Archives of Electrical Engineering
The journal of Polish Academy of Sciences

Authors:
Sri Sri, Muhammad Bachtiar, Andarini Rini, Bayu Bayu

Decision letter:
September 05, 2020
AEE-01257-2020-01
Lightning Density Prediction Tower based on Adaptive Neuro-Fuzzy Inference System

Dear Dr. Sri Sri,

We have carefully evaluated your manuscript, entitled: Lightning Density Prediction Tower based on Adaptive Neuro-Fuzzy Inference System, and feel that as it stands we cannot accept it. We might, however, be able to accept it if you could respond adequately to the points that have been raised during the review process (see below).

Please revise your manuscript strictly according to the attached Reviewers' comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Editors of the AEE intend to strengthen the position of the Archives of Electrical Engineering. Therefore, we would appreciate it if you will rely on the papers published in our journal. As a result, it will increase the rank of the journal, and thus raised by your papers.

In the interest of the journal's further development and strengthening its position, the editors of the Archives of Electrical Engineering (AEE) quarterly request that the submitted paper quote at least one article that has been published in AEE during the last 2 years.

Thank you for submitting your paper to our journal.

Yours sincerely,
Dr Mariusz Baranski
Scientific Secretary
aee@put.poznan.pl
on behalf of
Prof. Andrzej Demenko
Editor-in-Chief
Archives of Electrical Engineering

Review 1:

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Manuscript AEE-01257-2020-01 titled “Lightning Density Prediction Tower based on Adaptive Neuro-Fuzzy Inference System” is not warranted in Archives of Electrical Engineering.
The manuscript is poor. My main comments are presented below.
1. The title of the manuscript is confusing and not appropriate.
2. The abstract is unclear.
3. The translation into English is poor, which makes some sentences difficult to understand, including the manuscript title.
4. The introduction does not contain the review of the adequate literature. The author(s) should cite relevant papers and clearly state what is new in their work.
5. The presentation is not well organized, even chaotic in some places. The entire text is not clear on what was done and why. The results are unclear.
6. A large part of the text is already known. Some statements are confusing or erroneous, e.g. a “satellite dish” applied for the lightning protection (Section 2.2) or the cone protection method claimed to “provide good protection against interference”.
7. Symbols and abbreviations are not properly explained.
8. The aim of most figures is unclear. The figures are not adequately discussed.
9. The conclusion is poor.
10. The author(s) do not give adequate references to related work.
11. No references to Matlab and/or ANFIS.

Review 2:

Comments:

1) Line 104-106 The two equations have the same numbering (4)

2) Line 110-113. The parameters hg, span1, and span2 were not explained.

3) The reason for choosing ANFIS was not clearly explained and justified in the text.

4) The illustration of the first-order TSK fuzzy inference mechanism with two inputs seems to be incomplete. The schematic diagram (Fig. 4) lacks, inter alia, the parameter A1. The section dealing with the ANFIS architecture (lines 119-145) definitely needs to be improved.

5) Fig. 6 is not discussed in the text.
What does the term "Dataanfisrev" mean in the shown flowchart?

6) Section 3.2. The Results of ANFIS
The authors did not perform a thorough analysis and discussion of the obtained

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results (the whole is limited to one paragraph).

7) The conclusions are too general and trivial.

Review 3:

The content of the manuscript is of interest, but the text it is not written in correct English and this makes the comprehension of the paper difficult to be followed. Mainly the part related to the “lightning content” of the manuscript needs to be improved, including more discussion about the formulas and methods adopted to protect transmission lines. A complete review and explanation is needed. I suggest the authors to check references from IEEE, CIGRE and ICLP conference that deals with this kind of problem.
The motivation of the work needs to be clearly presented. From the present form, it is not clear if the authors want to present a contribution on the engineering aspect of transmission line protection or if the paper reflects a contribution on the mathematical and computational aspects of the implemented methods.
The paper also presents some errors that must be checked. For example, in the beginning of the work there is an indication that the work is related to a 77 kV transmission line, but the label of Figure 1 makes reference to a 150 kV line.

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Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System

Keywords

Adaptive Neuro-Fuzzy Inference System, Lightning Density Prediction Tower, Transmission Line Arrester

Abstract

Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in the susceptibility of lightning disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The results of the calculation system for the value of structural lightning strikes in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Explanation letter

I have explained point by point revision via comments on word files. Thank you.

