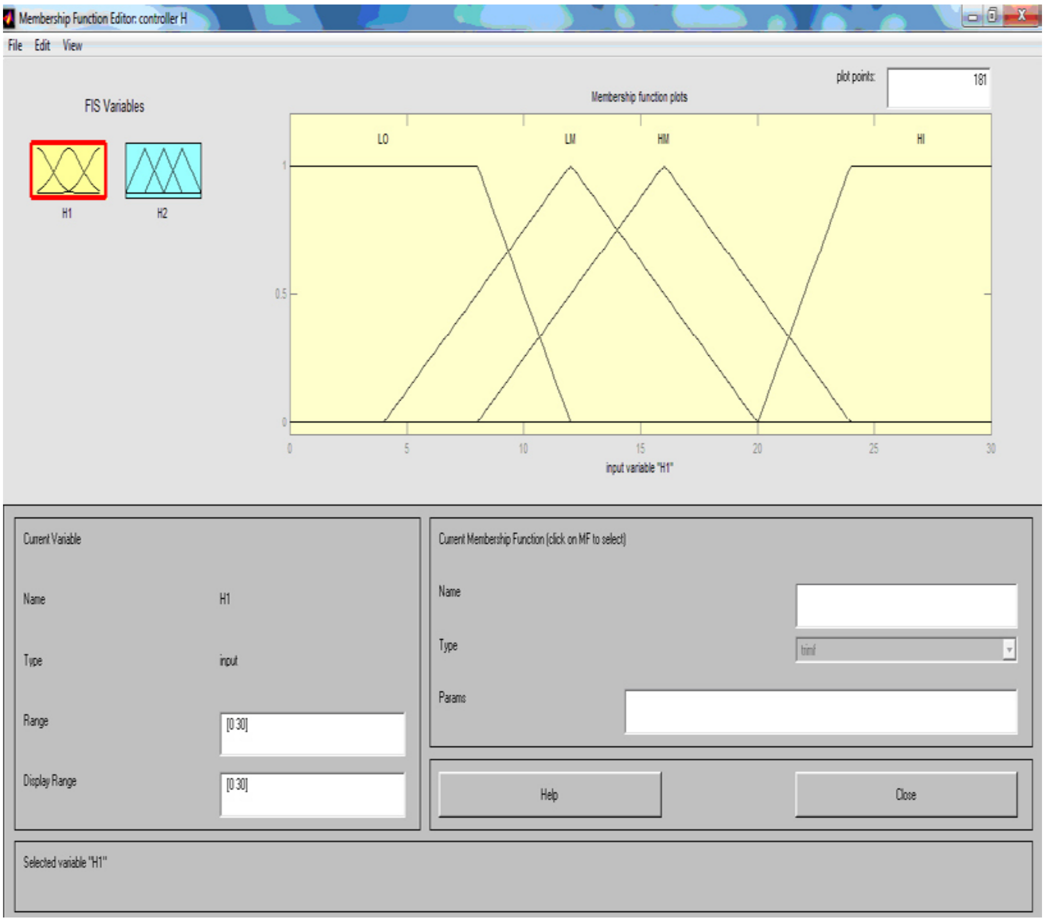


Fig. 3. Partitioning of the $H_1$ universes of discourse.

