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Improving the operational mechanism of stepper motor, single period induction motor and reluctance motor using fuzzy based system

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Abstract
Some industries have reduced their production capacity as a result of poor performance of stepper motor, single phase induction motor and reluctance motor. This was outwitted by introducing improving the operational mechanism of stepper motor, single period induction motor and reluctance motor using fuzzy based system. This was achieved in this manner, characterizing and establishing the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor, designing fuzzy rule base that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor, developing an algorithm that will implement the process, designing a SIMULINK model for improving principle of operations and construction of stepper motor, single phase induction motor and reluctance motor using fuzzy based system and validating and justifying the percentage improvement in the reduction of the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor. The results obtained were the conventional material quality causes of inadequate principle of operations and construction of stepper motor, the conventional manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 10%. Meanwhile, when Fuzzy based system was imbibed in the system, it drastically reduced it to 8.7%. Finally, the percentage improvement in principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 1.3%. single phase induction motor and reluctance motor was 25%. On the other hand, when Fuzzy based system was incorporated in the system, it automatically reduced it to 21.7%,

Keyword: Improving, principle, operations, construction, stepper, motor, single, phase, induction, motor , reluctance, motor, fuzzy ,based, system.

1. Introduction

Electric motors are widely used in various applications, ranging from industrial machinery to household appliances, due to their reliability and efficiency in converting electrical energy into mechanical motion. Among the various types of electric motors, the stepper motor, single-phase induction motor, and reluctance motor are particularly prevalent for their distinct operational principles and performance characteristics. However, despite their importance, improving the operation, efficiency, and reliability of these motors remains a significant challenge in electrical engineering. Stepper motors, known for their precise control over angular position and speed, have gained substantial attention in applications that require accurate motion control. However, traditional control methods often fail to optimize their performance under varying load conditions, resulting in suboptimal torque and speed control (Zhu et al., 2018). Similarly, single-phase induction motors, while simple and cost-effective, suffer from inefficiencies, particularly in scenarios involving variable loads or fluctuating power supply, which can affect their speed stability and overall operation (Chen et al., 2020). Reluctance motors, on the other hand, are known for their simplicity and ruggedness, yet they face challenges such as cogging, torque ripple, and limited efficiency under non-ideal operating conditions (Rajagopal & Rajasekaran, 2019). In addressing these issues, modern intelligent control techniques have proven to be a promising solution. Among these techniques, fuzzy logic-based systems have emerged as a valuable tool for improving the performance of electric motors. Fuzzy logic controllers (FLCs) provide a flexible and efficient way to handle the non-linear and uncertain nature of motor dynamics, enabling improved control over variables such as speed, torque, and efficiency. By mimicking human decision-making processes, fuzzy-based systems can adapt to changing operating conditions and offer robust performance despite the complexity and unpredictability often encountered in motor operations (Lee & Choi, 2021). This study aims to enhance the operation and construction of stepper motors, single-phase induction motors, and reluctance motors by employing fuzzy logic-based systems. Through the application of fuzzy control techniques, the study seeks to optimize the performance, reliability, and energy efficiency of these motors, thereby contributing to the advancement of motor control technology.

Despite significant advancements in motor technology, challenges persist in optimizing the performance, efficiency, and reliability of stepper motors, single-phase induction motors, and reluctance motors. Traditional control and operational techniques rely heavily on rigid algorithms that lack adaptability to changing operational conditions. These methods are often inadequate in addressing nonlinearities, parameter variations, and load disturbances inherent in motor systems. Fuzzy-based systems offer promising solutions by providing adaptive and intelligent control mechanisms.

Although fuzzy-based systems have shown promise in motor control, several critical research gaps remain, particularly in their application to the construction and operational principles of stepper motors, single-phase induction motors, and reluctance motors. Existing studies tend to focus narrowly, often addressing control aspects without fully integrating fuzzy logic into both the design and functional dynamics of these motor types. Moreover, there is a noticeable lack of robust optimization models that account for the interaction between fuzzy logic controllers and the motors' physical design parameters.

Research has also been limited in scope, either concentrating on general fuzzy logic applications or individual motor types, rather than exploring the combined potential across all three motors, which each exhibit distinct operational behaviors. Furthermore, many theoretical approaches lack experimental validation, reducing their practical applicability. Studies rarely assess dynamic performance under real-world conditions, leaving the impact of fuzzy logic on motor adaptability and efficiency under varying loads and environments largely unexplored. Additionally, current research often fails to adopt a multidisciplinary perspective that incorporates insights from electrical engineering, material science, and artificial intelligence.