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Prediction of Lightning Density Value Tower based on Adaptive Neuro-Fuzzy Inference System

Abstract: Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in the susceptibility of lightning disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The results of the calculation system for the value of structural lightning strikes in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Key words: Lightning Density Prediction Tower, Adaptive Neuro-Fuzzy Inference System, and Transmission Line Arrester

1. Introduction

The growth of technology at this time electricity demand is increasing. . This development must be followed by an improvement in the quality of the electricity produced, namely the quality and reliability of the electric power system [1]. PT. Perusahaan Listrik Negara (PLN) is one of the companies tasked with planning, making, and maintaining an electric power system. This company guarantees the electric power system and the quality of electricity to consumers [2].

South Sulawesi is located in the equatorial region with a tropical climate and high humidity [3]. This condition causes South Sulawesi to have a higher level of lightning strikes. This condition causes South Sulawesi to have a higher level of lightning strikes. This lightning strike can disrupt in the distribution area (transmission and distribution) of electric power, and one of the causes of interference among the many disruptions in the electric power system occur due to lightning strikes.

Previous research has discussed several research titles concerning disorder research causes of lightning and arrester placement. A lightning strike and the performance of the arrester input it between GI Bone and GI Sinjai [4]. The effect of the earthing value due to a lightning strike in the 150 kV transmission line system, especially the GI transmission line Sungguminasa- GI Tallasa [5]. Research on modeling 132 kV transmission tower simulated using ATP-EMTP by placing a variety of arrester including, IEEE Model, Pincetti Model, and Fernandez model [6]. And this research on how get determines the strike value of the structure

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petir accurately using the ANFIS method. ANFIS is used as a means to can get the value of the structure's lightning strike on the tower transmission. Then we can determine which towers are included in the critical category on the transmission line. The results of grouping the critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to lightning in the transmission line. Critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to lightning in the transmission line.

In this paper, a study will be conducted on how to obtain accurate lightning strike density values using the ANFIS method. ANFIS is a method that is often used for predictions and forecasting, with good accuracy. ANFIS is a combination of backpropagation neural network concept with fuzzy logic concept. Backpropagation neural network has the advantage of recognizing a data/object based on a set of features that are input to the system. Meanwhile, fuzzy-based systems can be expressed with knowledge in the form of "if-then" which provides the advantage of not requiring mathematical analysis for modeling. Besides, fuzzy systems can also process human reasoning and knowledge-oriented to qualitative aspects.

Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive neural network based on a fuzzy inference system with the use of a hybrid learning procedure. ANFIS can build an input-output mapping that is both based on human knowledge (in the form of fuzzy if-then rules) with the right membership function. Fuzzy conclusion systems that utilize fuzzy if-then rules can model aspects of qualitative human knowledge and provide reasoning processes without utilizing appropriate quantitative [7][8]. In this paper, the Adaptive Neuro-Fuzzy Inference System (ANFIS) is used as a means to get the value of the structure of lightning density in the transmission tower. ANFIS is used to obtain the value of critical tower lightning density. The tower is in critical condition due to the high lightning strike value of the tower which will be input in the installation of the Transmission Line Arrester (TLA).

2. Transmission System

An electric power system consists of three main parts of a central power plant, transmission line, and distribution system. The transmission line is a link between power centers and distribution systems, and the connection between systems can also lead to other power systems. A distribution system connects all loads that are separated from each other to the transmission line [9].

2.1. Transmission Tower

The electric power that is channeled through the transmission system generally uses bare wire so that it relies on-air on as a media of insulation between the conductive wire with surrounding objects. The tower is sturdy building construction, whose function is to support/span the connecting wire with height and distance sufficient to be safe for humans and the surrounding environment.

There are three different transmission tower models examined. One of them we know is the multistory model designed [6]. A multistory tower is a composition of parameter distributions with parallel RL [10].

Several tower structures are modeled, in research [11], tower structures at a voltage of 150 kV, as shown in Figure 1.

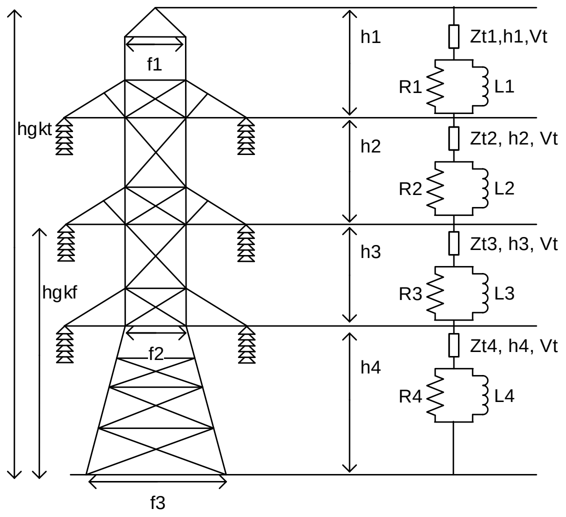

Fig.1. Tower Transmission 150 kV

2.2. Transmission Line Protection from Lightning Strikes

The conventional protection system that is commonly used is the cone protection system, which is a simple method of making a protected area by an upright conductor that is the 1st method. The second way is the Faraday Cage used for lightning protection against buildings or buildings. The third method will be discussed later by using a rolling ball. For the 4th way, similar to the 3rd way, but the drawing model uses a *satellite dish method*. By selecting several methods used are the Cone protection method (existing design) and the Rolling sphere method (design improvement).