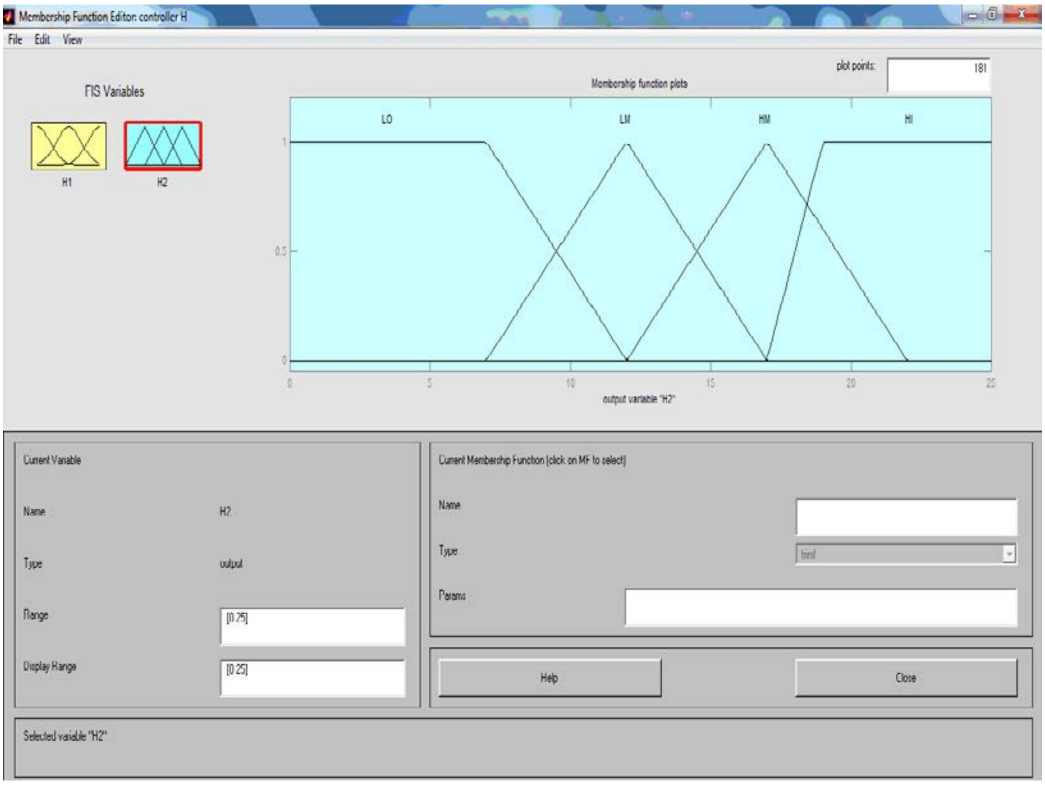


Fig. 4. Partitioning of the $H_2$ universes of discourse.

Accordind to pump specifications the rated head (corresponding to maximum efficiency) is $H_1$=17m. The correspondent of this value in Fig. 4 gives the membership values for the LM and HM fuzzy sets of $\mu_{LM}$=0.36 and $\mu_{HM}$=0.87.

The logic sentence is:

| IF | $H_1$ | THEN | $H_2$ | μ | CONCLUSION |
|---|---|---|---|---|---|
| | HM | | LM | 0.87 | 0.87LM |
| | LM | | HM | 0.36 | 0.36HM |

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

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

TABLE II.
RULE BASE FOR $H_1 - H_2$ RELATIONSHIP

| $H_1$ | LO | LM | HM | HI |
|---|---|---|---|---|
| $H_2$ | HI | HM | LM | LO |

where:

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

The first controller is shown in Fig. 5.

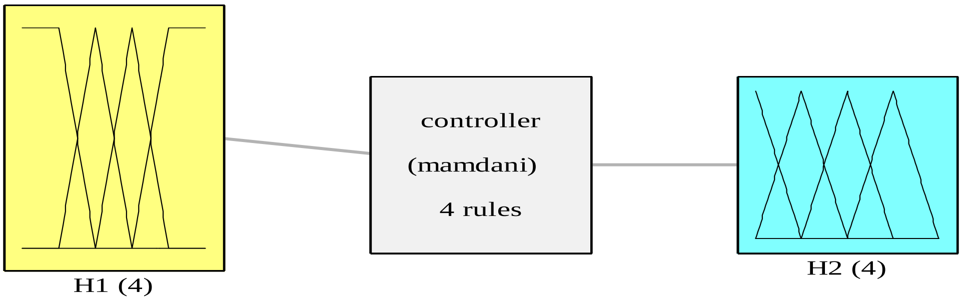


Fig. 5. Head of pump controller.

The membership functions for input and output are triangular; the min-max method inference engine is used and the defuzzify method used in these FLCs is centroid.

The conclusion is illustrated in Fig. 6 and Fig. 7.

Next, determine the frequency corresponding to H=13.8m. H and f can be partitioned into five fuzzy sets each, as is illustrated in Fig. 7 and Fig. 8.

The corresponding rule base reflecting opposite tendencies in $H_1$ and $H_2$ is shown in Table 3.

