Fuzzy Logic-Based Optimization Of Inductance Active Filters: A Simulation Approach

[1]Rafiya Begum, [2]Zakeer Husain, [3]S.V. Halse
[1]Selection Grade Lecturer, [2]Selection Grade Lecturer, [3]Professor
[1, 2]Department of Electrical & Electronics Engineering, Department of Electronics & Communication Engineering
[1, 2] Goverment Polytechnic Bijapur, [3]Karnataka State Women's University Bijapur, Karnataka, India

Abstract:

This paper presents the application of fuzzy logic in the simulation and optimization of an inductance-based active filter. Fuzzy logic provides a form of knowledge representation suitable for concepts that cannot be precisely defined but are context-dependent. Unlike traditional mathematical modeling, fuzzy logic employs a problem-solving control methodology based on a simple rule-based **IF-THEN** approach, leveraging empirical knowledge rather than complex system equations. The proposed fuzzy logic-based simulation optimizes the inductance value by incorporating expert knowledge, enabling approximate labeling of component values in a circuit designed around an operational amplifier. This method enhances the efficiency of inductance-based active filters, making them highly useful in industrial applications where precise tuning of inductance is required. The simulation results demonstrate the effectiveness of the fuzzy logic approach in improving filter performance, offering a flexible and intelligent alternative to conventional optimization techniques.

Index Terms - Fuzzy Logic, Inductance Simulation, Active Filter, Optimization, Operational Amplifier.

I. Introduction

Designing active filters is fundamentally based on the simulation of an LC ladder realization of the filter. The starting point for simulation methods is an LC ladder prototype, which is typically derived using computational techniques. The low sensitivity performance of LC ladders, combined with the extensive research accumulated in the field of passive LC filter design, has provided strong motivation to develop methods for designing active filters by simulating passive LC ladder prototypes.

One of the simplest and most conceptually intuitive approaches for achieving this is the **component simulation method**, where ladder inductors are replaced by simulated inductance. Among the various circuits developed for inductance simulation, the **autonomous circuit** stands out as an efficient inductance simulator or a generalized inductance converter, typically utilizing two operational amplifiers. While numerous floating inductor simulation circuits have been proposed in the literature, practical viability remains a challenge, necessitating the invention of alternative techniques for simulating these classes of filters.

The **component simulation approach** has found widespread applications, particularly in filters with stringent specifications. It is particularly well-suited for **high-pass filters** and a specific class of **band-pass filters** that do not require floating inductors. This approach has also been instrumental in alternative filter design techniques based on the operational simulation of LC ladders.

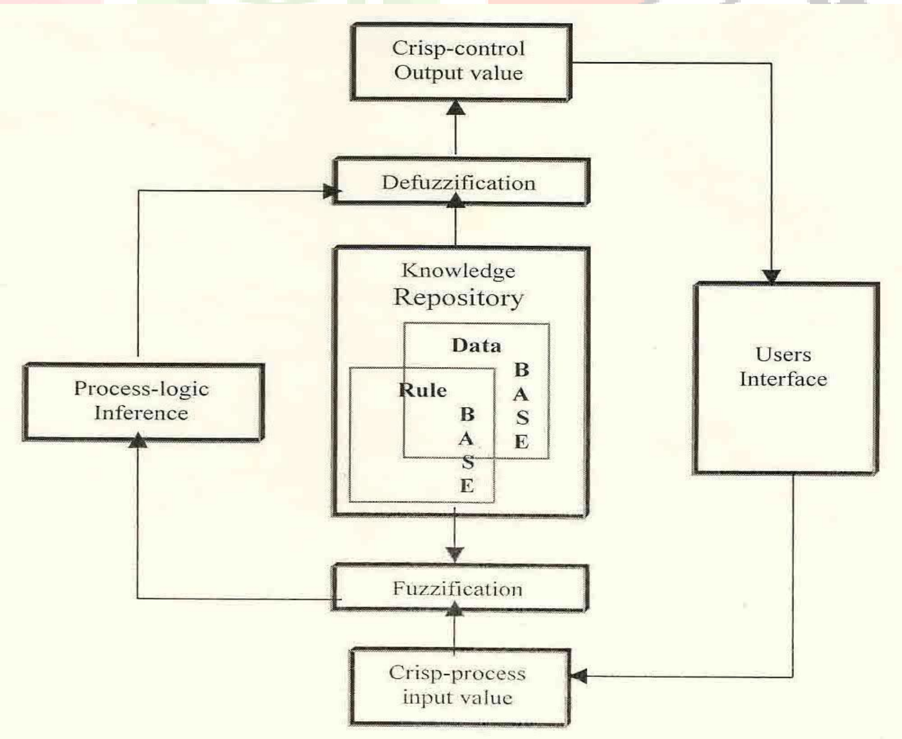
In this paper, we propose a **fuzzy logic-based simulation of inductance** that integrates expert knowledge in optimizing the inductance value. This method enables approximate labeling of component values within a circuit designed around an operational amplifier, allowing for enhanced precision and adaptability in inductance-based active filter design. The proposed approach leverages **fuzzy logic control principles** to refine inductance simulation, improving performance and adaptability in industrial applications where active filters play a crucial role.

