International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

Performance Evaluation of Fuzzy Logic Controller's Certain Membership Functions for Control of Slip Energy Recovery Drive for Improved Power Factor

Paul B. Anyin[1*], Gregory O. Odama[2]and Franklyn C. Njoku[3]
[1]Department of Electrical and Electronics Engineering, Joseph Sarwuan Tarka University, Makurdi, Nigeria.
[2]Department of Electrical and Electronics Engineering, Cross River University Technology, Nigeria.
[3]Department of Electronics/Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

Submitted: 15-05-2022 Revised: 25-05-2022 Accepted: 28-05-2022

ABSTRACT: Recent development in advanced control systems engineering, has made great evolutions in the control of electric drive systems using smart controllers. Slip Energy Recovery Drive (SERD), as an energy recovery scheme is faced with high inrush current, and excessive reactive power drawn by the inverter and less real power returned to the ac mains, due to inefficient dc-link inverter switching capabilities which result in poor power factor. This paper is aimed at, evaluating the performance of inference systems in the standard Simulink model of both Mamdani and Sugeno based fuzzy logic controllers (FLC) in the control of the inverters and dc-link of a SERD for improved drive performance and power factor. Different built in membership functions of both inference systems were chosen for evaluation. The assessment was done using the established fuzzy rules through Matlab/Simulink model execution. The results of stator and rotor current, rotor speed and torque of the drive were compared and evaluated. The performance of both FLC inference systems (Mamdani and Sugeno) displayed their relative advantages. However, the Sugeno FIS is showed precise response at half load and full-load conditions, and at no-load, it displayed overshoots and delayed response compared with the Mamdani FIS which offers faster response without overshoot in no-load condition, and faster improved power factor in all load conditions. Thus, both Mamdani and Sugeno FIS are fit for the control of the dc-link configuration and inverter of SERD, especially for application where low inrush current, controlled reactive power and improved power factor are of great significance.

Keywords: Slip energy recovery drive, Fuzzy logic control, Mamdani model, Sugeno model, Simulink model, Power factor, dc-link, and Fast response.

I. INTRODUCTION

Control theories for industrial applications are experiencing progressive innovations in precise control process design, component sizing and improvement of existing theories [1][2], due to uncertainty of load characteristics, and variable load demands. Fuzzy Logic Control (FLC) has gained extra relevance in control system designs, due to a rational degree of it use in control system applications. Fuzzy logic systems is fast, precise and acute in response and adopts artificial intelligence in disseminating tasks, which makes it fit to overcome the drawbacks of poor switching response [3][4][5]. FLC is made up of inference systems controlled by their respective membership functions, the most used of them are the Sugeno and Mamdani inference system. The former is made up of a unique unity membership function, while the latter is characterized with different membership functions, such as; trapezoid, triangular, Gaussian and so on [4][5][6][7]. Certain control theories have disfavored or favored FLC without a clear knowledge of its membership function suitability. Such as, the performance comparison of Proportional Integrator Derivative (PID), Artificial Neural Network (ANN) and other smart controllers with FLC techniques [6][8][10][11][12][13][14][15][16][17]. Perhaps these performance comparisons were done without specifications of the inference systems used in the fuzzy logic controller [13][14][17]. A research on comparison of FLC rules for induction motor speed control revealed that, improved performance is a

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

function of accurate number of rules, choice of membership functions and best fit inference system used [9]. Hence, many designers have always considered rules precisions for improved performance applications [3][4][9]. Therefore, it is very pertinent to evaluate the control response of FLC, concerning smart response with respect to these inference systems membership functions. In this work, both Mamdani and Sugeno inference systems of FLC are compared for their performance appraisals through simulation of Matlab/Simulink models in variable load conditions, for the control of the inverter in the dc-link of Slip Energy Drive (SERD) to ascertain improved power factor.

SERD is an energy recovery scheme which recoups the slip power that exist in the slip rings of the traditional wound rotor induction motor and feeds it back to the ac mains supply, via static converters and three phase optional step-up transformer [1][18][19]. The SERD is traditionally characterized with substantial input current harmonics, and reactive power drawn by the inverter and less real power returned to the ac mains [19] which undesirably result in poor drive power factor. For applications where improved power factor, low current harmonics, high mechanical power, switching speed and efficiency are increasingly important, a SERD with improved power factor and a robust dc-link configuration is extremely needed. [20]. Hence the exploration of the dc-link inverter control mechanism is empirically inevitable using smart controllers such as FLC. An illustration of this scheme is presented Figure 1.

II. LITERATURE REVIEW

In this section, the review of similar works done on fuzzy logic control are presented logically and the limitations of these works, possible suggestions and improvement are presented. And the summary of the research gap is portrayed respectively.

2.1 Literature Survey

The concept of FLC was conceived by Professor Zadeh in 1965. And got recognized by Dr. Mamdani, who applied FLC to control an automatic steam engine, almost ten years after it was invented [11]. Also, it was applied in cement industries in Denmark for cement kilns control, which started full-time operation in 1982. After this era, applications and research interest on FLC became common placed [17]. FLC can be seen as unique depiction of idealization adopting the fuzzy IF-THEN rules [21]. Majorly, FLC is made up of four parts, viz: inference system, knowledge system, fuzzification and deffuzzification. However, fuzzification refers to converting real-time values into fuzzy syntactical format, and the formulation of mapping between the input real-time values to their respective output values is inference system. While this simple conversion from fuzzy syntactical format to real-time values is term defuzzification [14].

2.2 Review of Related Works

This section chronologically reviews some of the works related to fuzzy logic controller.

2.2.1 Review of fuzzy based controllers

In **2017, Putri and Robbi,** compared trapezoid, triangular, and Gaussian membership functions of the Mamdani system (FIS) for the syntactical format, using their structural pattern. The details of the various membership functions where presented based of their most fit applicability. But it was limited to only the Mamdani FIS [7]. A year later, **Nasser and Isa (2018),** used fuzzy logic controller in optimizing the performance of an advanced pH controller. It was established that the FLC is a good alternatives for improved application, due to its ability to cover wider range processes. And the particular FIS most fit for improved application was not presented [20]. In **2019, Anil et al.,**displayed the importance of FLC in the regulation of the variables of a DC motor in MATLAB environment, among linguistic variables rather than numeric variables. The response of the fuzzy controller was robust, faster and flexible, with shorter settling time compared to the normal response of DC motor. However, it was realized with the variation of rules, and FMF, and they was no review on the inference systems [12]. Also, **Kheir et al., (2019),** presented a comparative study between type-1 (Grades of membership Crisp) and interval type-2 (Grades of membership Fuzzy) FLC for robot manipulator. The simulations where done on three robot joints in the presents and absent of noise, and quantification of errors were achieved. It was shown the type-two FLC model generated lesser noise than the type-one FLC model [17]. But they was no emphasis on neither the fuzzy membership function (FMF) nor the inference system. **Arpit and Abhinav (2020),** presented a detailed analysis of fuzzy logic system for researchers and industrial practitioners. The diverse FMF generation schemes with respect to their operational approaches where discussed, and suggestion on the controller algorithms and membership function improvements where established. But they was no discussion on the inference system used [13]. And in **2021, Muhammad et al.,**worked on the likelihood of sunspots. The FMF used was triangular FMF on C-means approach. And submitted that triangular and Gaussian membership functions can be used for prediction of sunspots, and accurate choice of FMF is very essential in the use of FLC, and there was no review on the fuzzy inference system [21].

2.2.2 Review of comparison between FLC and ANN, PID and Others

In 2017, Abdullahi et al., and Azman et al., compared ANN and FLC for identifying and discerning partial discharge (PD) defects categories. And in controlling the speed of a separately excited DC motor respectively [11][14]. The former conditioned the parameters through testing and deep training for the ANN and FLC to achieve result, which showed that, both ANN and FLC could recognize PD defects, but the ANN appeared to be stronger than FLC [11]. While the later used DC chopper to control the speed of DC motor and it was also shown that although both triangular FMF functioned great in controlling the DC motor, but ANN controller reacted faster than it, with a lesser settling time [14]. However these were limited to only FMF, and further investigations on different FIS were needed. Similarly, in **2018, Prakruthi et al.,** presented a comparative study of ANN and FLC for crack detection in beam like structures. The first three relative natural frequencies and corresponding relative crack depths and location were used as input and output respectively [22]. It was concluded although both concepts are good but FL concept performed better in defining comparative degree of cracks depth while ANN concept achieve the location of cracks better [22]. Although different FMF were used but there was no defined FIS adopted. **Hendra et al., (2019),** compared the performance two controllers: FLC and ANN for the navigation of mobile robot to create a smart robot. Result showed that ANN is more suitable for faster task completion than FLC [16]. But there was no evidence of the particular FIS used in the comparison but only the FMF were presented. And **Didem (2019),** compared PID and FLC controller for the regulation of a separately excited DC motor. This was simulated. The performances were compared based on step input and FLC was recommended. The triangular FMF was used but the FIS was not justified [13].

2.3Statement of the Problem

From the reviews above, it is justified that, only a surface knowledge of the fuzzy logic controller characteristics configuration in comparative applications were exploited. However, this characteristics configuration is very relevant, as improved performance is an absolute function of accurate number of rules, choice of membership functions and best fit inference system. However, many researchers have always considered rules precisions, a few consider membership function and almost a negligible fraction considers the type of inference engine (systems) used, in examining the fuzzy logic controller for optimum performance application. Hence, most results established on comparative analysis on fuzzy logic controller and other controllers have remain untruly investigated and justified. This is because the concept of fuzzy logic controller remains unexploited based on the adequate knowledge of the inference system. Therefore, it is very pertinent to evaluate the control response of FLC.

III. METHODOLOGY

This section presents the various materials and methods employed in achieving the aim of this research. These are: The mathematical model of the scheme to be controlled (SERD), the fuzzy logic controller (FLC), with precise rules, applicable membership functions and best fit inference systems.

3.1 Slip Energy Recovery Drive Model

SERD is an energy recovery scheme which recoups the slip power that exist in the slip rings of the traditional wound rotor induction motor and feeds it back to the ac mains supply, via static converters and three phase optional step-up transformer [18].