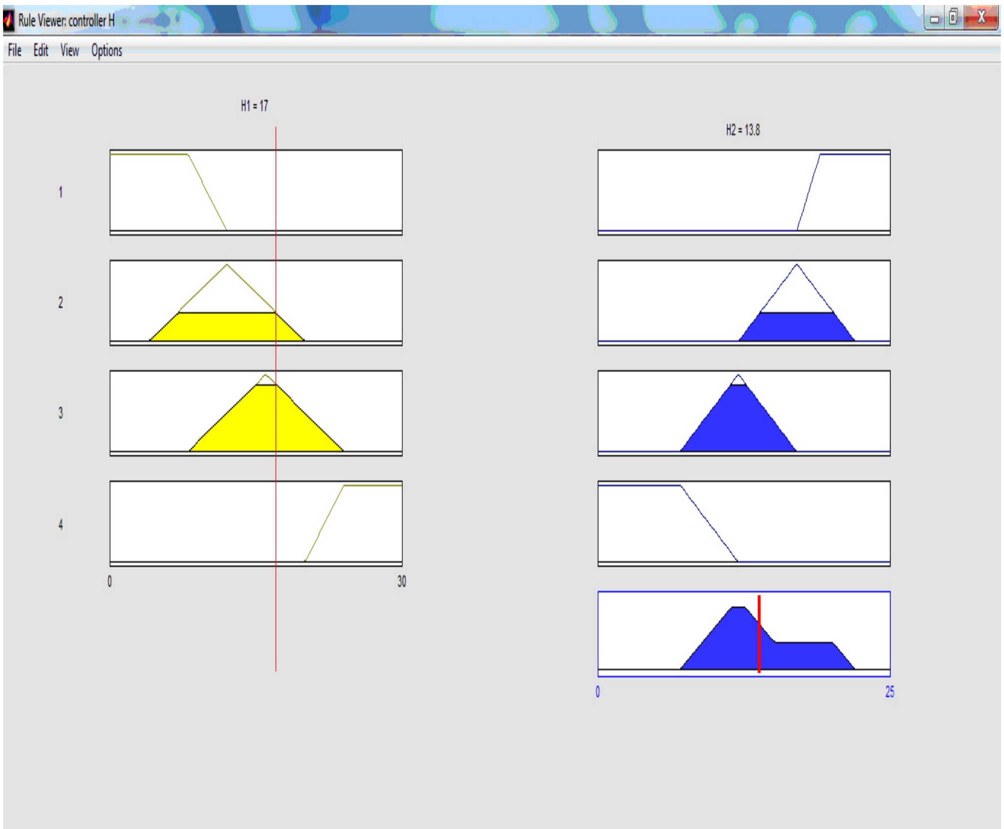


Fig. 6. Final output of H for H1=13.8 m.

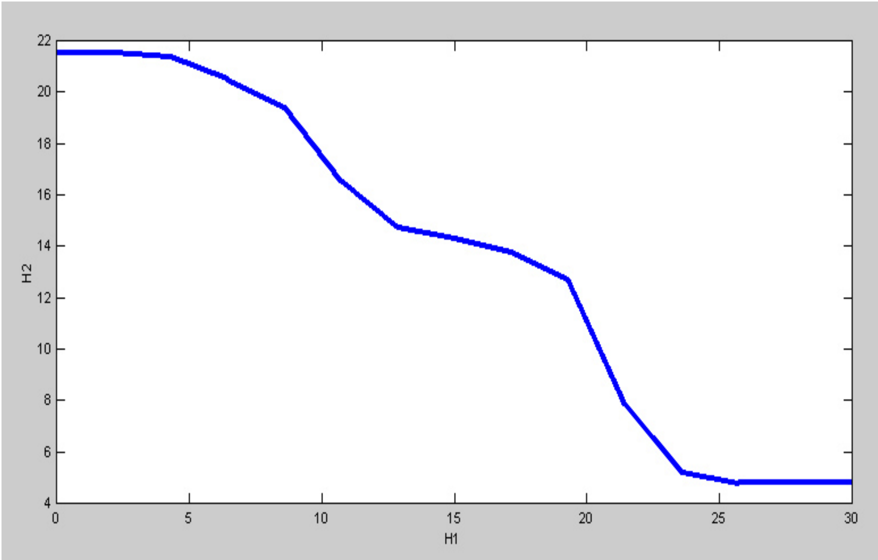


Fig. 7. The first control surface.