Existing design (Cone protection method) method is used to facilitate the determination of a good protection angle, in determining the magnitude of the angle that can provide good protection against interference, especially in lightning strikes, can be seen in Figure 2.

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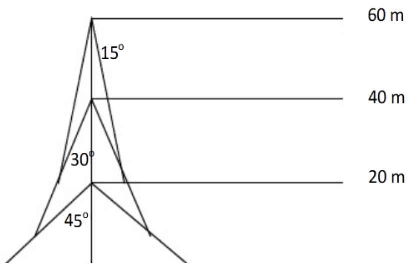

Fig.2. Cone Model Lightning Protection System

The rolling sphere method is an electrometric concept or rolling ball method connecting the distance of lightning to its peak current. This concept says that an imaginary ball with the lead of the leader at the center of the ball is rolled into a structure. All contact points that hit the surface of the ball will then be struck by lightning. This method is very easy in determining the design of reliable lightning protection. The following is Figure 3. which shows a 150 kV SUTT tower using the Rolling sphere method [12][13].

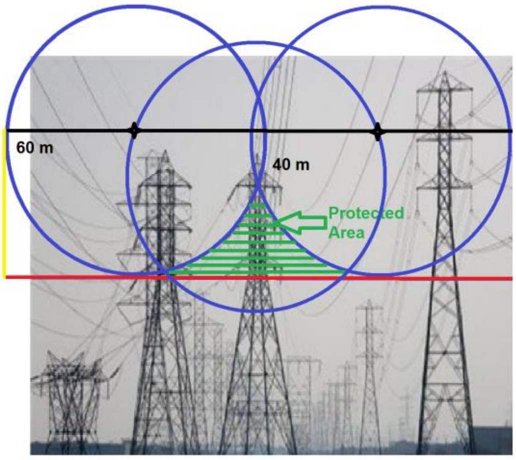

Fig.3. SUTT Tower 150 kV using Rolling Sphere Method

The concept of electrometry or the rolling ball method relates the distance of the lightning strike to its peak current. This concept states that an imaginary sphere with the leading tip at the center of the ball rolls into a structure. All points of contact that hit the surface of the ball will then be struck by lightning. This method makes it very easy to determine a reliable lightning protection design. From the analysis, it is found that the height of the high-voltage overhead tower affects the disturbance that occurs due to lightning strikes. And to minimize transmission disruption due to lightning strikes, the existing design method (Cone protection method) can be used very well for lightning strike protection while the rolling sphere method is better because it is more reliable in protecting lightning strikes on transmission lines 150 kV.

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2.3. Calculation of Lightning Structure Value of Lightning Tower

An overhead transmission line can be said to form a shadow of electricity on the ground below the transmission line. The width of the electric shadow for a transmission line has been provided [14].

$$hgwkt=hgkt-1/2(hgkt-hgkf) \quad (1)$$

$$hg=hgkt-2/3\ (hgkt-hgwkt) \quad (2)$$

The width of the shadow is formulated:

$$W2=\left(b+4.hg^{1.09}\right) \quad (3)$$

The span of tower 2 is the average distance from the tower to tower.
Area of shadows for a transmission span (L) :

$$L2=(span\ 1+span\ 2)/2\ \ meters \quad (4)$$

The span protection area (A2):

$$A2=W2\times L2 \quad (5)$$

The lightning density on the tower (Nd):

$$N_d=0.15\ IKL.A \quad (6)$$

Where: $\boldsymbol{hgkt}$ is the maximum height of the ground wire, $\boldsymbol{hgkf}$ is Maximum Height of phase wire, $\boldsymbol{hg}$ is Heigh of Tower $\boldsymbol{hgwkt}$ is Maximum height of ground wire in span, $\boldsymbol{b}$ is distance between ground wires, $\boldsymbol{W2}$ is Protection shadow width, $\boldsymbol{L2}$ is Average tower distance, **Span 1** is distance for tower 1, **Span 2** is distance for Tower 2 or after the tower before. $\boldsymbol{A2}$ is Area of protection, $\boldsymbol{N_d}$ is Value of strikes on structure (annual strokes).