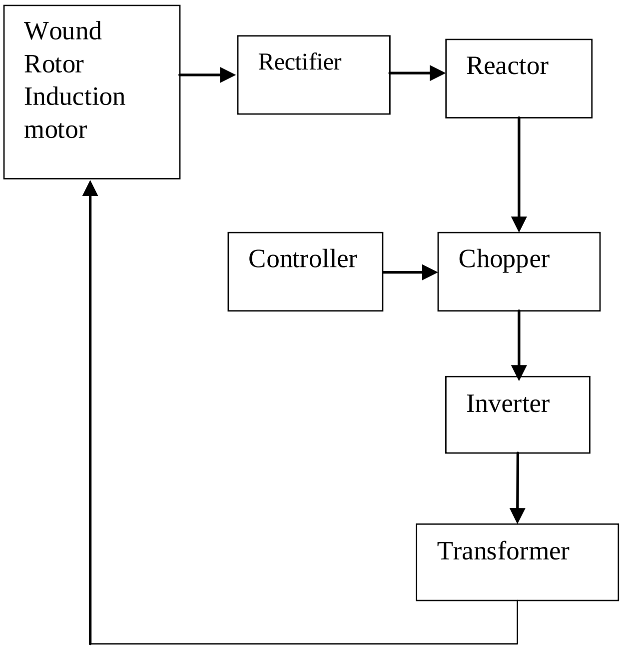


Figure 1. Schematic Diagram of Slip Energy Recovery Drive

3.2 Dynamic Model/Equivalent Circuits

From Induction Motor flux equation;

$$V_{ds} = \frac{1}{\omega_s} p\psi_{ds} - \omega\psi_{qs} + R_s i_{ds} \quad (1)$$

$$V_{qs} = \frac{1}{\omega_s} p\psi_{qs} - \omega\psi_{ds} + R_s i_{qs} \quad (2)$$

$$V_{0s} = \frac{1}{\omega_s} p\psi_{0s} + R_s i_{0s} \quad (3)$$

$$V_{dr} = \frac{1}{\omega_s} p\psi_{dr} - (\omega - \omega_r)\psi_{qr} + R_{dr} i_{dr} \quad (4)$$

$$V_{qr} = \frac{1}{\omega_s} p\psi_{qr} - (\omega - \omega_r)\varphi_{dr} + R_{dr} i_{qr} \quad (5)$$

$$V_{0r} = \frac{1}{\omega_s} p\psi_{0r} + R_{dr} i_{0r} \quad (6)$$

With the supply voltages V_{sa}, V_{sb}, and V_{sc} set as;

$$V_{sa} = V_m \cos \omega_e t$$

$$V_{sb} = V_m \cos(\omega_e t - \frac{2\pi}{3})$$

$$V_{sc} = V_m \cos(\omega_e t + \frac{2\pi}{3})$$

$$\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \sqrt{\frac{3}{2}} V_m \begin{bmatrix} \cos(\omega_e t - \theta_r) \\ \sin(\omega_e t - \theta_r) \end{bmatrix}$$

Finally, the equation associated with the mechanical motion is given by

$$p\omega_r = \frac{N\left(Te - TL - (\frac{2}{N})Bwr\right)}{2J} \quad (7)$$

Where the electromagnetic torque T_e is determined by equation (8) and TL representing the load torque.

$$T_e = \frac{3N}{4}(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad (8)$$

3.3 Fuzzy Logic Controller (FLC)

The speed of the drive is managed by a fuzzy controller. This is simulated with the fuzzy Matlab toolbox. Fuzzy linguistic descriptions can be seen as unique depiction of idealization adopting the fuzzy IF-THEN rules [6]. Basically, the fuzzy logic controller comprises four basic components: fuzzification, knowledge base, inference engine,

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

and a defuzzification interface. In popular situations, systems with fuzzy outputs are easier to assume a smart (crisp) decision, when their outputs are symbolized as single scalar quantity. However, this simple conversion from fuzzy set to single crisp value is referred to as defuzzification [5][23][24]. More details of fuzzy logic is contained in Figure 3 and 4.

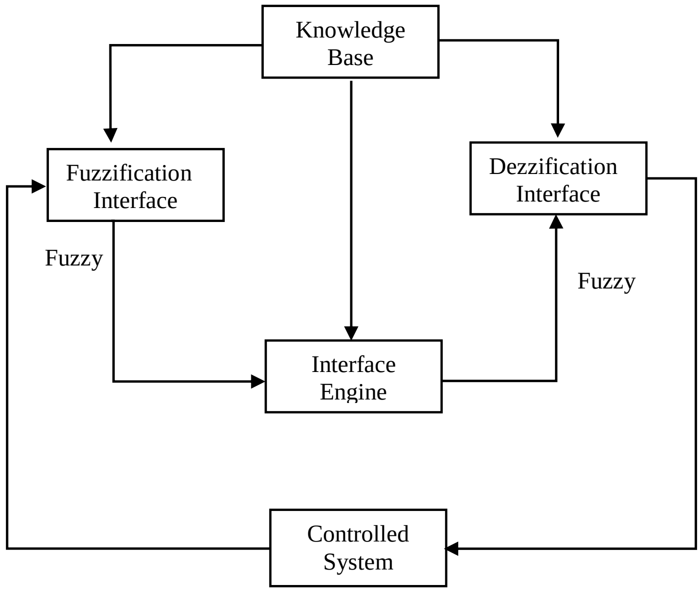


Figure 3. Basic Configuration of Fuzzy Logic Controller

- **Fuzzification**: This is the process of transforming crisp value into fuzzy value. It is the first stage of the fuzzy system, where input values are mapped to domain of Fuzzy variables. The crisp inputs variable are assign to linguistic label. This is seen in Figure 11 (a and b). And the Fuzzy rule base are formed based on the expected knowledge of the system. These Fuzzy rules are used on Fuzzy input variables to give Fuzzy output variables. This process is called Fuzzy inference [6][23][25].
- **Inference Engine**: is also seen as the process of formulating the mapping from a given input to an output. According to [3][26], there are two types of approaches in designing of the inference engine. These are: Composition based inference and Individual rule-based inference.
- **Defuzzification**: This is the process of producing a crisp set from fuzzy set. It is also seen as the stage where all consequents are accumulated to obtain a crisp output. As seen in Figure 12 (a and b). It produces a non-Fuzzy control that best represents the degree of certainty of an inferred Fuzzy control action [8][25][27].

The FLC is integrated in the system as shown in Figure 9. The output signal is produced based on the magnitude of the inputs signals. The fuzzy logic controller compares the motor output speed and power factor with the modulation index and balance the desire speed and power factor by adjusting the values of the modulation index. The modulation index and motor speed are related as seen in the Table 1, where an increase in modulation index is reflected as an increase in speed. Alternatively, the modulation index can be varied manually to balance the desired speed. A walk into modern age avails the fuzzy controller to vary the speed digitally. A total of 9 possible control signals are sent to the system depending on the degree of variation of error angle and its derivative as shown in Table 6. The membership function of both the inputs and output were chosen to be three for a simple and accurate speed control. The membership functions as represented by [6][28], are N, Z, P, which represent Negative, Zero and Positive respectively. In this work, N signifies Low speed, power factor and modulation index of 0.8, Z signifies Average speed, power factor and modulation index of 0.9 and P signifies High speed, unity power factor and modulation index of one. The Table 6 portrays the various speed values for distinctive values of modulation index, moreover, an excessive increase in modulation index yields a high speed and this aids the adjustment of the motor speed under large load torque, except for all modulation indexes greater than one.

Table 1. Modulation Index versus Speed

MODULATION INDEX	SPEED (rpm)
0.1	800
0.2	960
0.3	1100
0.4	1240
0.5	1330
0.6	1380
0.7	1400
0.8	1470
0.9	1488
1	1502
1.2	1499

With these values, the fuzzy logic circuit is designed to vary the modulation index to compensate the speed for a desire response. Figure 10 (a and b) shows the internal details of a fuzzy logic controller. This approach adopted accommodates the non- linearity and uncertainty [3].

1. If (Speed is Negative) and (Power Factor is Negative) then (Modulation-Index is Negative) (1)
2. If (Speed is Negative) and (Power Factor is zero) then (Modulation-Index is Zero) (1)
3. If (Speed is Negative) and (Power Factor is positive) then (Modulation-Index is Negative) (1)
4. If (Speed is zero) and (Power Factor is Negative) then (Modulation-Index is Positive) (1)
5. If (Speed is zero) and (Power Factor is zero) then (Modulation-Index is Zero) (1)
6. If (Speed is zero) and (Power Factor is positive) then (Modulation-Index is Positive) (1)
7. If (Speed is positive) and (Power Factor is Negative) then (Modulation-Index is Zero) (1)
8. If (Speed is positive) and (Power Factor is zero) then (Modulation-Index is Zero) (1)
9. If (Speed is positive) and (Power Factor is positive) then (Modulation-Index is Positive) (1)

The program is set from the fuzzy inference system to the rules-editor and finally the rules-view. Fuzzy outputs are without under or over shoots, this makes it the most suitable for this design [8][29]. The internal system is automatically adjusted by the fuzzy wizard as shown in Figure 10. The deffuzification circuit generated by the wizard is presented in Figure 10.