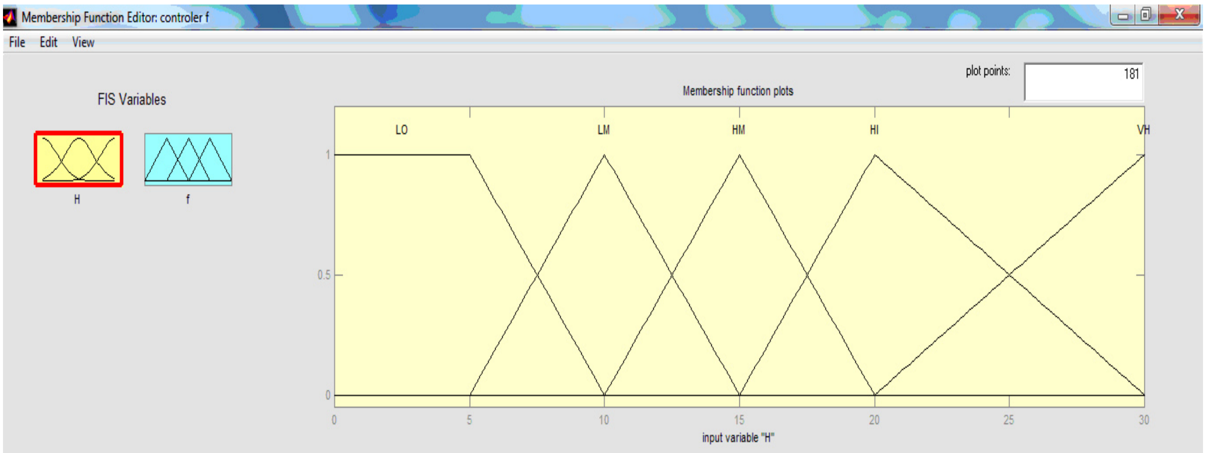


Fig. 8. Partitioning of the H universes of discourse.

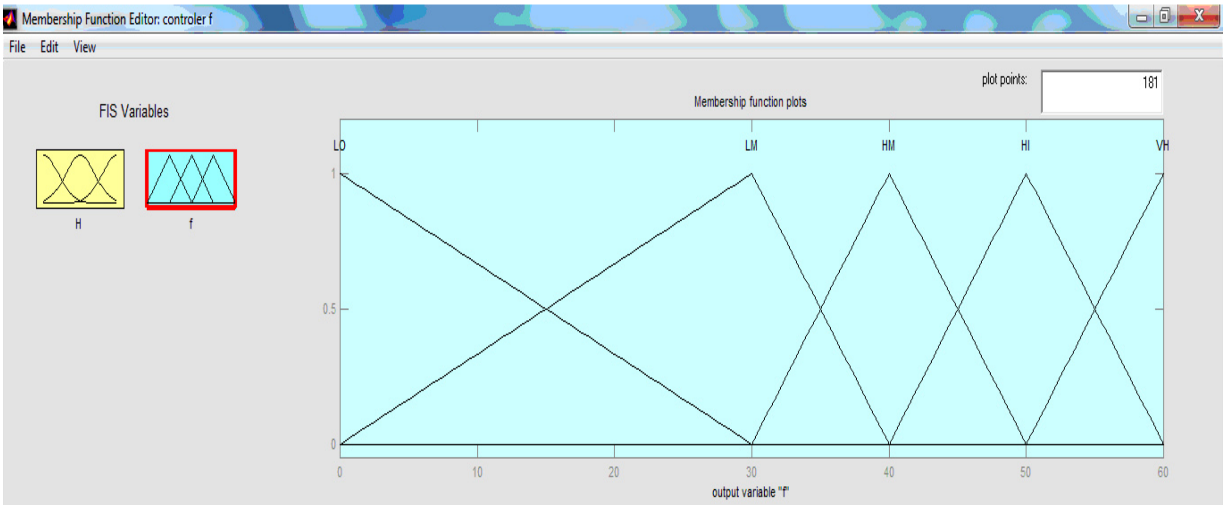


Fig. 9. Partitioning of the f universes of discourse.

TABLE III.
RULE BASE FOR $H-F$ RELATIONSHIP

| | | | | |
|---|---|---|---|---|
| H | LO | LM | HM | HI |
| f | LM | HM | HI | VH |

The second controller is presented in Fig.10. The conclusion is illustrated in Fig.11 and Fig.12.