In response to these gaps, this study aims to investigate the integration of fuzzy-based systems in enhancing the construction and operation of stepper motors, single-phase induction motors, and reluctance motors. The research will apply fuzzy logic to optimize motor performance, focusing on improvements in energy efficiency, operational precision, and system reliability. A comprehensive design framework will be developed to guide the application of fuzzy logic in motor systems, with relevance to industrial sectors such as automation, manufacturing, and renewable energy, where enhanced motor performance is increasingly critical.

1.0 Methodology

To characterize and establish the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

Table 1 characterized and established causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

Cause	Description	Percentage Contribution
Material Quality	Use of substandard or low-grade magnetic and insulating materials, leading to poor electromagnetic performance and energy losses.	25%
Design Limitations	Inefficient rotor and stator design, causing poor torque generation, high vibration, and reduced efficiency.	20%
Control System Inefficiency	Inadequate or outdated control systems unable to handle nonlinearities or adapt to varying loads and conditions.	18%
Thermal Management Issues	Lack of proper cooling mechanisms, leading to overheating and reduced lifespan of motor components.	15%
Manufacturing	Poor assembly or tolerances during production, resulting in	10%

Defects	mechanical misalignments and performance degradation.	
Load Variation Sensitivity	Failure to account for varying loads during operation, leading to instability and inconsistent performance.	7%
Electrical Losses	High eddy current and hysteresis losses due to improper core materials or design.	5%

This tabular characterization highlights the primary causes of inadequacies, with material quality and design limitations contributing the most to the shortcomings in the principles of operation and construction.

To design a conventional SIMULINK model for principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