Table 2. Fuzzy Logic Rules

Speed / PF	N	Z	P
N	N	Z	N
Z	P	Z	P
P	Z	Z	P

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

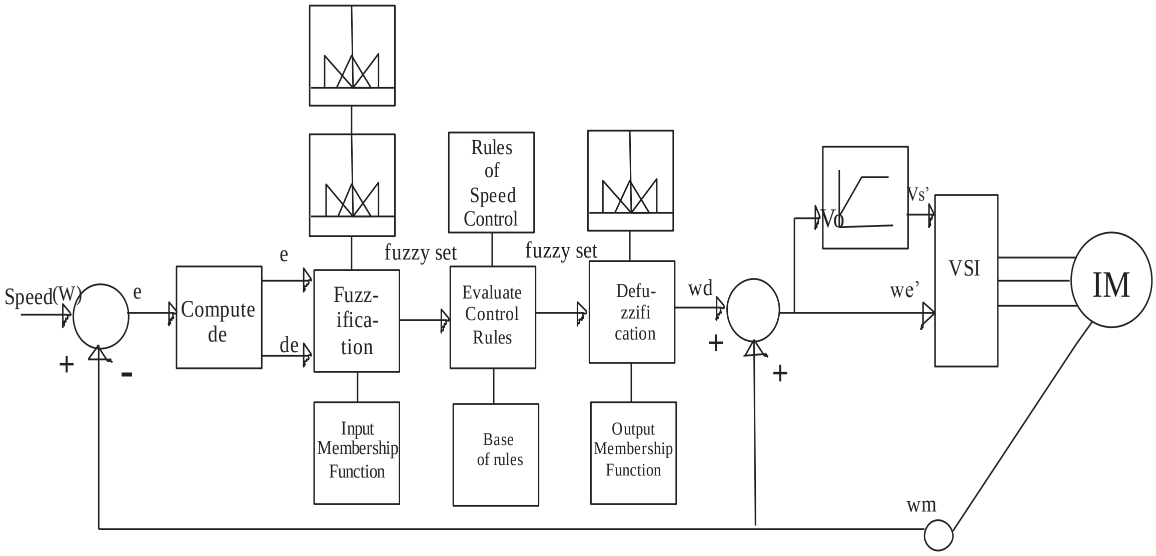


Figure 4.Basic Block Diagram of Speed Control of Induction Motor Using FLC

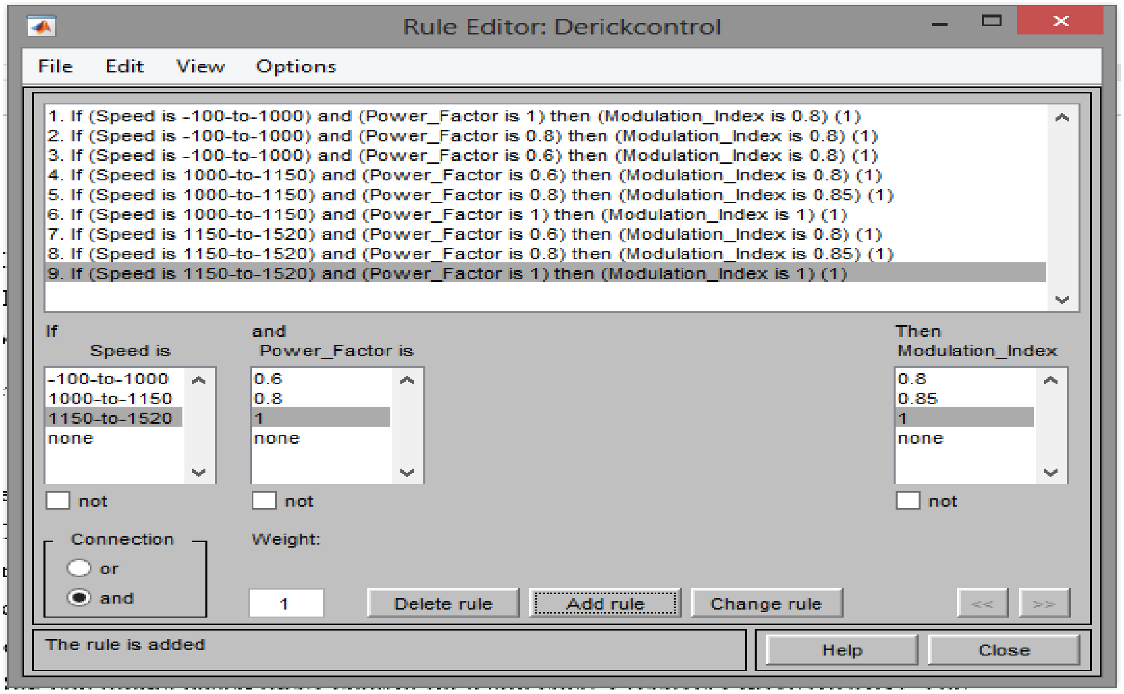


Table 5. Rules Editor Diagram showing the rules

3.4 Fuzzy Inference System

Fuzzy inference system is a scheme of logical reasoning process that decodes and maps the given inputs to the corresponding output values based on some assigned set of fuzzy rules. Fuzzy inference system functions with the fuzzy operator, membership functions, and the if/then rules, thereby enabling the mapping of the various input to their outputs respectively. Fuzzy logic inference system mainly has two types, which are the Mamdani and Sugeno [23][26]. The common difference of these two inference systems is in the determination of their outputs [23][25][27][29][30].

The Mamdani inference system delivers the output in form of fuzzy sets with the help of the membership functions. After the accretion and mapping stage. There are distinctive fuzzy sets for the various output variable, which results in defuzzification. Sometimes it is essential and more efficient, to represent the output membership function with a single spike rather than multiple distributed fuzzy sets. This concept of single spike is referred as Singleton/Unit Output Membership

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

Function [28] [31][32], which is also considered as a pre-defuzzified fuzzy set [26][32]. This approach improves the efficiency of defuzzification concept, due to it simple process against the conventional Mamdani FIS method which locates the centroid of a two-dimensional function. Hence in recent times the Mamdani design approach uses a fewer membership functions to simplify its output. This can be seen in the output membership function presented in Figure 9.

While the Sugeno inference system is comprise of a unique output structure, with the same input and fuzzy operator as the mamdani inference. However, the major difference between these inference systems is that the output membership functions are only constant or linear for the Sugeno inference system [32]. A first-order Sugeno fuzzy model of a common fuzzy rule is presented as If m is C and n is D, then y=km+ln+r where C and D are fuzzy sets in the origin, while k, l, and r are al kept unchanged. Although, the sugeno Higher-order models are achievable, but it is characterized with the introduced substantial complications with minor advantages. More details of the differences of these inference systems is presented in Table 3, Figure 7 and 9.

Table 3. Comparison between Mamdani FIS and Sugeno FIS

Mamdani	Sugeno
The output is a membership function	The output is not a membership function
There is a distribution output	No output distribution There is only ‘resulting computation of the rules and the output and not distributed output
The resulting output is a crisp value and its obtained through rules defuzzification	The resulting output is a crisp and its obtained from the weighted average of the rules, without defuzzification
There is a non-continuous output surface	There is a continuous output surface
It suitable for both multiple and single output systems	It’s only suitable for single output systems
Characterized with Expressive power and interpretable rules	Characterized with loss of interpretability
Few flexibility in the output system design	More flexibility in the output system design

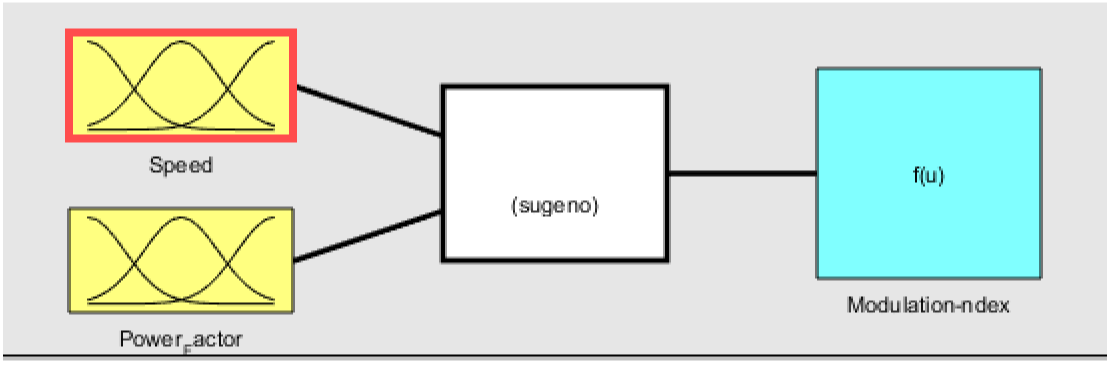


Figure 6. FIS Fuzzy editor with two input one output (Sugeno)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

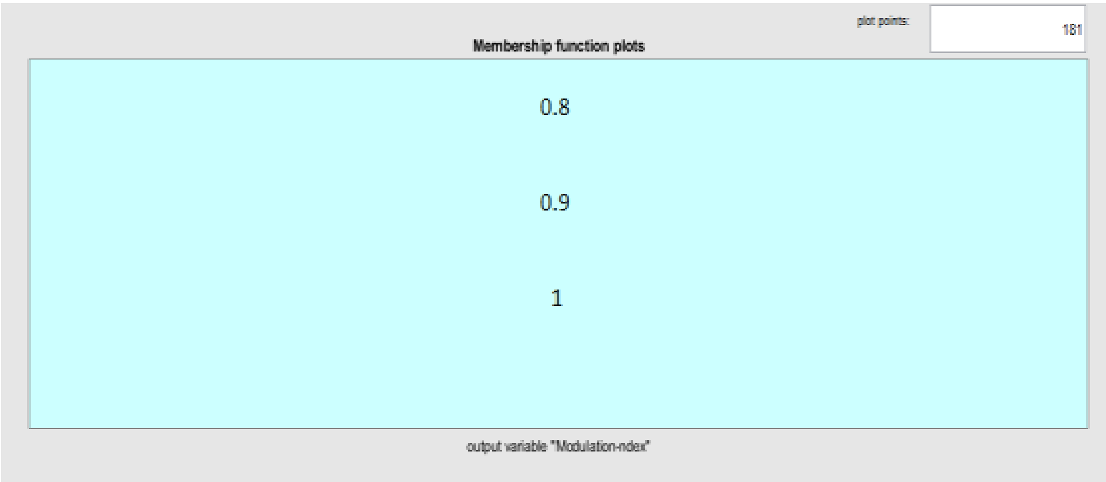


Figure 7. Sugeno FIS output

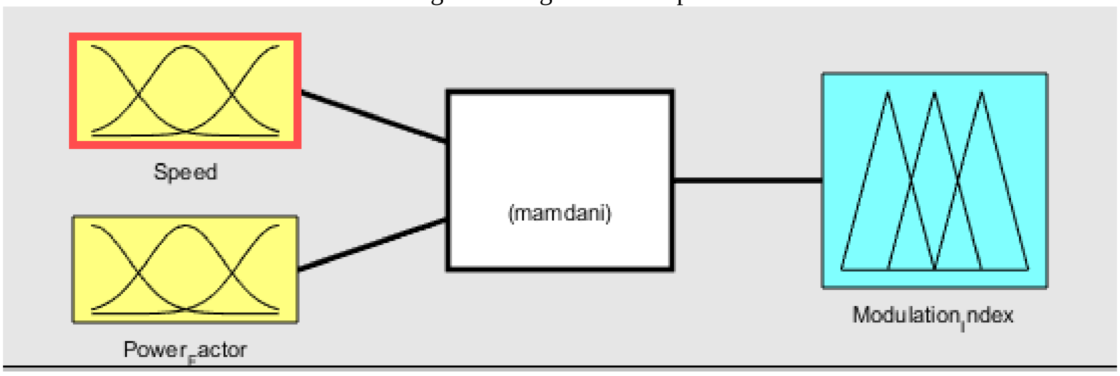


Figure 8. FIS Fuzzy editor with two input one output (Mamdani)

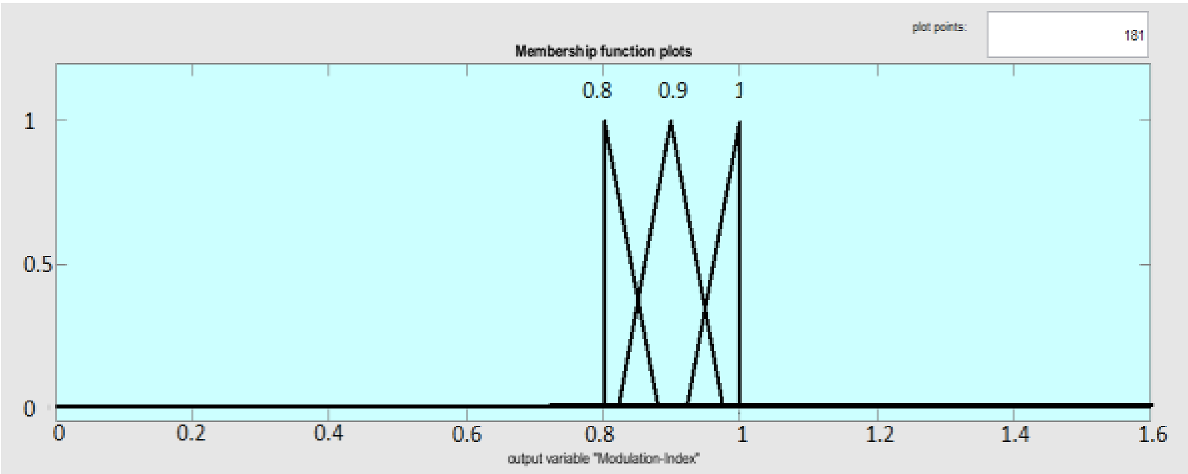


Figure 9. Mamdani FIS output

This program is set from the fuzzy inference system to the rules editor and finally the rules view. The final developed model is shown thus.