2.4. Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive network based on a fuzzy inference system. By using a hybrid learning procedure, ANFIS can build an input-output mapping that is both based on human knowledge (in the form of fuzzy if-then rules) with an appropriate membership function.

Illustration of first-order TSK fuzzy inference mechanism with two inputs x and y [8]. Rule base with two fuzzy if-then rules as below:

Rule 1: $if\ x\ is\ A_1\ and\ y\ is\ B_1$ then $f_1=p_{1x}+q_{1y}+r_1$

premise consequent

Rule 2: $if\ x\ is\ A_2\ and\ y\ is\ B_2$ then $f_2=p_{2x}+q_{2y}+r_2$

premise consequent

Input: x and y Consequent are f.

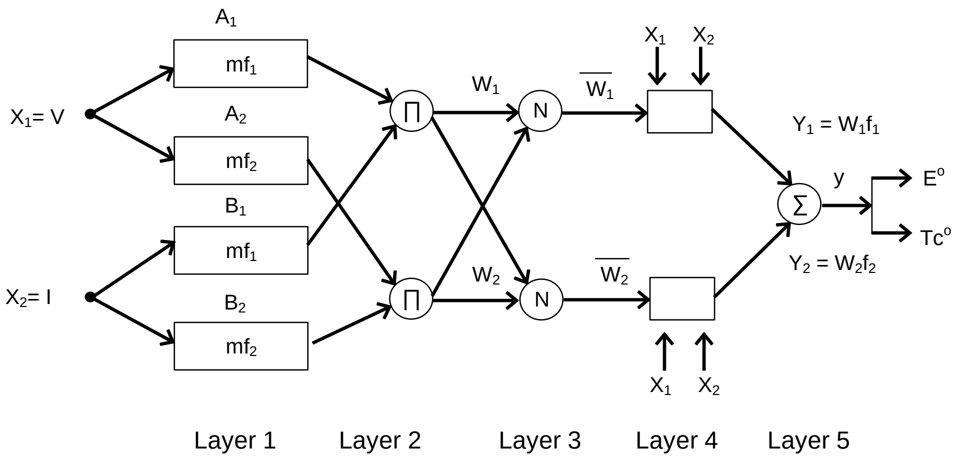

Fig.4. ANFIS structure for the first-order

The ANFIS architecture consists of five layers, each of which has functions that can be explained as follows:

1. Layer 1: Serves as a fuzzy process. The output of node i on layer 1 is denoted as Oi. So, each node in layer 1 functions to generate a degree of membership (part of the premise)
2. Layer 2: Notated π. Each node in this layer functions to calculate the activation strength (firing strength) on each rule as a product of all incoming inputs
3. Layer 3: Denoted by N. Each node in this layer is non-adaptive which functions only to calculate the ratio between firing strength in the I rule to the total firing strength of all rules
4. Layer 4: Each node in this layer is adaptive w_1 'is the output of layer 3 $(p_{1x} + q_{1y} + r_1)$ is the set of parameters in the first order Sugeno fuzzy model
5. Layer 5: A single node denoted $\sum$ on this layer functions to aggregate all output from layer 4.

2.6. Strengths and Weakness of ANFIS

The control system used will use a system that combines a fuzzy system and an artificial neural network system. This system is known as the neuro-fuzzy system or ANFIS.

The basis of the integration is the advantages and disadvantages of each system. Artificial neural networks can recognize the system through a learning process to improve adaptive parameters. The advantage of fuzzy inference systems is that they can translate knowledge from experts in the form of rules, but it usually takes a long time to determine the membership function. Therefore it takes learning techniques from artificial neural networks to automate the process so that it can reduce search time; this causes the ANFIS method to be very well applied in various fields. The weakness of this system is the complexity of the structure. The

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fuzzy system has a concept similar to the concept of human thinking. The combination of the two will complement each other's strengths and weaknesses. Several studies have been carried out to see the comparison between ANFIS and Fuzzy Logic Controller (FLC), the ANFIS results are better than LFC [15][16]. There are also studies on the comparison of ANFIS and Artificial Neural Network (ANN), the results of this study indicate that ANFIS is better than ANN [17]. And other studies also compared ANFIS with some Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA). The results of this study indicate that ANFIS is better than Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA) [18].

3. Simulation Result and Discussion

Processing calculation data into artificial intelligence to make it easier to get the value of the lightning strike density of the tower [19]. The artificial intelligence used is the Adaptive Neuro-Fuzzy Inference System (ANFIS).