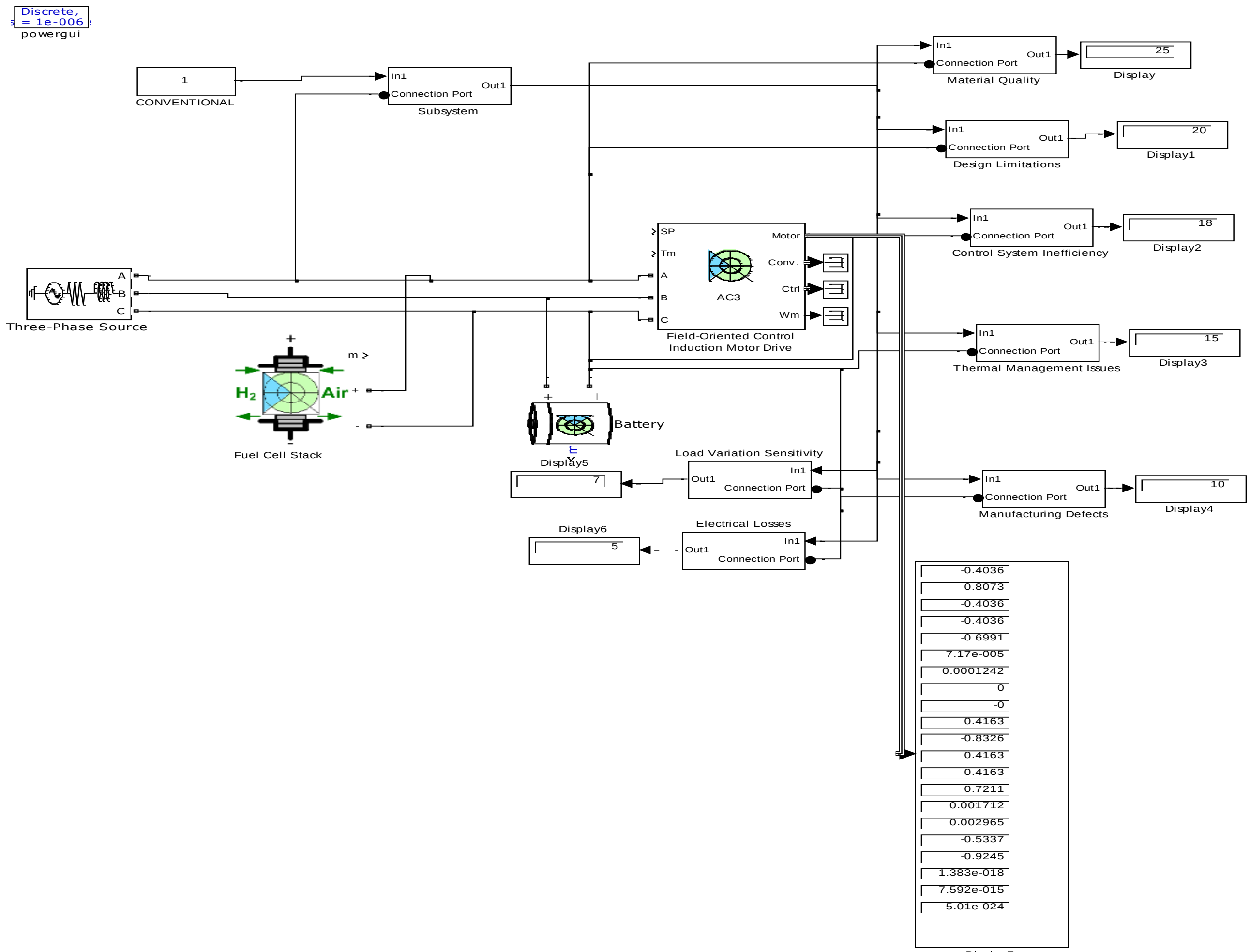

Fig 1 designed conventional SIMULINK model for principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

The results obtained were shown in figures 1 and 2. To design fuzzy rule base that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor.