Table 4. Motor Specification

Rated power	4 HP
Rated stator voltage	460 V
Rated frequency	50 Hz
Rated slip	0.046

Rated speed	1100, 1300, 1500 rpm
Maximum torque	19.006 N-m
Number of pole pairs	2
Stator connection	Wye/Wye
Stator resistance R_s	0.435 Ω/phase
Stator inductance L_s	0.004 H/phase
Rotor resistance R_r	0.816 Ω/phase
Rotor inductance L_r	0.027 H/phase
Mutual inductance M_{sr}	0.06931 H/phase
Rotor mass moment of inertia J	0.089 Kgm^2
dc-link inductance	0.2 mH
Transformer turn ratio	1:2

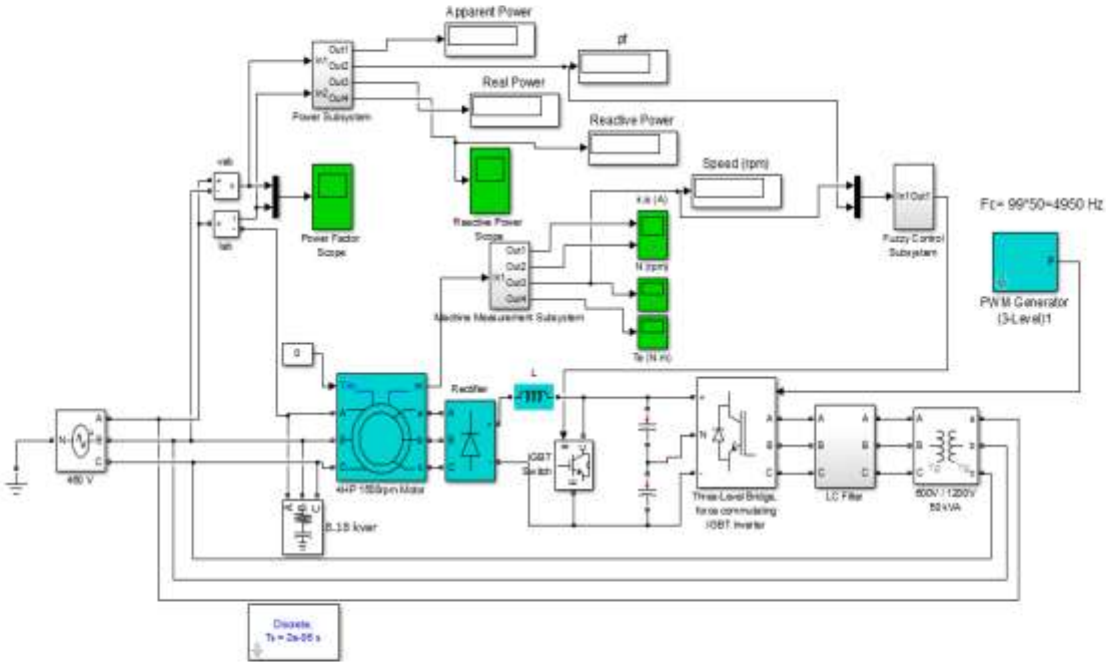


Figure 10. A developed SIMULINKS Model

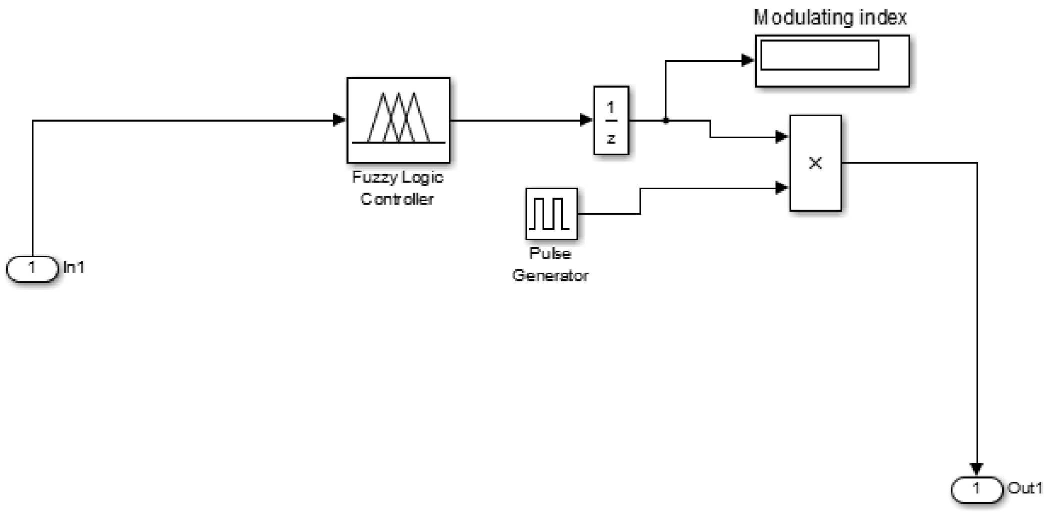


Figure 11. Fuzzy Logic block

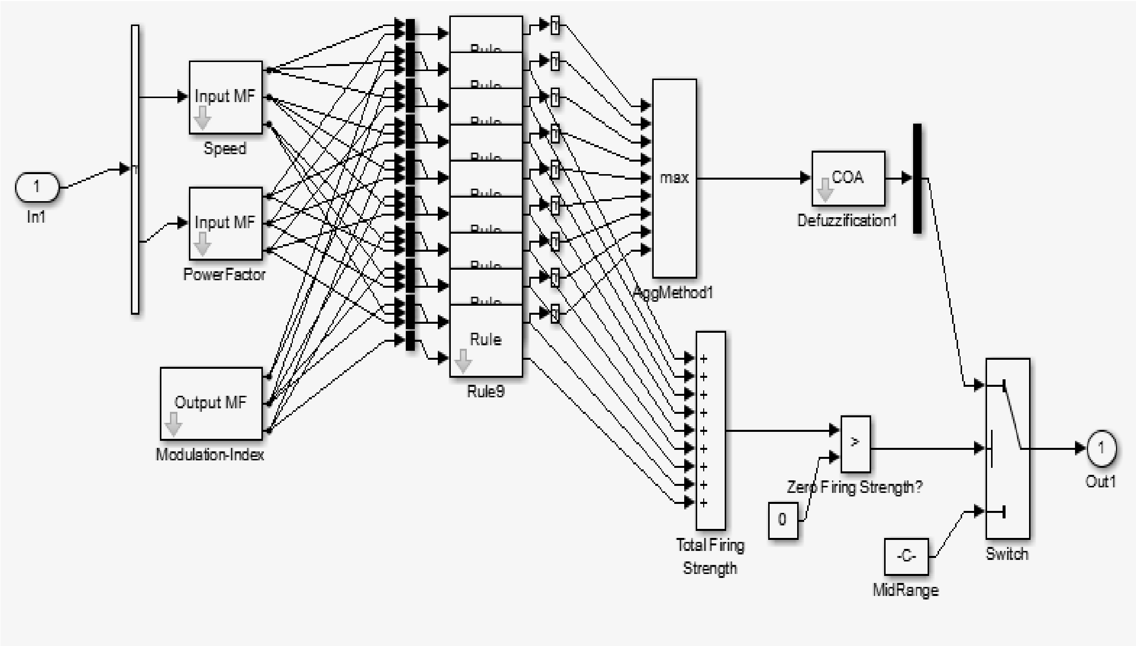


Figure 12. Unmasked Internal Circuit of the Fuzzy Wizard.

IV. RESULT OF SIMULATION

The simulations are carried out in Matlab with triangular membership functions for Mandani inference system model and the unique value for the Sugeno inference system model. The result is presented in four sections. Section A, presents the response curves of the stator and rotor current, rotor speed, and torque at no-load (0N-m). The second Section (B), presents their half load (1N-m) condition. The third Section (C) presents the full load (2N-m) condition and the final Section (D) presents the speed response at different rated speed (1100rpm, 1300rpm and 1500rpm) respectively.

Section A:

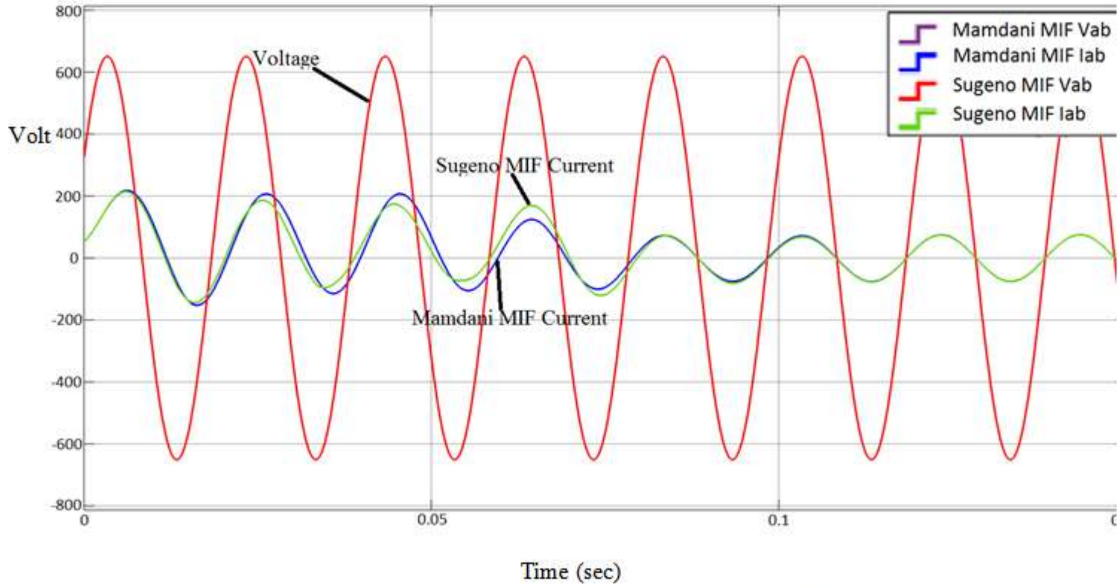


Figure 13. Power Factor at different Inference System,at no-load, (Load torque =0N-m)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