II. Development

Inductance design requires precise numerical information regarding specifications, along with other relevant parameters, making the conventional design approach complex and time-consuming. To address these challenges, we propose **Fuzzy Logic Simulation of Inductance (FLIS)**—a novel approach that overcomes these constraints by allowing the use of **linguistic values** for inductance specifications. This method enhances flexibility in inductance optimization and simplifies the design process for **inductance-based active filters**. The general schematic of **FLIS** is illustrated in **Figure 1**, and its development involves multiple key phases. A **fuzzy logic controller** consists of four primary stages: **fuzzification, knowledge base, inference mechanism, and defuzzification**. Fuzzification converts crisp input values into fuzzy values using membership functions. The **knowledge base**, composed of a **database** (input and output membership functions) and a **rule base**, ensures optimal performance under uncertainty in process parameters and external disturbances. The **inference mechanism** applies a set of **linguistic rules** to transform input conditions into fuzzy outputs. Finally, **defuzzification** converts fuzzy outputs into precise control signals, which optimize the inductance value in the active filter circuit. By integrating **fuzzy logic control** into **inductance active filter design**, the proposed **FLIS** method enhances performance, improves adaptability, and simplifies inductance tuning without the need for extensive mathematical modeling. This approach ensures efficient inductance simulation, making it highly beneficial for industrial applications where **optimized active filters** play a critical role.

III. Fuzzification

First, the input and output variables involved in each step of the design algorithm must be identified along with their acceptable ranges. Among these, the variables suitable for fuzzification are selected and assigned meaningful **linguistic values**. The fuzzification process involves converting crisp (point-wise) values into **fuzzy sets** using appropriate **membership functions** within their respective practical domains. These fuzzy sets are labeled as **NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), and PL (Positive Large)**. These linguistic variables enable more flexible and adaptive control of inductance values in the simulation process. The fuzzification of **desirable inductance values** and the required **hardware resistance** are illustrated in **Figures 2a and 2b**, demonstrating how fuzzy logic enhances the optimization and implementation of inductance in active filter circuits.



IV. Knowledge Representation

The knowledge relevant to **inductance design** is formulated into **fuzzy inference rules**, which are supported by a **knowledge base**. This knowledge base comprises two key components: a **database** and a **rule base**.

Database:

The **database** provides essential information to the **fuzzification, rule base, and defuzzification** modules. This information includes **membership functions**, which define the **linguistic values** of input and output variables, along with their **labels, shapes, slopes, and domain ranges**.