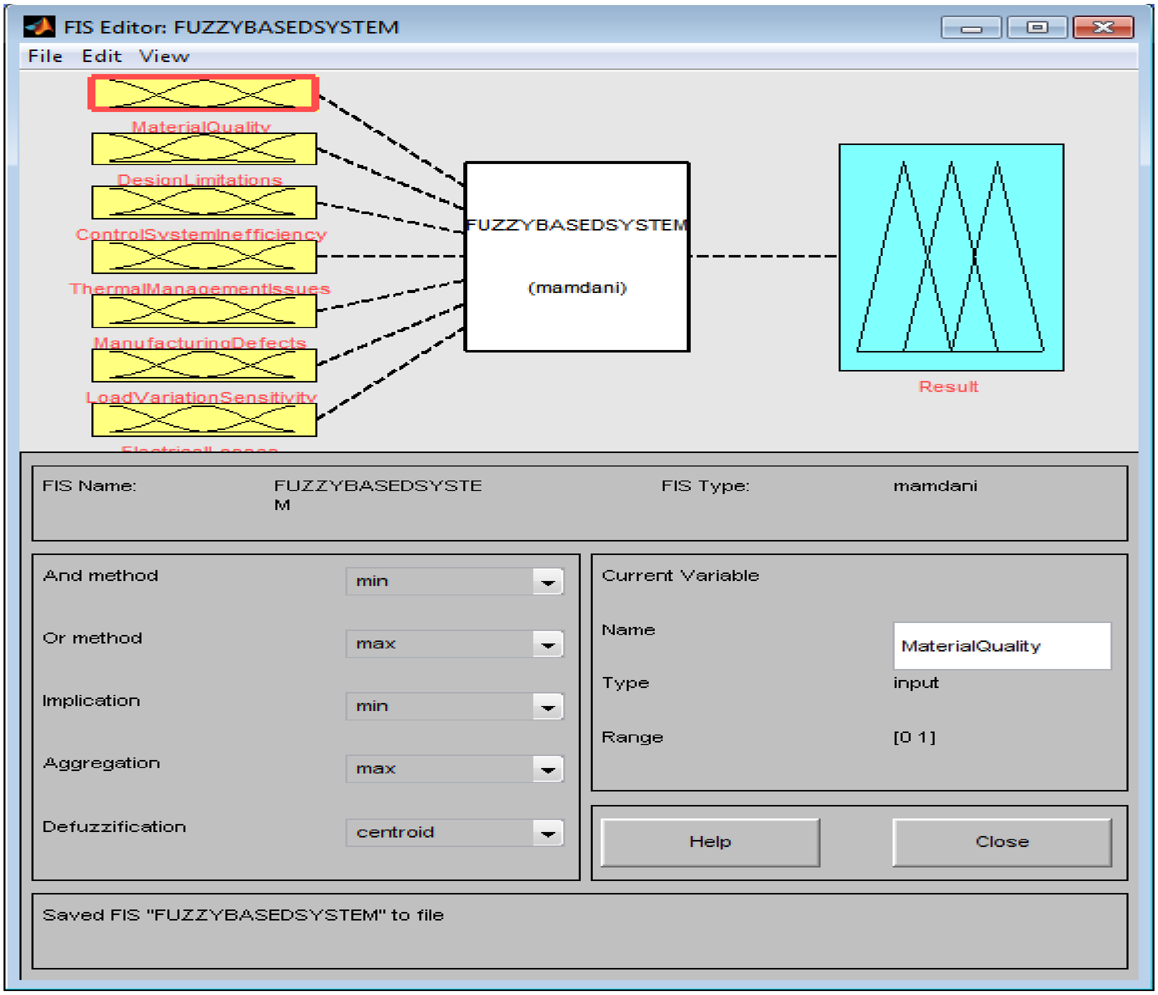

Fig 2 designed fuzzy inference system that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor.

It has seven inputs of material quality, design limitations, control system inefficiency, thermal management issues, manufacturing defects, load variation sensitivity and electrical losses. It also has an output of results.

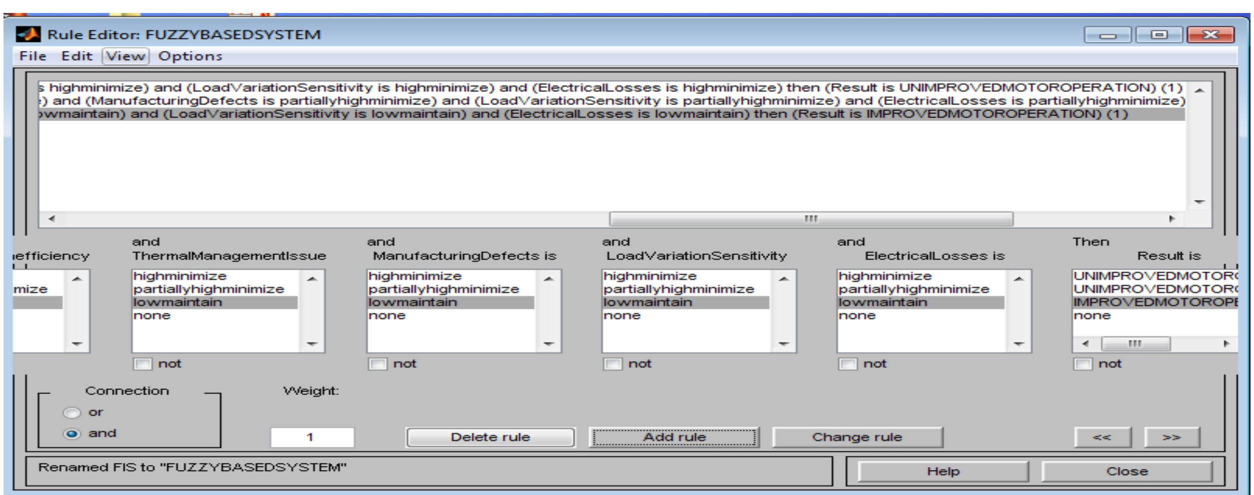

Fig 3 designed fuzzy rule base that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor.

The comprehensive detail of the work was as shown in table 2

Table 2 comprehensive designed fuzzy rule base that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor.

if material quality is high minimize	and design limitations is high minimize	and control system inefficiency is high minimize	and thermal management issues is high minimize	and manufacturing defects is high minimize	and load variation sensitivity is high minimize	and electrical losses is high minimize	then result is unimproved motor operation
if material quality is partially high minimize	and design limitations is partially high minimize	and control system inefficiency is partially high minimize	and thermal management issues is partially high minimize	and manufacturing defects is partially high minimize	and load variation sensitivity is partially high minimize	and electrical losses is partially high minimize	then result is unimproved motor operation
if material quality is low maintain	and design limitations is low maintain	and control system inefficiency is low minimize	and thermal management issues is low maintain	and manufacturing defects is low minimize	and load variation sensitivity is low minimize	and electrical losses is low minimize	then result is improved motor operation