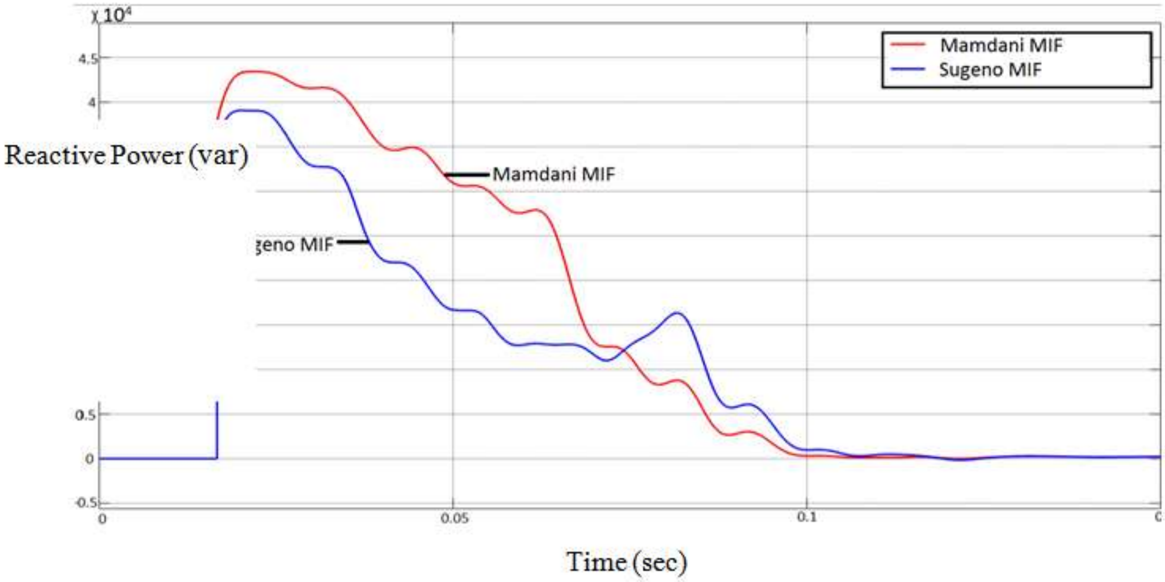


Figure 14. Reactive Power at different Inference System,at no-load, (Load torque =0N-m)

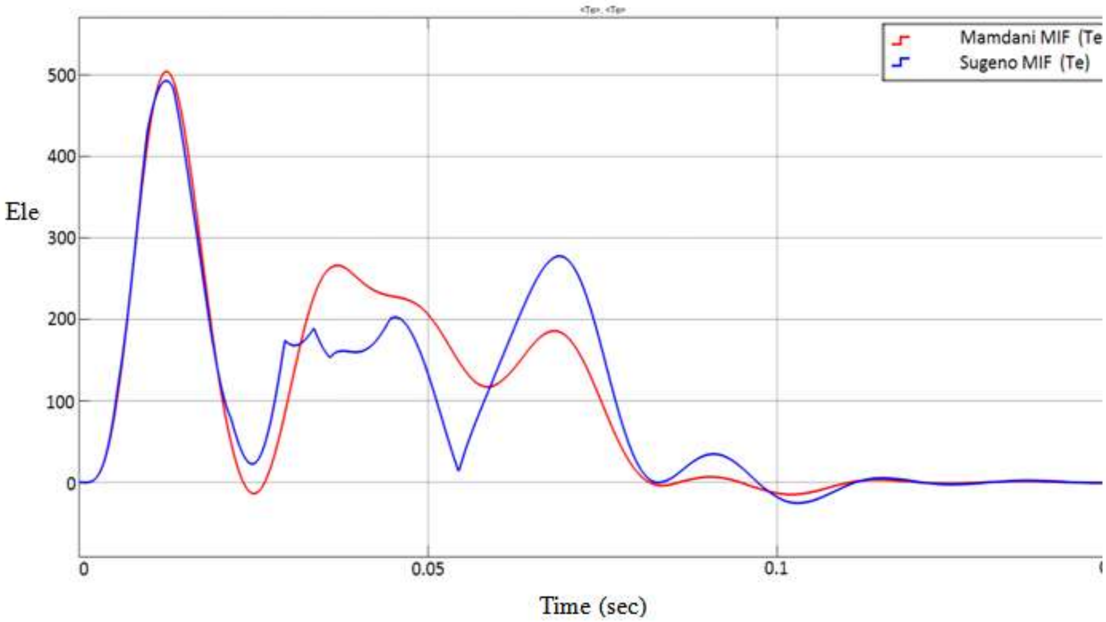
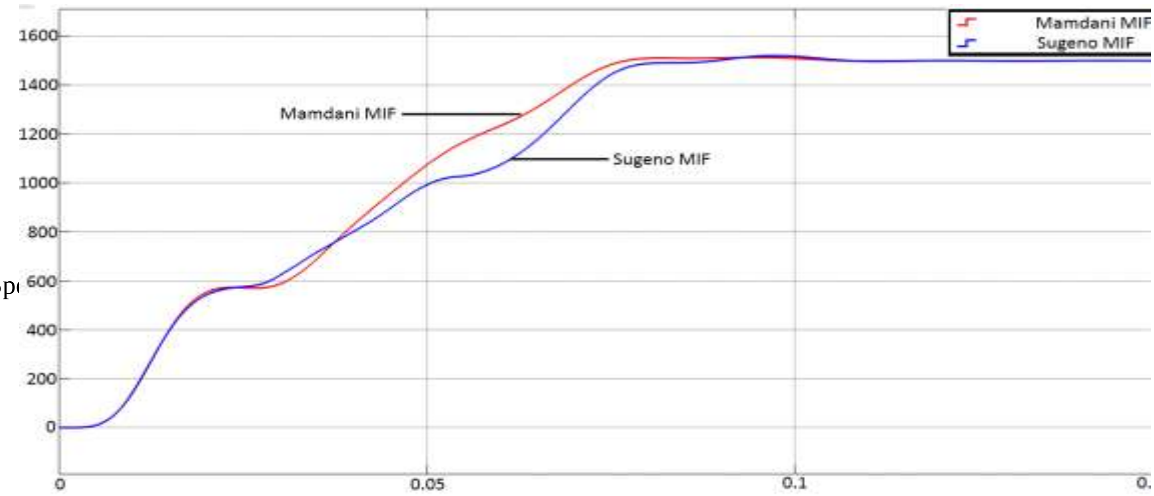


Figure 15. Electromagnetic Torque at different Inference System,at no-load, (Load torque =0N-m)

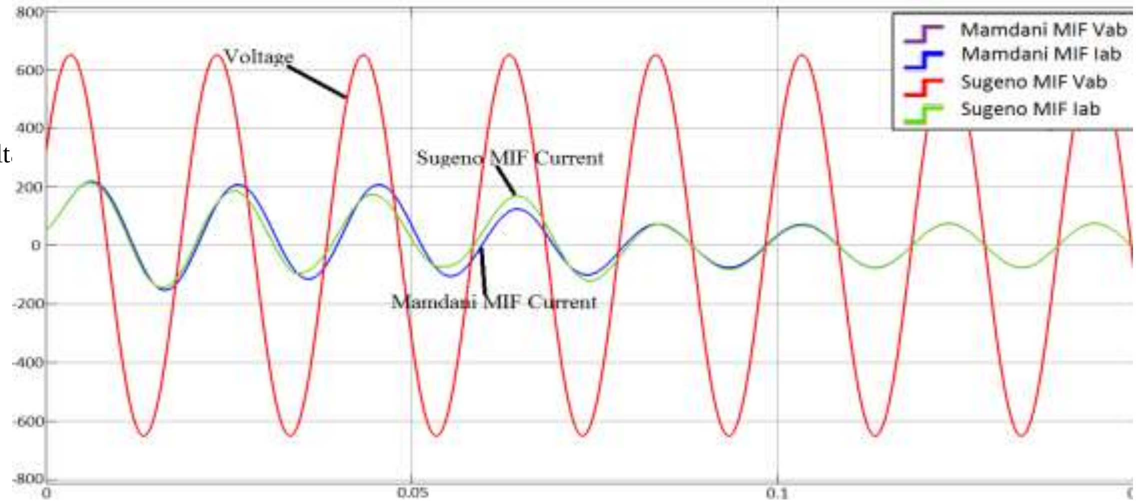


Spe

Time (sec)

Figure 16. Speed Response at different Inference System, at no-load, (Load torque =0N-m)

Section B:



Volt

Time (sec)

Figure 17. Power Factor at different Inference System, at half- load (Load torque=1N-m)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

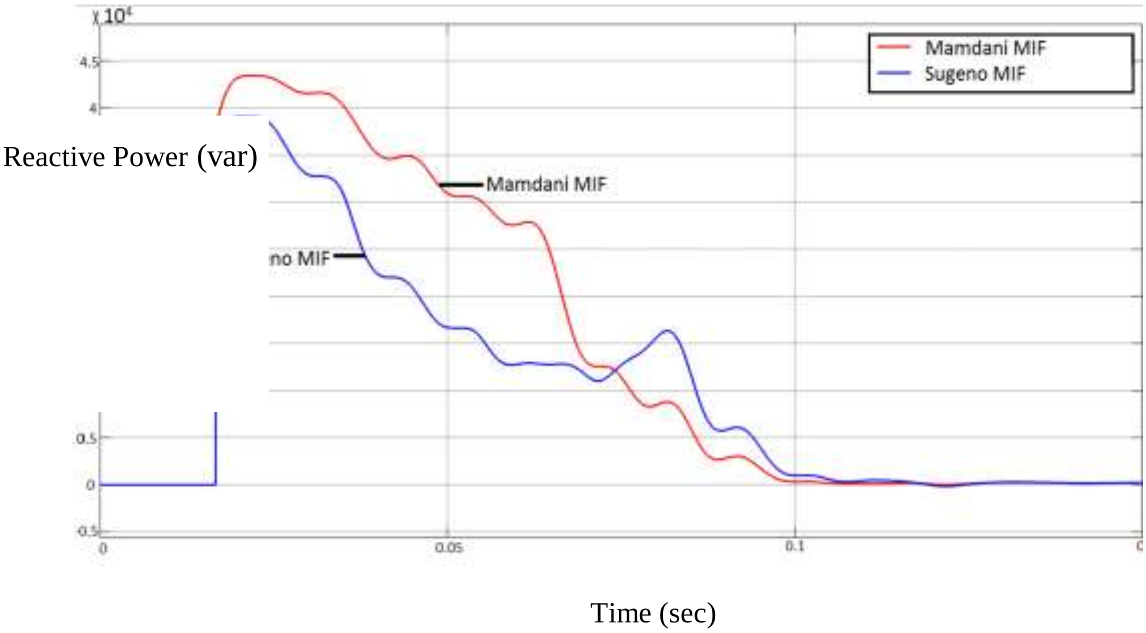


Figure 18. Reactive Power at different Inference System, at half- load (Load torque=1N-m)