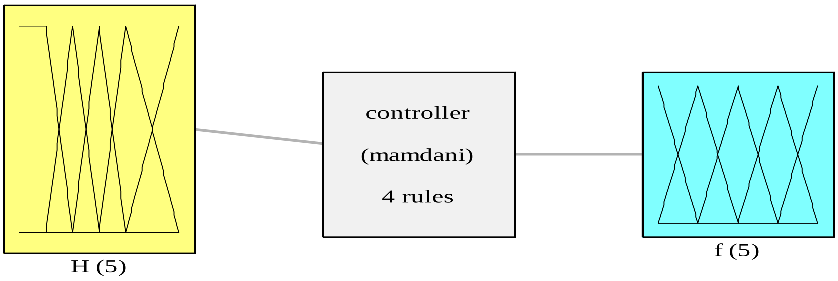


Fig. 10. The frequency controller.

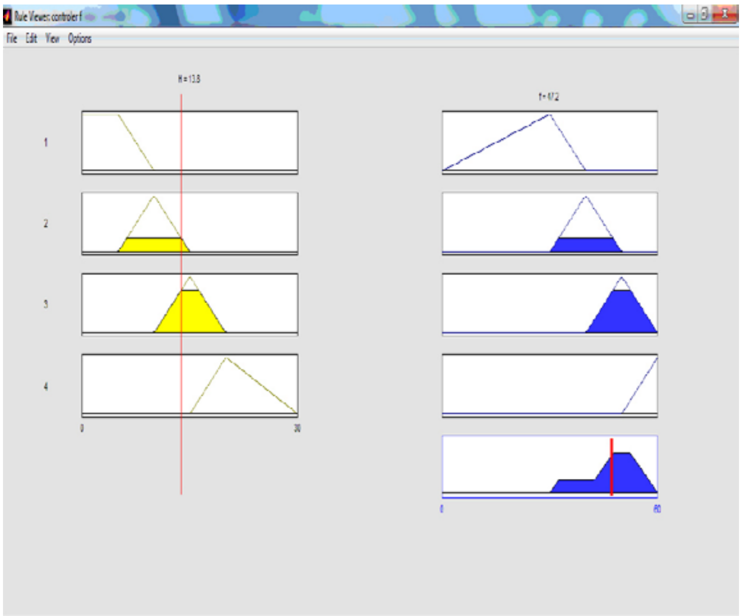

Fig. 11. Final output of f: f=47,2Hz H2=13,8m.

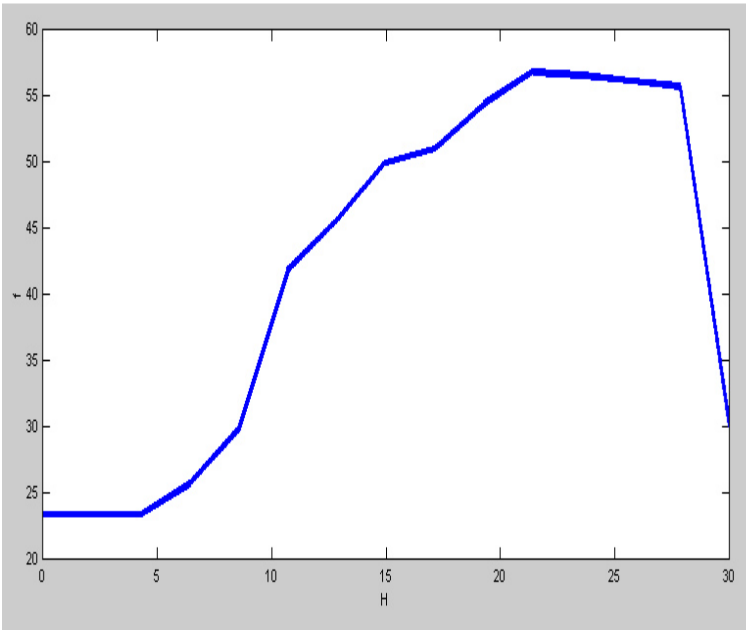


Fig. 12. The second control surface.

Comparing this value to that date of Affinity Law, $f_g$=37.5Hz, it is found that the difference is great, and the 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.

## IV. CONCLUSIONS

An optimization method for the operation of cooling system is achieved by fuzzy control system. The fuzzy control system determines a required water ratio precisely to regulate the pressure instead of using trials for adjusting the water ratio when applying conventional control.

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. 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.

The fuzzy logic control means: accuracy of pressure control and saves energy.

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