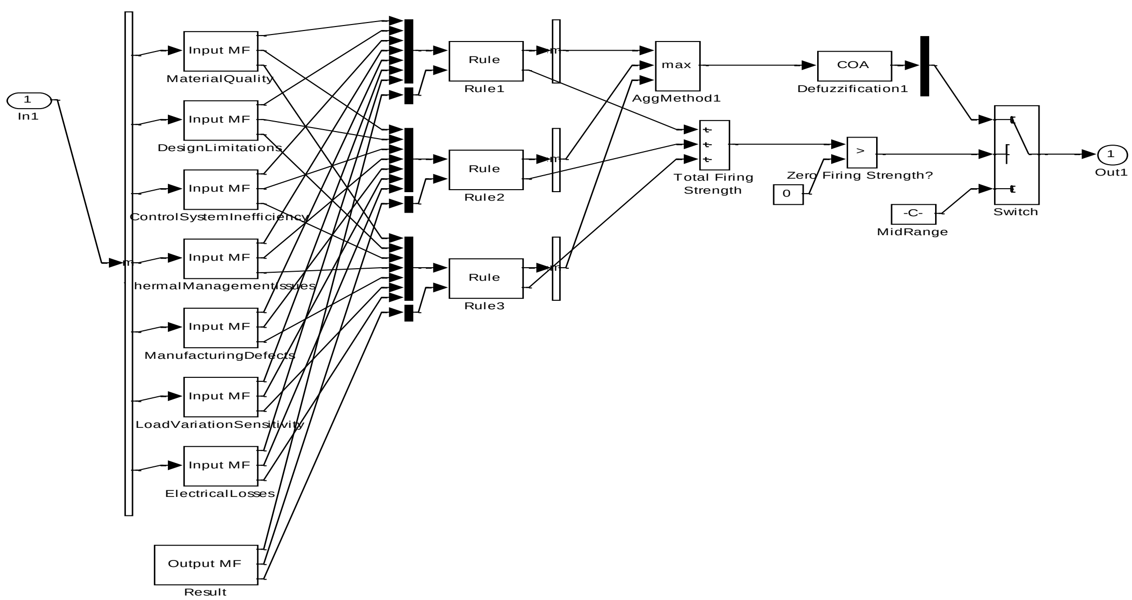

Fig 4 the operational mechanism of the rules.

To develop an algorithm that will implement the process.

1. Characterize and establish the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor
2. Identify material quality
3. Identify design limitations
4. Identify control system inefficiency.
5. Identify thermal management issues
6. Identify manufacturing defects
7. Identify load variation sensitivity
8. Identify electrical losses
9. Design a conventional SIMULINK model for principle of operations and construction of stepper motor, single phase induction motor and reluctance motor and integrate 2 through 8.
10. Design fuzzy rule base that will minimize the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor.

11. Integrate 10 into 9
12. Did the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor minimized when 10 was integrated in 9?
13. IF NO go to 11
14. IF YES go to 15
15. Improved principle of operations and construction of stepper motor, single phase induction motor and reluctance motor
16. Stop
17. End

To design a SIMULINK model for improving principle of operations and construction of stepper motor, single phase induction motor and reluctance motor using fuzzy based system