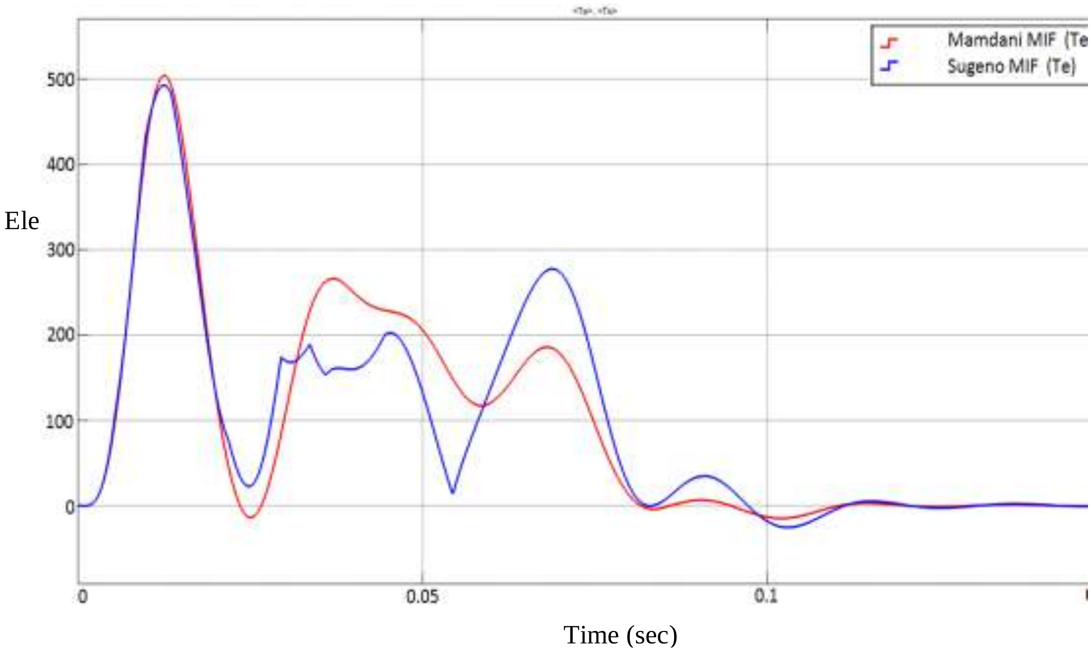


Figure 19. Electromagnetic Torque at different Inference System, at half- load (Load torque=1N-m)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

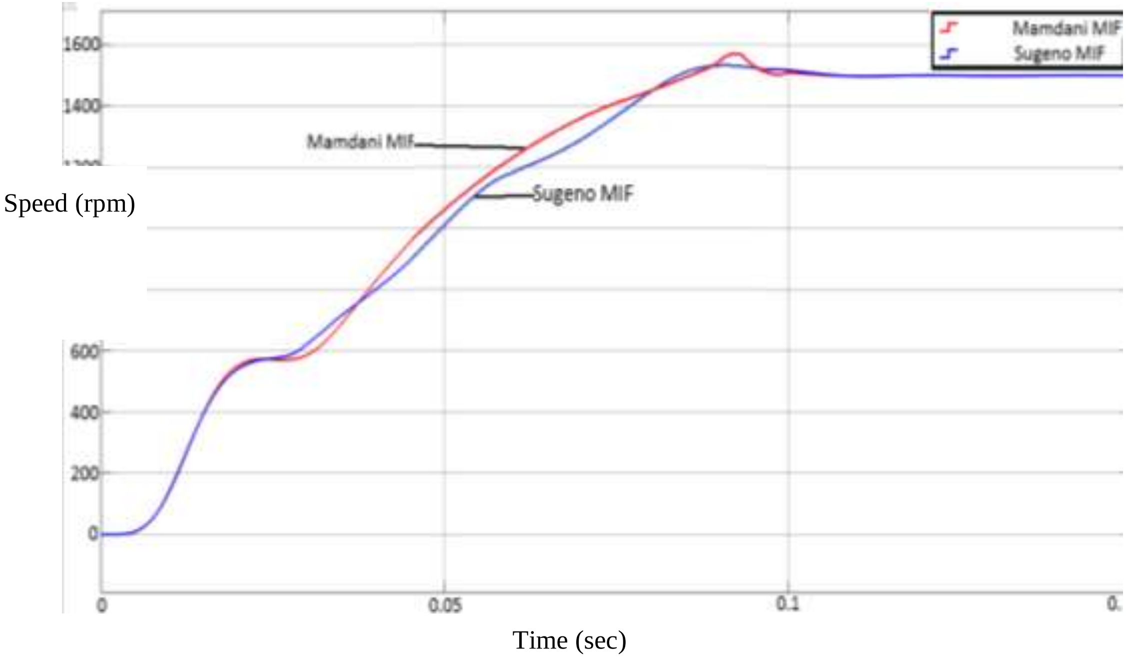


Figure 20. Speed response at different Inference System, at half- load (Load torque=1N-m)

Section C:

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

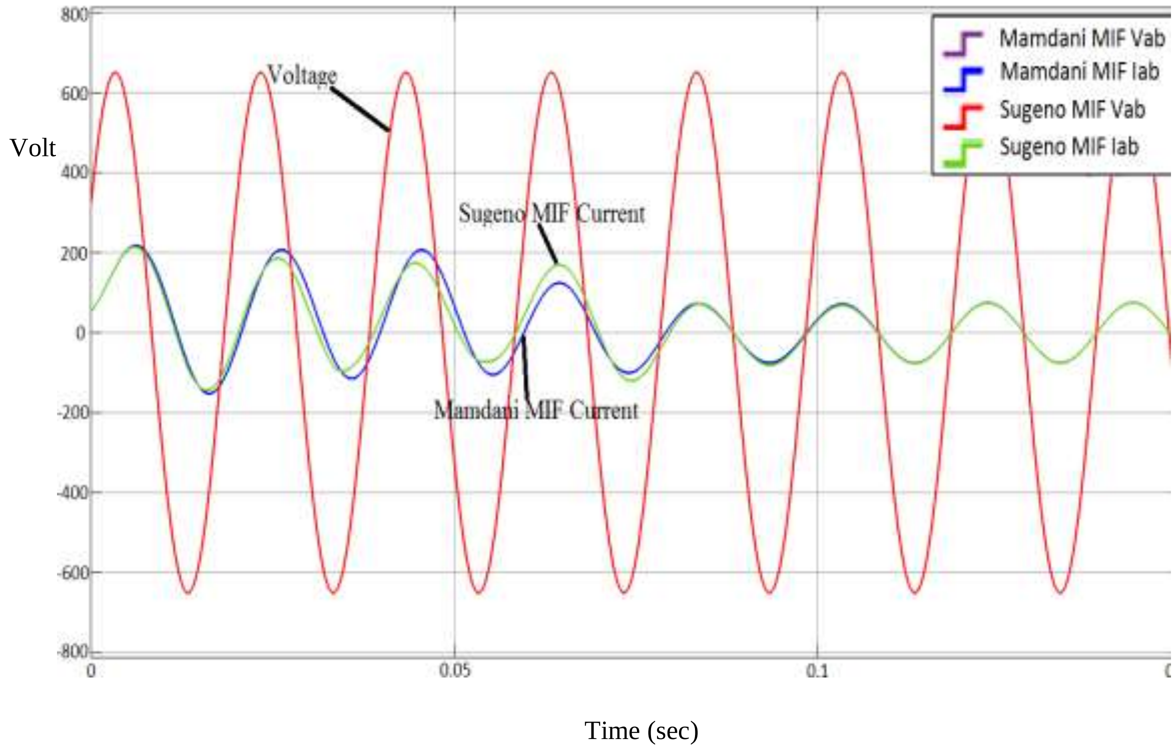


Figure 21. Power Factor at different Inference System, at full-load (Load torque=2N-m)

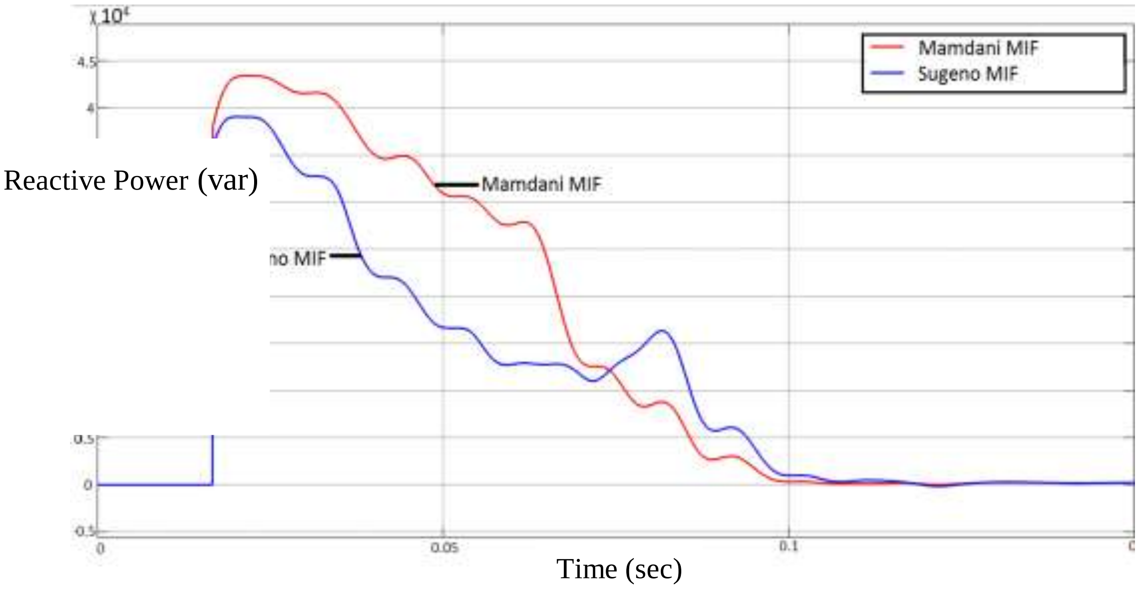


Figure 22. Reactive Power at different Inference System, at full-load (Load torque=2N-m)

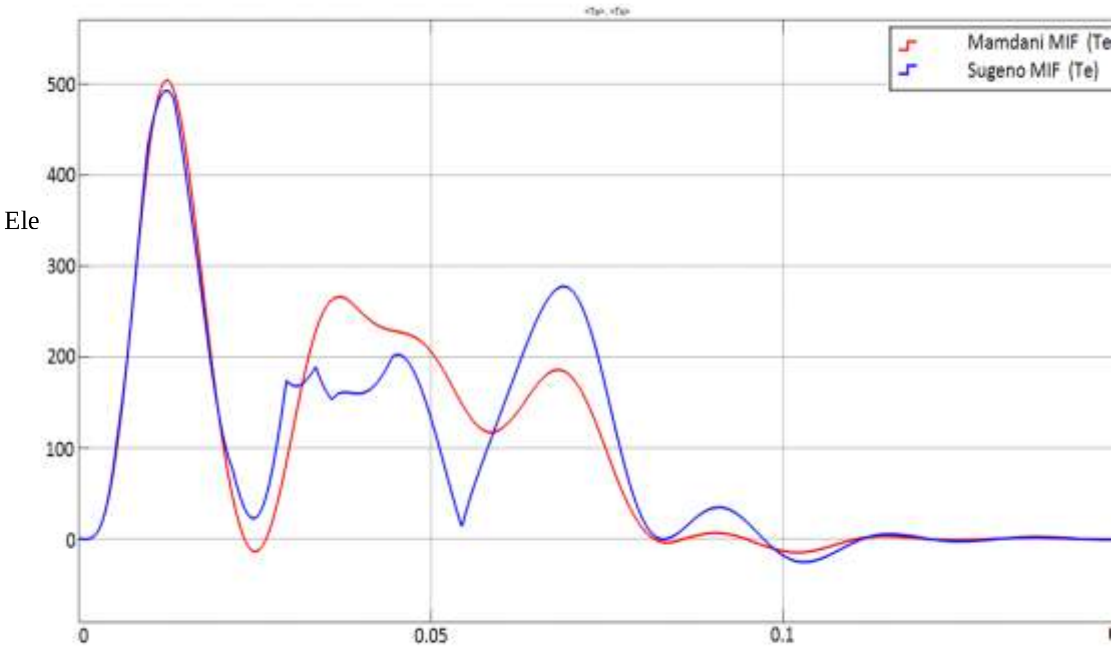


Figure 23. Electromagnetic Torque at different Inference System, at full-load (Load torque=2N-m)