For example, typical **membership functions** for input variables such as **core area (a)** can be defined as follows:

For Inductance (L):

- **NL (Negative Large):** µNL(L) = L(L, 0.1, 0.3)
- **NM (Negative Medium):** µNM(L) = Λ(L, 0.1, 0.3, 0.45)
- **NS (Negative Small):** µNS(L) = Λ(L, 0.3, 0.45, 0.5)
- **Z (Zero):** µZ(L) = Λ(L, 0.45, 0.5, 0.55)
- **PS (Positive Small):** µPS(L) = Λ(L, 0.5, 0.55, 0.7)
- **PM (Positive Medium):** µPM(L) = Λ(L, 0.55, 0.7, 0.9)
- **PL (Positive Large):** µPL(L) = Ʈ(L, 0.7, 0.9)

For Resistance (R):

- **NL (Negative Large):** µNL(R) = L(R, 0.1, 0.173)
- **NM (Negative Medium):** µNM(R) = Λ(R, 0.1, 0.173, 0.212)
- **NS (Negative Small):** µNS(R) = Λ(R, 0.173, 0.212, 0.224)
- **Z (Zero):** µZ(R) = Λ(R, 0.212, 0.224, 0.235)
- **PS (Positive Small):** µPS(R) = Λ(R, 0.224, 0.235, 0.265)
- **PM (Positive Medium):** µPM(R) = Λ(R, 0.235, 0.265, 0.3)
- **PL (Positive Large):** µPL(R) = Ʈ(R, 0.265, 0.3)

The **membership functions for inductance** are generated immediately after selecting a likely inductance value, followed by **membership functions for resistance**. The **user can modify these membership functions** to fine-tune the design data and achieve optimal results.

Rule Base:

The **rule base** represents the **design policy** of an **experienced inductance designer** in a structured form using a set of **fuzzy logic inference rules**. These rules define the relationship between **input and output variables** and help optimize the inductance simulation process in **active filter circuits**.

Rule 1	IF Inductance is NL	THEN Resistance is NL
Rule 2	IF Inductance is NM	THEN Resistance is NM
Rule 3	Inductance is NS	THEN Resistance is NS
Rule 4	Inductance is Z	THEN Resistance is Z
Rule 5	Inductance is PS	THEN Resistance is PS
Rule 6	Inductance is PM	THEN Resistance is PM
Rule 7	Inductance is PL	THEN Resistance is PL

Typical rules are given in table-1

These **fuzzy logic rules** are incorporated using **fuzzy set theory** and **fuzzy logic principles**. The **user has the flexibility to modify the rule base**, allowing customization according to specific design requirements. For every incoming **numeric value of inductance**, the **Fuzzy Logic Simulation of Inductance (FLIS)** enters the **fuzzy inference process**, ensuring accurate inductance estimation.

Process Inference Logic

The **FLIS employs a Mamdani-type** individual rule-based **fuzzy logic inference system** [5-6]. In this approach, each **fuzzy logic rule** is **evaluated separately**, contributing to the overall decision-making process. The primary objective of **fuzzy inference** is to compute a final **design outcome** based on the cumulative effect of all rules within the **rule base**.

During the **inference process**, each rule is **activated (fired)** by the **crisp input values** obtained from the **fuzzification module**. These crisp values are then mapped to their corresponding **fuzzy sets**, which represent the **overall fuzzy output variable** at the specific stage of the **inductance design process**. The result is a **clipped fuzzy set**, which refines the **inductance estimation**, ensuring precise and adaptive design parameters.

I. DEFUZZIFICATION PROCESS

The **final step in the development of the Fuzzy Logic Simulation of Inductance (FLIS)** is **defuzzification**, which aims to derive a **compromise crisp value** from all the **clipped fuzzy sets** representing the overall **fuzzy output variable**. This step is essential in translating the **fuzzy logic decisions** into **real-world numerical values** that can be applied to the **inductance design process**.