The results of the calculation of the lightning strike value in the form of whitehead then become input data for data processing in ANFIS, Process Stages of Simulation:

a. Data Load Phase (Data Entering Phase)
b. The Generate FIS Phase (Generating FIS Stage)
c. FIS Training Stage (FIS Learning Stage)
d. FIS Test Stage (FIS Validation Stage)

3.1. Learning Process Model (Training)

Based on the comparison of RMSE (Root Mean Square Error) learning process (training) in Table 5, the most optimal method for this case is:

a. Learning Algorithm: Hybrid method
b. Type of Membership Function (MF): psignmf
c. Epoch: 50
d. Error tolerance: 0
e. Input Parameters: (3 3 3 3) f.

Consists of 81 rules The method is taken from the lowest error rate.

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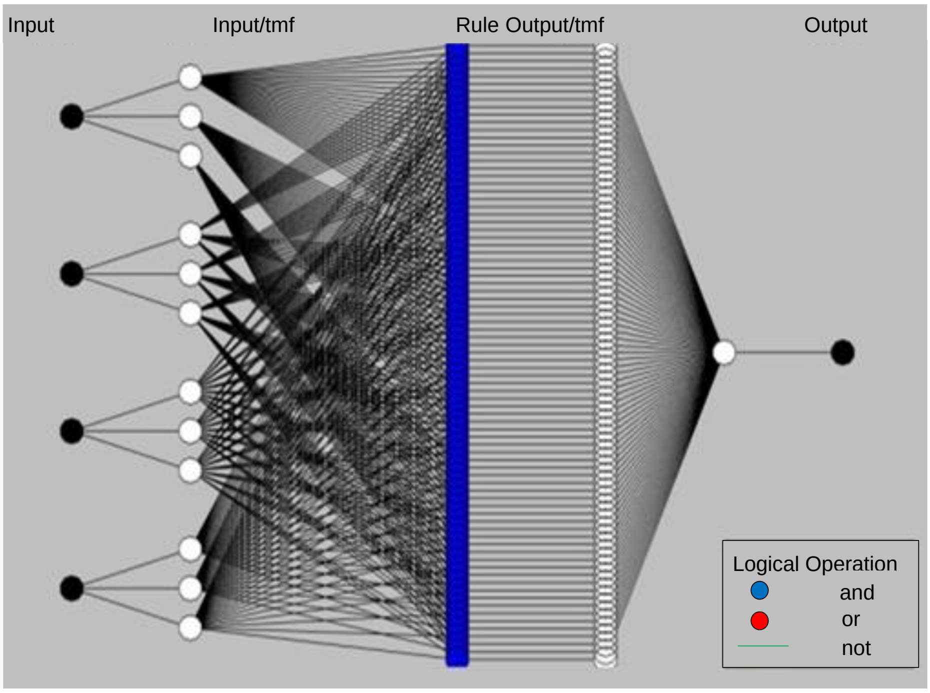

Fig.5. Learning Process Model (Training)

In Figure 5 shows ANFIS neurons consisting of 4 inputs and one output and 81 rules.

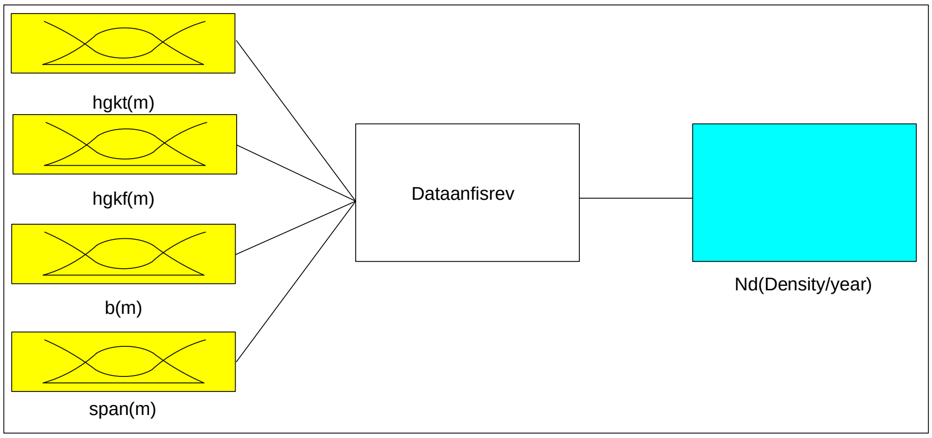

Fig.6. FIS Learning Editor (Training)

To make it easier to see the rule, we can see the surface viewer in Figure 7 through Figure 6 to see the relationship between the four inputs and the output of the ANFIS. Figure 6 shows there are four input (*hgkt* , *hgkf, b, and span*) and one output (*Nd*). Dataanfisrev is a traning process in anfis processing to produce output of the ANFIS .