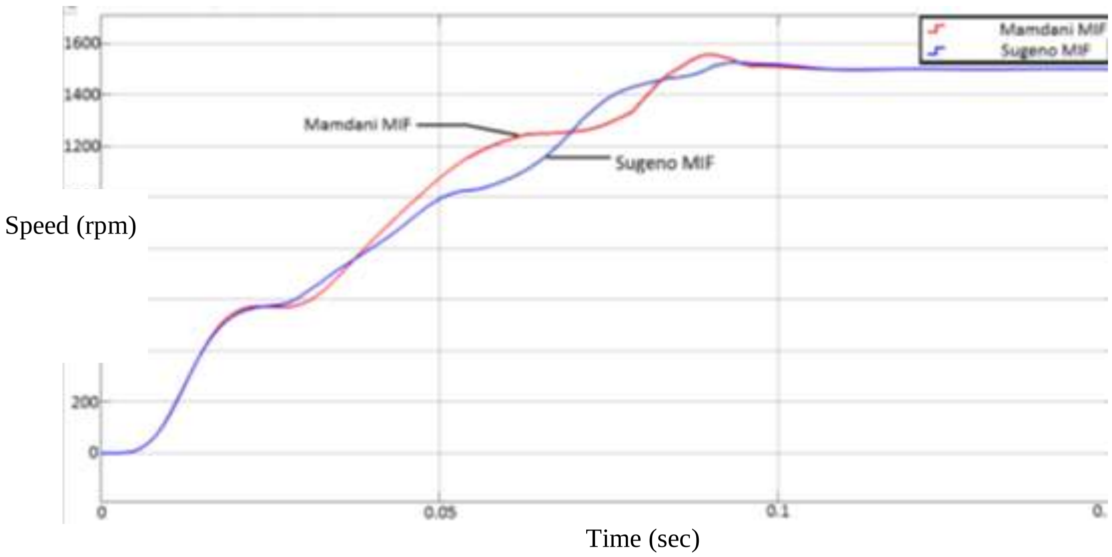


Figure 24. Speed response at different Inference System, at full-load (Load torque=2N-m)

Section D:

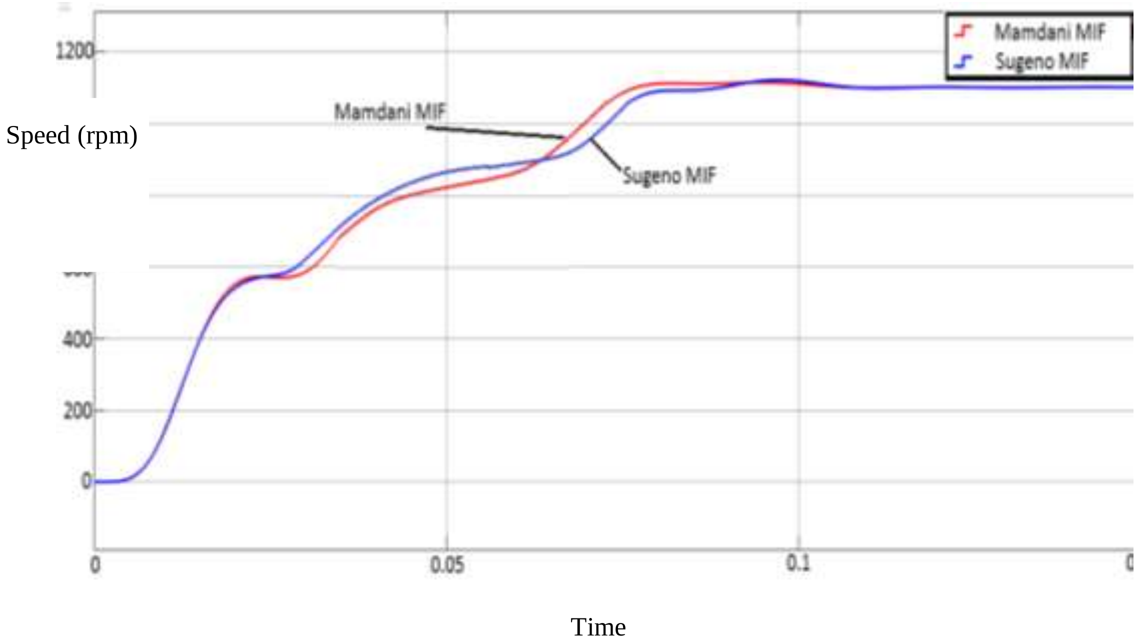


Figure 25. Speed response at different Inference System, at speed = 1100rpm

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 1937-1958 www.ijaem.net ISSN: 2395-5252

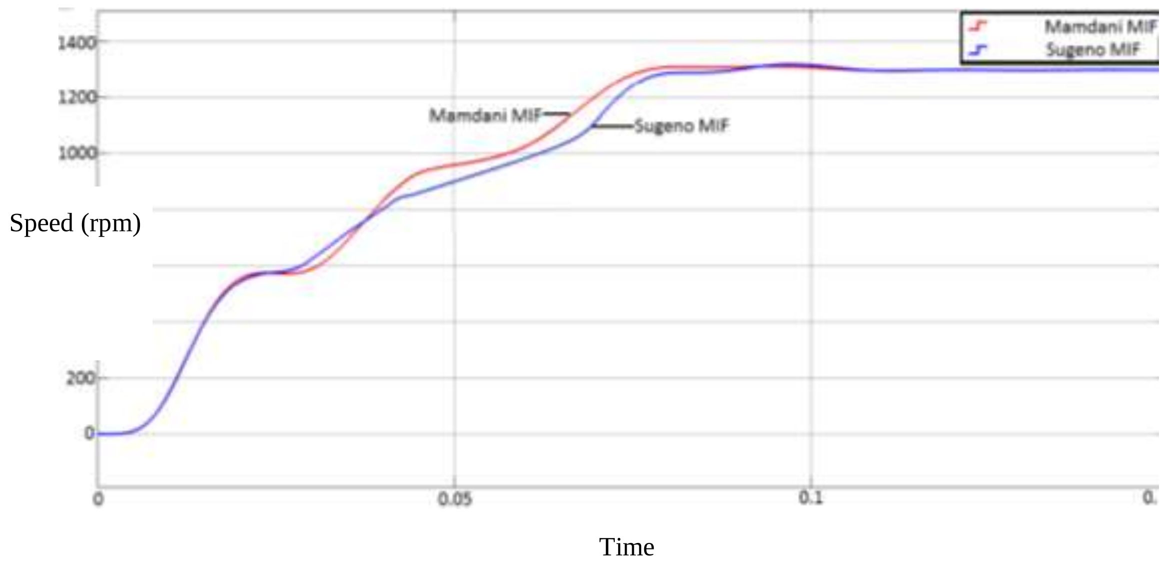


Figure 26. Speed response at different Inference System, at rated speed = 1300rpm

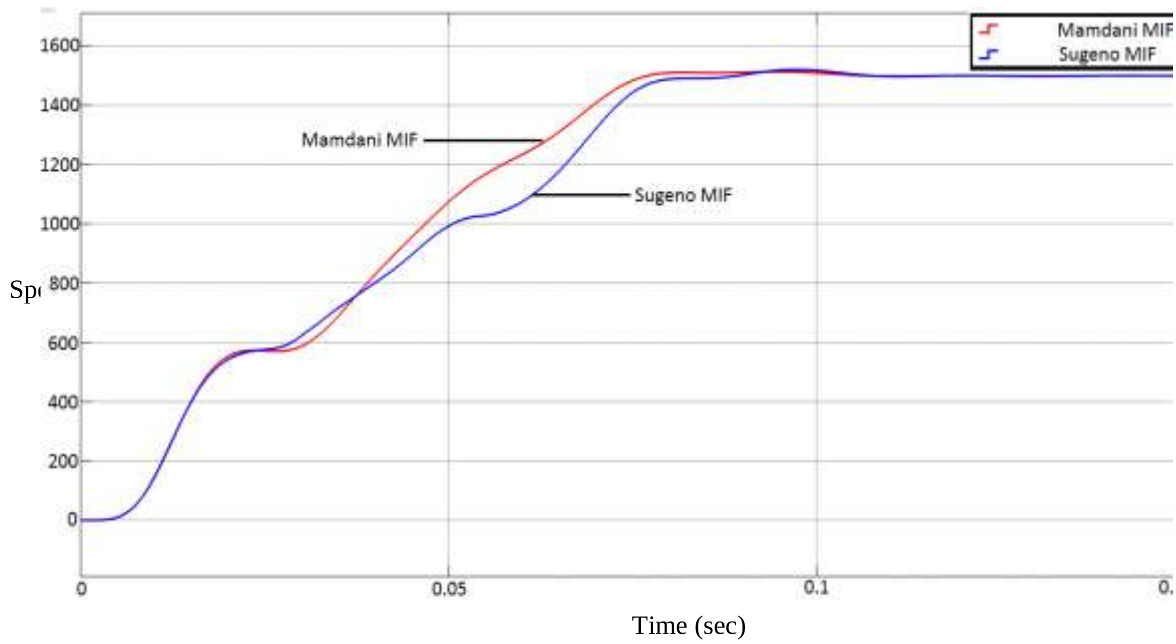


Figure 27. Speed Response at different Inference System, at rated speed = 1500rpm