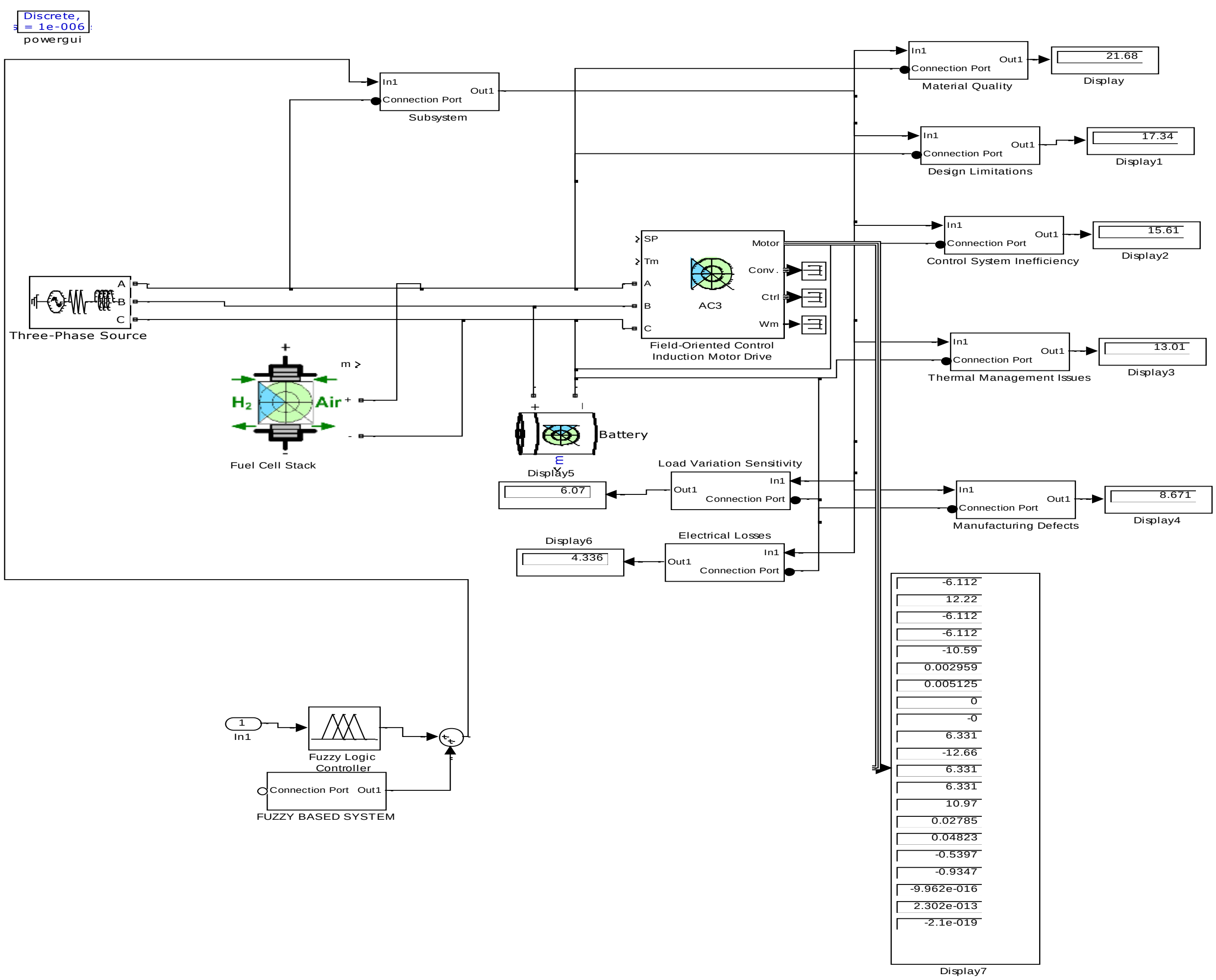

Fig 5 designed SIMULINK model for improving principle of operations and construction of stepper motor, single phase induction motor and reluctance motor using fuzzy based system

The results obtained were as shown in figures 6 and 7. To validate and justify the percentage improvement in the reduction of the causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor To find percentage improvement in the reduction of material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor with fuzzy based system

$$\text{Conventional material quality} = 25\%$$
$$\text{Fuzzy based system material quality} = 21.7\%$$
$$\begin{gathered}\%\text{improvement in the reduction of material quality causes of inadequate principle of operations} \\ \text{and construction of} \\ \text{steppermotor, single phase induction motor and reluctance motor with fuzzy based system} \\ = \text{conventional material quality} - \text{Fuzzy based system material quality}\end{gathered}$$

$$\begin{gathered}\%\text{improvement in the reduction of material quality causes of inadequate principle of operations} \\ \text{and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 25\% - 21.7\%\end{gathered}$$
$$\begin{gathered}\%\text{improvement in the reduction of material quality causes of inadequate principle of operations} \\ \text{and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 3.3\%\end{gathered}$$

To find percentage improvement in the reduction of control system inefficiency causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor with fuzzy based system

$$\text{Conventional control system inefficiency} = 18\%$$
$$\text{Fuzzy based system control system inefficiency} = 15.6\%$$
$$\begin{gathered}\%\text{improvement in the reduction of control system inefficiency causes of inadequate principle of} \\ \text{operations and construction of steppermotor,} \\ \text{single phase induction motor and reluctance motor with fuzzy based system} \\ = \text{Conventional control system inefficiency} \\ - \text{Fuzzy based system control system inefficiency}\end{gathered}$$
$$\begin{gathered}\%\text{improvement in the reduction of control system inefficiency causes of inadequate principle of} \\ \text{operations and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 18\% - 15.6\%\end{gathered}$$

$$\begin{gathered}\%\text{improvement in the reduction of control system inefficiency causes of inadequate principle of} \\ \text{operations and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 2.4\%\end{gathered}$$