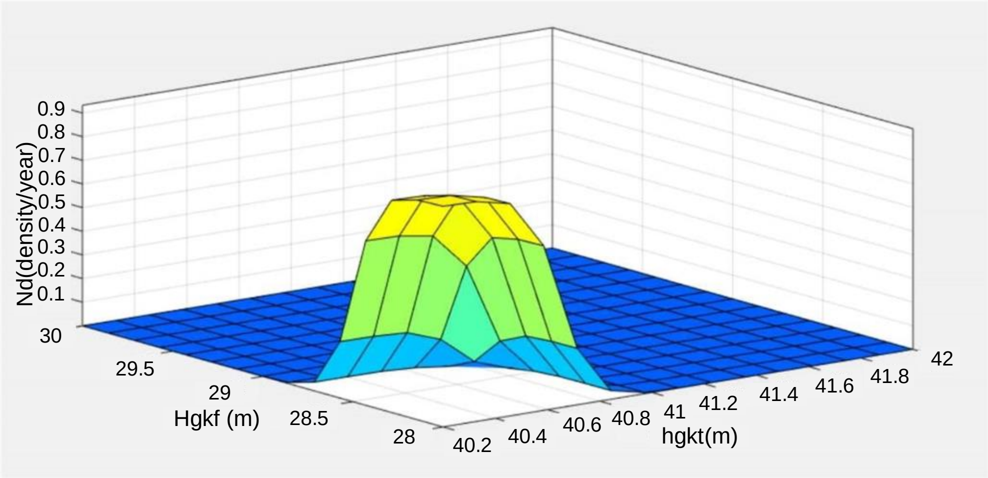

Fig.7. Surface viewer between Hgkt and Hgkf

Figure 7 shows the surface viewer of Hgkt, Hgkf, and Nd where the X-axis is Hgkt Y-axis is Hgkf and the Z-axis is Nd.

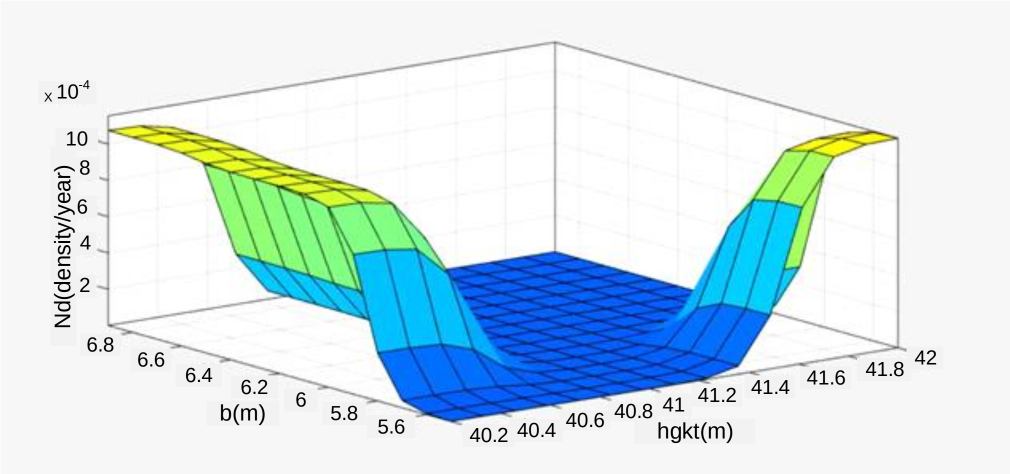

Fig.8. Surface viewer between Hgkt and b

Figure 8 shows the surface viewer of Hgkt, b, and Nd where the X-axis is Hgkt the Y-axis is b and the Z-axis is Nd.

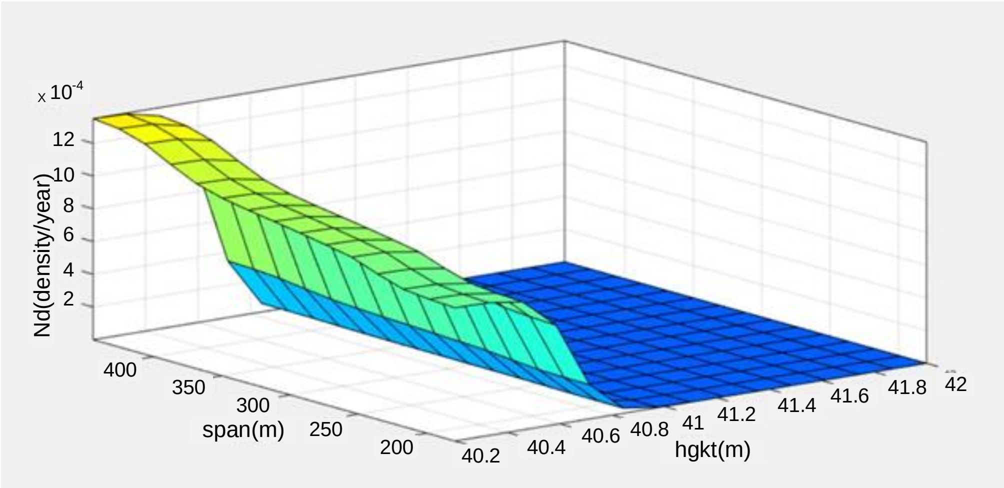

Fig.9. Surface viewer Hgkt and span distance

Figure 9 shows the surface viewer of Hgkt, span, and Nd where the X-axis is Hgkt Y-axis is span distance and the Z-axis is Nd.