V. DISCUSSION

This paper is based on comparison of the performance of fuzzy logic inference system with distinct membership functions, in the control of high inrush current and reactive power in the dc-link configuration of a Slip Energy Recovery Drive, as a requirement in the switching configuration of the system for improved drive performance (power factor) [3][4][5][23][32]. Hence, the simulations was carried out in Matlab/Simulink with Triangular membership functions for Mandani inference system model and single value for the Sugeno inference system model in terms of smart shift to meet load demands. For better result comparison, the drive was tested at full-load, half load and no-load respectively and the drive speed performance at different rated speed values (1100rpm, 1300rpm, and 1500rpm) were established. From the result of the scope in Figure 13, the Mamdani FIS attained improved power factor faster than Sugeno. Whereas, there was a delay of a half circle and this correspond to 0.01sec delay for the Sugeno inference system and this is applicable in all load conditions as seen in Figure 17 and 21. Also, in Figure 14, the reactive power control at no-load conditions, showed the smooth control performance of the Sugeno at the first 0.075 sec, with the reactive power reduced substantially at the start of the drive, whereas, the Mamdani inference system displayed a higher reactive power at the start of the drive. However, at 0.080 sec, the Mamdani FIS showed a better response, with a calm response to near zero reactive power, as compared with the Sugeno with an overshoot at 0.075sec, and delay of 0.002sec. This is also applicable in both half load and full load condition as seen in Figure 18 and 22. From Figure 15, 19 and 23, the torque response of the Mamdani inference system triangular membership function possess a better respond to the Sugeno inference system, displaying similar characteristics at no-load, half load and full-load respectively. And in Figure 16, the speed waveforms at no-load showed, the Sugeno inference system with a speed delay of 0.002sec and an overshoot in attaining the steady state, against the Mamdani inference system triangular membership function, which attained the steady state speed faster with no overshoot. In Figure 20, the speed response at half load condition, the Sugeno FIS displayed better speed performance over the Mamdani FIS with an overshoot at 0.085sec. And in Figure 24, the Mamdani FIS showed unstable response with overshoot at the steady-state, while the Sugeno FIS showed stable response without overshoot, thereby displaying better response at load conditions. In section D, the various no-load speed response at rated speed of 1100rpm, 1300rpm and 1500rpm, showed Mamdani FIS attaining the steady-state faster that the Sugeno FIS at all load conditions. This hence implies that; the both models have advantages and disadvantages. However, the Mamdani fuzzy inference system triangular membership function shows better speed response at no-load conditions, better power factor and torque response at all load conditions. While the Sugeno FIS displayed better speed response at half load and full load condition, with better reactive power control over the Mamdani counterpart. Therefore, the result displays that the Sugeno inference system triangular membership function offers relatively better response to variable load demands in SERD while the Mamdanii FIS shows improved power factor and torque performance at all load conditions.

This thus, implies that, both models can achieve an improved control of the inrush current and reactive power in the dc-link configuration of the drive system.

VI. CONCLUSION

Conclusively, poor control capabilities of inverter and dc-link configuration being a significant concern in SERD application, has been investigated using different fuzzy logic inference systems and membership functions. This was examine in the Matlab/Simulink interface, and the result showed that, the Sugeno FIS is characterized with precise response at variable and full load conditions, and at no-load, it is associated overshoots and delay in its response, compared with the Mamdani FIS which offers faster response without overshoot in no-load condition and faster improved power factor in all load conditions. Thus, both Mamdani and Sugeno FIS are fit for the control of the dc-link configuration and inverter of SERD, especially for application where low inrush current, controlled reactive power and improved power factor are of great significance. However, it can be recommended that further works can be done on the improvement of the precise Sugeno single values selection technique hence to improve the aptness of the Sugeno model.

REFERENCE

[1] K. Rajesh, D. Roopali and A. Puneet (2017) “Rotor Side Speed Control Methods Using MATLAB/Simulink for Wound Induction Motor” World Academy of Science, Engineering and Technology International Journal of Mechanical and Mechatronics Engineering Vol:11, No:7, 2017

[2] R. B. Mohammad, M. Sabahi and M. F. Reza (2015). A New Soft Starting Method for Wound-Rotor Induction Motor. Journal of electrical Engineering January 2011 DOI:10.2478/v10187-011-0005-3

[3] J.A. Bala, O.M. Olaniyi, T.A Folorunso and O.T. Arulogun (2019). Poultry Feed Dispensing System Control: A Case between Fuzzy Logic Controller and PID Controller. Balkan Journal of Electrical & Computer Engineering, 7(2), April 2019

[4] G. Sudha (2014). Performance Based Comparison between Various Z-N Tuninng PID and Fuzzy Logic PID Controller in Position Control System of dc Motor. Electronics & Instrumentation Engineering

Department Vivekanandha College of Technology for Women, Tiruchengode.

[5] A. A. Philip (2016). DC Motor Speed Control: A Case between PID Controller and Fuzzy Logic Controller. International Journal Of Multidisciplinary Sciences And Engineering, Mechatronics Engineering Option, Department of Mechanical and Biomedical Engineering, Bells University of Technology, Ota, Nigeria

[6] T. D. Dongale, S. R. Jadhav, S.V. Kulkarni, T. G. Kulkarni, R. R. Mudholkar, M. D. Uplane (2016). Performance Comparison of PID and Fuzzy Control Techniques in Three Phase Induction Motor Control: International Journal on Recent Trends in Engineering and Technology, Vol. 7, No. 2, March 2016 Department of Electronics, Shivaji University, Kolhapur, India.

[7] H. Putri and R. Robbi (2017), Comparative Analysis of Membership Function on Mamdani Fuzzy Inference System for Decision Making. International Conference on Information and Communication Technology (IconICT) IOP Publishing IOP Conf. Series: Journal of Physics: Conf. 1(6)1:1-6

[8] L. A. Yusuf and N. Magaji (2014). Performance Comparison of Position Control of Inverted Pendulum using PID and Fuzzy Logic Controllers. Electrical Engineering Department, Bayero University Kano, Nigeria. Journal of Engineering and Technology (JET) Vol.9 No.2, August 2014.

[9] M. S. M. Aras, E. C. S. Hoo, M. H. B. Hairi, S. B. S. Salim, and I. W. A. Razak (2015). Comparison of Fuzzy Control Rules using MATLAB Toolbox and Simulink for Induction motor-speed control. International conference of soft computing and pattern recognition.

[10] H. S. Mohsen, R. A. Navid, K. Abbas, and A. M. Gholamreza (2014). A comparison of fuzzy logic and PID controllers to control transmitted power using a TCSC. Turkish Journal of Electrical Engineering & Computer Sciences. 22: 1463 – 1475 doi:10.3906/elk-1207-45

[11] A. M. Abdullahi, A. A. R. Jorge, A. Ricardo, M. S. Firdaus and A. B. Nurul (2017) Comparison of the Performance of Artificial Neural Networks and Fuzzy Logic for Recognizing Different Partial Discharge Sources. MDPI journal of energy, 2(3): 862-866

[12] K. R. Anil, R. Sandhya, S. N. Syed and K. T. Suresh (2019), Speed Control of DC Motor using Fuzzy Logic Controller by PCI 6221 with MATLAB , E3S Web of Conferences, 0100 (201 https://doi.org/10.1051/e3sconf

[13] J. Arpit, and S. Abhinav (2020), Membership Function Formulation Methods For Fuzzy Logic Systems: A Comprehensive Review, Journal of Critical Review, 7(19): 8717-8733. ISSN- 2394-5125 VOL 7, ISSUE 19, 2020

[14] M. A. H. Azman, J. M. Aris, Z. Hussain, A. A. A. Samat and A, M. Nazelan (2017), A Comparative Study of Fuzzy Logic Controller and Artificial Neural Network in Speed Control of Separately Excited DC Motor 7th IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2017), Penang, Malaysia, 7(2): 336-341

[15] A. Didem, (2019), Performance Comparison of Fuzzy Logic and PID Controller for Speed Control of DC Motor in Distribution Grid, International Research Journal of Engineering and Technology (IRJET), 6(6):649- 654

[16] M. Y. Hendra, R. Pola, D. Tresna, O. Yurni, H. Nurul and K. Sari (2019), Performance Comparison of Fuzzy Logic and Neural Network Design for Mobile Robot Navigation, International Conference on Electrical Engineering and Computer Science (ICECOS). -DOI: 10.1109/ICECOS47637.2019.8984577

[17] S. Kheir, B. Brahim, A. Ouarda, and A. K. Mohammed (2019), Type-1 and Type-2 fuzzy Sets to Control a Nonlinear Dynamic System, International journal of information and Engineering Technology Association,Revue d'IntelligenceArtificielle, 33(1): 1-7 Journal homepage: http://iieta.org/journals/ria

[18] B. Ishan and S. Bhupender (2017). Modeling and Simulation for Transformer Ratio Controlled Slip Power Recovery Scheme. International Research Journal of Engineering and Technology (IRJET), 4(7): 2395-2399.

[19] K. Ajay, S. Aggarwal, L. Saini and K. Ashwani (2011). Performance analysis of a microcontroller based slip power recovery drive. International Journal of Engineering, Science and Technology Vol. 3, No. 3, 2011, pp. 25-35

[20] M. R. Nasser and Z. M. Isa (2018), Advanced pH Control Using Fuzzy Logic. International Journal of Scientific Engineering and Science 2(2) pp. 26-30, 2018. ISSN (Online): 2456-7361

[21] H. A. Muhammad, H. H. Mohd, J. A. K. Said and H. Saima (2021), Prediction of Sunspots using Fuzzy Logic: A Triangular Membership Function-based Fuzzy C-Means Approach International Journal of Advanced Computer Science and Applications (IJACSA), 12(2):357-362

[22] B. G. Prakruthi, K. Jayasree and N. H. Manjunath (2018), Comparison of Artificial Neural Networks and Fuzzy Logic Approaches for Crack Detection in a Beam-like Structure, International Journal of Artificial Intelligence and Applications (IJAIA), 9(1):35-51

[23] Mazandarani, M., & Li, X. (2020). Fractional fuzzy inference system: The new generation of fuzzy inference systems. IEEE Access, 8, 126066-126082.

[24] Zubaidi, S. L., Al-Bugharbee, H., Ortega-Martorell, S., Gharghan, S. K., Olier, I., Hashim, K. S., ... & Kot, P. (2020). A novel methodology for prediction urban water demand by wavelet denoising and adaptive neuro-fuzzy inference system approach. Water, 12(6), 1628.

[25] Zeinalnezhad, M., Chofreh, A. G., Goni, F. A., &Klemeš, J. J. (2020). Air pollution prediction using semi-experimental regression model and Adaptive Neuro-Fuzzy Inference System. Journal of Cleaner Production, 261, 121218.

[26] Babanezhad, M., Behroyan, I., Nakhjiri, A. T., Marjani, A., Rezakazemi, M., &Shirazian, S. (2020). High-performance hybrid modeling chemical reactors using differential evolution based fuzzy inference system. Scientific Reports, 10(1), 1-11.

[27] Ilbahar, E., Karaşan, A., Cebi, S., & Kahraman, C. (2018). A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system. Safety science, 103, 124-136.

[28] Rejeesh, M. R. (2019). Interest point based face recognition using adaptive neuro fuzzy inference system. Multimedia Tools and Applications, 78(16), 22691-22710.

[29] Jain, N., & Singh, A. R. (2020). Sustainable supplier selection under must-be criteria through Fuzzy inference system. Journal of Cleaner Production, 248, 119275.

[30] Karaboga, D., & Kaya, E. (2019). Adaptive network based fuzzy inference system (ANFIS) training approaches: a comprehensive survey. Artificial Intelligence Review, 52(4), 2263-2293.

[31] Zubaidi, S. L., Al-Bugharbee, H., Ortega-Martorell, S., Gharghan, S. K., Olier, I., Hashim, K. S., ... & Kot, P. (2020). A novel methodology for prediction urban water demand by wavelet denoising and adaptive neuro-fuzzy inference system approach. Water, 12(6), 1628.