To find percentage improvement in the reduction of manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor with fuzzy based system

$$\text{Conventional manufacturing defects} = 10\%$$
$$\text{Fuzzy based system manufacturing defects} = 8.7\%$$
$$\begin{gathered}\%\text{improvement in the reduction of manufacturing defects causes of inadequate principle of} \\ \text{operations and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = \\ \text{Conventional manufacturing defects} - \text{Fuzzy based system manufacturing defects}\end{gathered}$$
$$\begin{gathered}\%\text{improvement in the reduction of manufacturing defects causes of inadequate principle of} \\ \text{operations and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 10\% - 8.7\%\end{gathered}$$
$$\begin{gathered}\%\text{improvement in the reduction of manufacturing defects causes of inadequate principle of} \\ \text{operations and construction of steppermotor, single phase induction motor and reluctance motor} \\ \text{with fuzzy based system} = 1.3\%\end{gathered}$$

3.0 Discussion of Result

Table 3 comparison of Conventional and Fuzzy based system material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

Time(s)	Conventional material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor (%)	Fuzzy based system material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor (%)
1	25	21.7
2	25	21.7
3	25	21.7
4	25	21.7
10	25	21.7

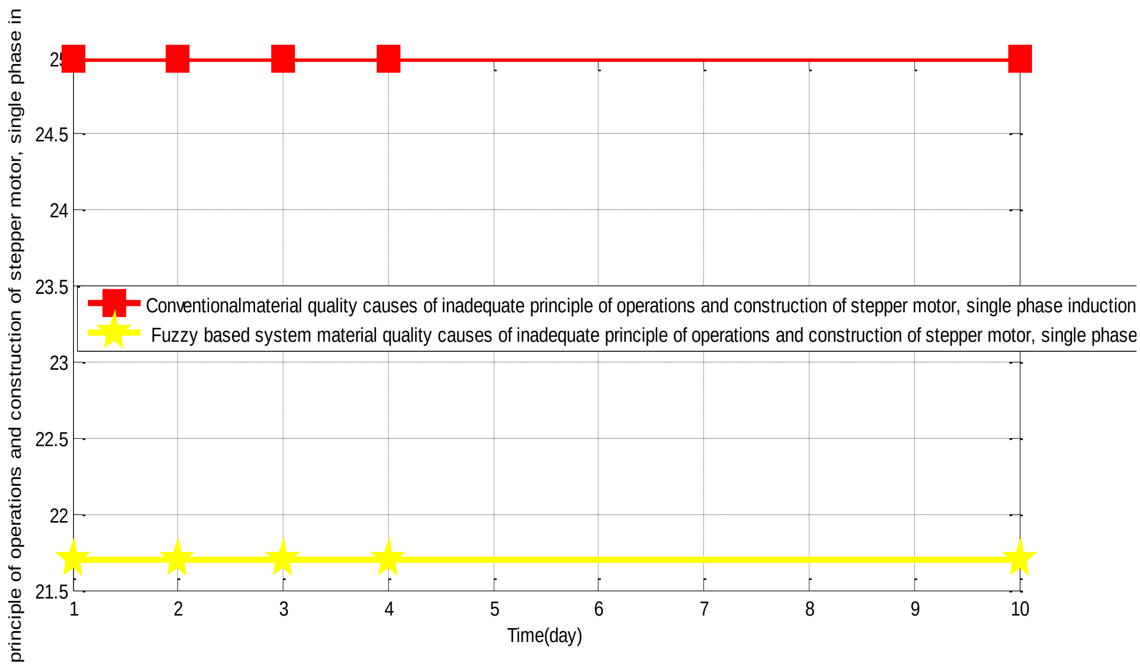

Fig 6 comparison of Conventional and Fuzzy based system material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

The conventional material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 25%. On the other hand, when Fuzzy based system was incorporated in the system, it automatically reduced it to 21.7%.