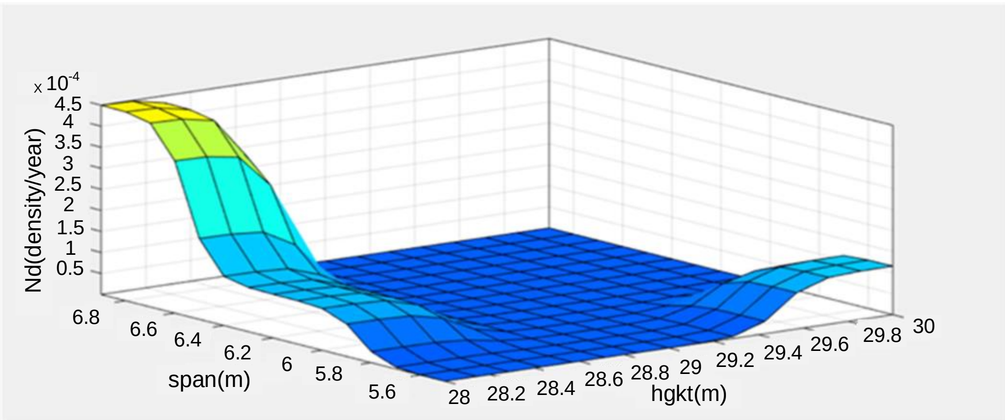

Fig.10. Surface viewer Hgkf and b

Figure 10 shows the surface viewer of Hgkf, b, and Nd where the X-axis is Hgkf the Y-axis is b and the Z-axis is Nd.

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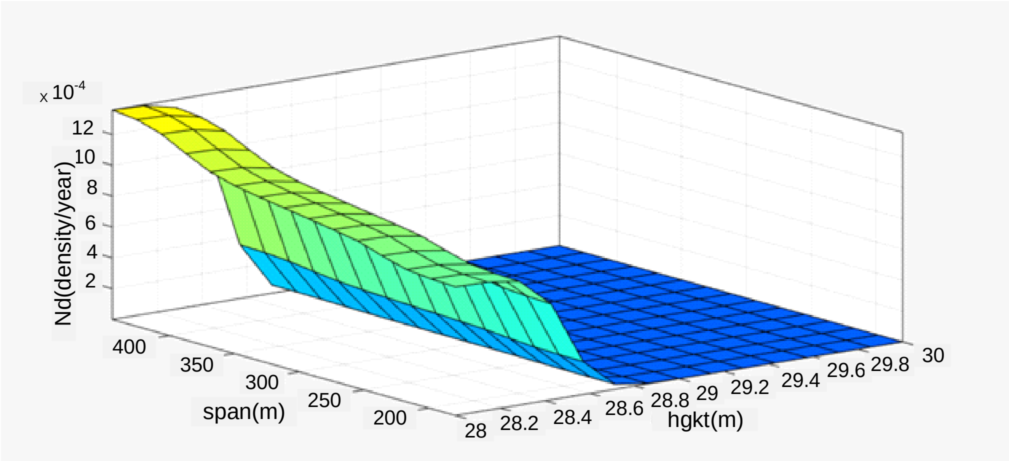

Fig.11. Surface viewer Hgkf and Span Distance

Figure 11 shows the surface viewer of Hgkf, span distance, and Nd where the X-axis is Hgkf the Y-axis is Span distance and the Z-axis is Nd.