Several **defuzzification methods** exist, but FLIS employs the **Height-Defuzzification (HD) method** [7] due to its **simplicity and computational efficiency**. The **crisp output value u∗u^*** is determined using the formula:

u∗=∑r=1qPk(r)·h(r)∑r=1qh(r)u^* = \frac{\sum_{r=1}^{q} P_k(r) \cdot h(r)}{\sum_{r=1}^{q} h(r)} where:

$$u^* = \frac{\sum_{r=1}^{q} P_k(r) \cdot h(r)}{\sum_{r=1}^{q} h(r)}$$

- qq = **number of rules fired**
- Pk(r)P_k(r) = **peak value of the rthr^{th} clipped fuzzy set**
- h(r)h(r) = **height of the rthr^{th} clipped fuzzy set**

The **resulting defuzzified output** either **triggers the next step** in the design process or **represents the intermediate/final design result**.

Performance Validation

To validate the effectiveness of FLIS, **simulated and expected values** of inductance were analyzed for **two different frequencies**, as summarized in **Table 2**. The comparison highlights the **accuracy and efficiency** of the FLIS-based approach in **inductance design optimization**.

Frequency (KHz)	Inductance Expected (H)	Inductance Simulated
2.0	0.633	0.645
4.0	0.158	0.165

Table 2: Expected and simulated values of inductance.

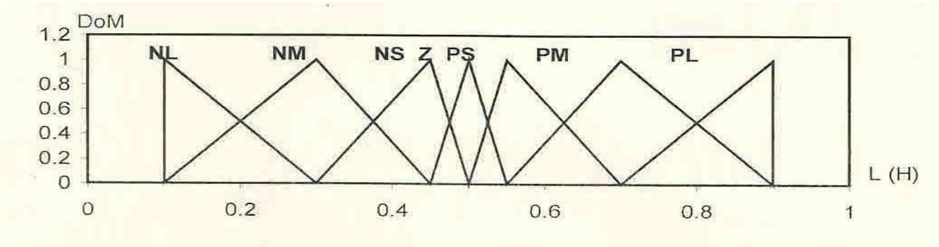


Fig.1 Block Diagram of fuzzy Logic Inductance Simulation System

V. CONCLUSION

The primary objective of developing the **Fuzzy Logic Inductance Simulation (FLIS)** is to accommodate **linguistic terms** and **human reasoning** in the design of inductance circuits. The testing and implementation of FLIS have demonstrated that the **fuzzy logic-based technique** allows inductance designers to **estimate approximate values, make assumptions**, and **use imprecise specifications** during the initial stages. This approach enables designers to refine the inductance value through **iterative adjustments**, ultimately yielding **optimal final results**.

The fuzzy approach not only facilitates the incorporation of **practical experience** into the design process but also relies on a **rule-based system** to guide decision-making. The effectiveness of FLIS largely depends on the **design of membership functions** and the development of **IF-THEN rules** that accurately reflect the designer's reasoning process.

At this preliminary stage, FLIS operates with **minimal input data** and has successfully produced **initial simulation results**. Further advancements in membership function design and rule-based algorithms will enhance the system's performance and broaden its application in **inductance-based active filter circuits**.

REFERENCES

[1] S.Franco, Design with operational amplifiers and anal integrated circuits, MC Graw Hill, New York, 1998.

[2] S.K.Biswa simplified Design of coils electronics for you New Delhi pp 19-21, Jan. 1984

[3] S.K.Biswas Simplified Design of Chokes, Electronics for you delhi pp 25-27 Sept 1982

[4] R.R.Mudholkar, S.R.Sawant, Fuzzy Logic Transformer Build Estimation Transaction on Industrial Electronics IEEE, 2001

[5] R.R.Mdholkar,S.R.Sawant, G.G.Tengshe and A.B.Bagwan, Fuzzy logic Transformer build estimation , Transaction on industrial Electronics IEEE, 2001

[6] E.Cox The Fuzzy Systems Handbook A practioners Guide to building, using and maintaining fuzzy systems. AP professional, Boston pp 45 – 469, 1998.