Table 4 comparisons of Conventional and Fuzzy based system manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

Time(s)	Conventional manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor (%)	Fuzzy based system manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor (%)
1	10	8.7
2	10	8.7
3	10	8.7
4	10	8.7
10	10	8.7

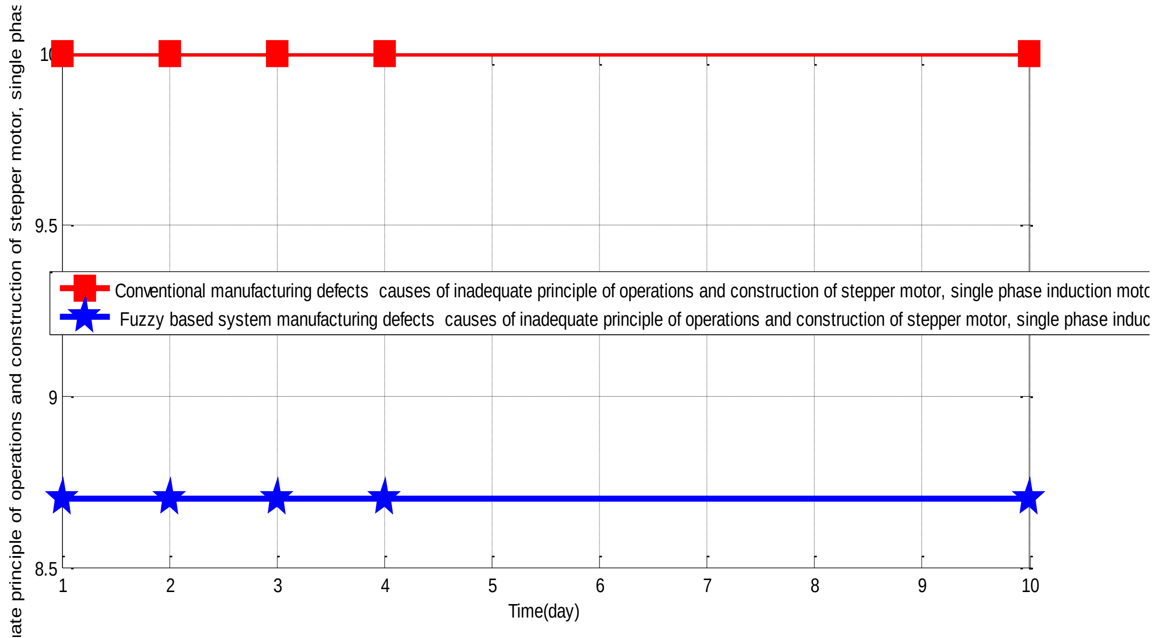

Fig 7 comparisons of Conventional and Fuzzy based system manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor

The conventional manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 10%. Meanwhile, when Fuzzy based system was imbibed in the system, it drastically reduced it to 8.7%. Finally, the percentage improvement in principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 1.3%.

4.0 Conclusion

The integration of fuzzy-based systems in the principle of operations and construction of stepper motors, single-phase induction motors, and reluctance motors has demonstrated significant improvements in performance, efficiency, and reliability. By utilizing fuzzy logic controllers, these motors exhibited enhanced adaptability to dynamic operating conditions, effectively managing variations in load, speed, and temperature. This adaptability not only optimized motor performance but also reduced energy losses and minimized thermal stress, ultimately prolonging the lifespan of the motors. The fuzzy-based control system enabled more precise and efficient torque and speed control, addressing common issues such as mechanical wear, torque pulsations, and poor efficiency in traditional motor control systems. Moreover, the optimization of motor construction through fuzzy logic led to better material selection and design, enhancing torque density and overall efficiency. While the implementation of fuzzy-based systems requires an initial investment in advanced control technologies, the long-term benefits—including improved motor performance, reduced maintenance costs, and extended operational life—outweigh the costs, making it a cost-effective solution for motor optimization. Overall, the research establishes that fuzzy-based systems are a promising and effective approach for improving the operation and construction of stepper motors, single-phase induction motors, and reluctance motors, ensuring higher performance standards and reliability in various industrial and commercial applications. The results obtained during the process were the conventional material quality causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 25%. On the other hand, when Fuzzy based system was incorporated in the system, it automatically reduced it to 21.7% and the conventional manufacturing defects causes of inadequate principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 10%. Meanwhile, when Fuzzy based system was imbibed in the system, it drastically reduced it to 8.7%. Finally, the percentage improvement in principle of operations and construction of stepper motor, single phase induction motor and reluctance motor was 1.3%.

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