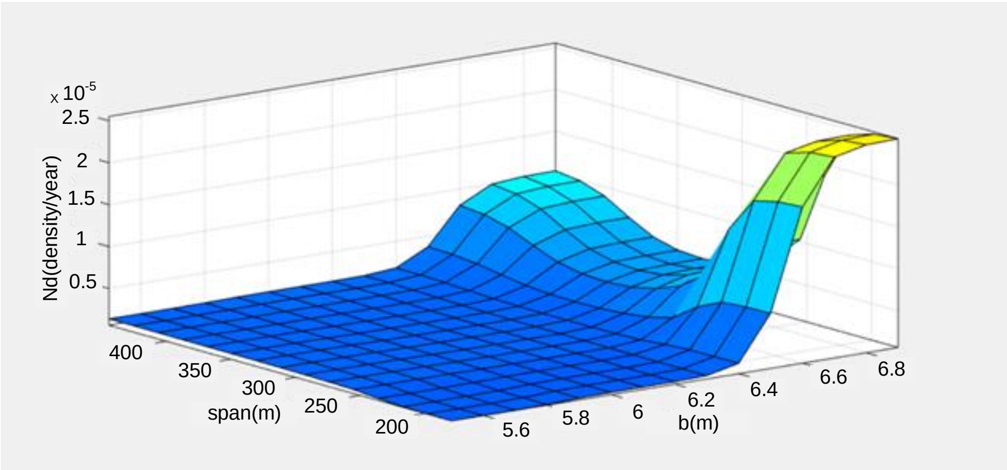

Fig.12. Surface Viewer Span Distance and b

Figure 12 shows a surface viewer of b, span distance, and Nd where the X-axis is b the Y-axis is the span distance and Z-axis is Nd.

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3.2. The Results of ANFIS

Table 1. RMSE comparison of hybrid and backpropagation methods

RMSE (Root Mean Square Error)				
Membership Function	*Data training*		*Data Testing*	
	Hybrid	*Backpropagation*	*Hybrid*	*Backpropagation*
Trimf	0.07589	0.48271	0.07589	0.47364
Trapmf	0.07886	0.46583	0.07886	0.45786
gbellmf	0.07597	0.51851	0.07597	0.50895
gaussmf	0.07592	0.49996	0.07592	0.49049
gauss2mf	0.07782	0.46550	0.07782	0.45746
pimf	0.07989	0.46534	0.07989	0.45754
dsignmf	0.07588	0.44199	0.07588	0.43343
psignmf	0.07588	0.44181	0.07588	0.43325

In Table 1 shows the comparison of RMSE for the two methods, Hybrid and Backpropagation in the learning process (training) and the validation process (testing). The lowest RMSE in the learning process is 0.07588 for training data and 0,07588 for testing with dsignmf and psignmf membership functions.

From the results obtained through ANFIS, the results are loading and testing, ANFIS can predict through the lightning density values that often appear when a lightning strike occurs based on tower input data that has been processed by ANFIS.

3.3. GUI (Graphical User Interface)

The display of the model of determining the value of the structure of lightning strikes based on adaptive neuro-fuzzy inference systems uses the Matlab software, with lightning strike value output. The rule used is from the ANFIS rule with the AND logic function. The display of the lightning strike value structure based on the adaptive neuro-fuzz inference system is shown in Figure 13.

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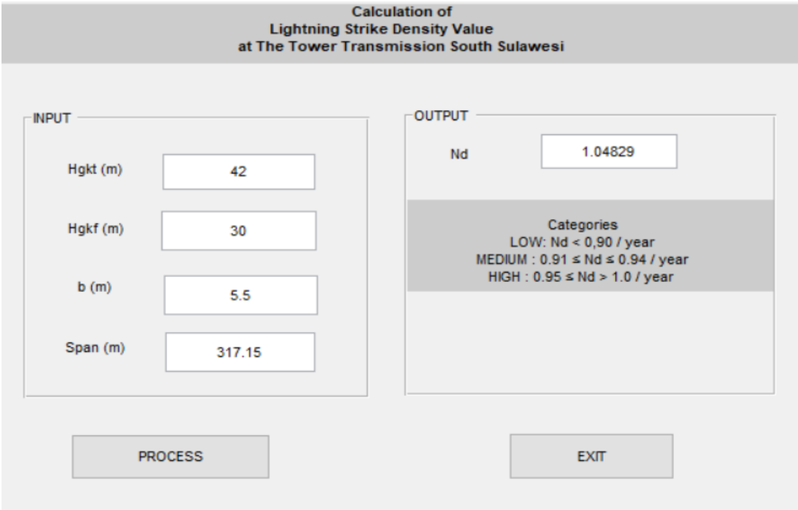

Fig.13. Display GUI Prediction of Lightning Strike Tower Value

3. Conclusions

In this paper , it can be analyzed and concluded several things that are needed to determine the value of the lightning strike structure of the South Sulawesi region:

1. The resulting ANFIS simulation with hybrid algorithm and backpropagation algorithm hybrid and backpropagation algorithm with *trimf, tramf, gbellmf, and gaussmf* functions shows the comparison of RMSE for the two methods, namely Hybrid and Backpropagation in the learning process (*training*) and the validation process (*testing*). The lowest RMSE in the learning process is 0.07588 with the gaussmf membership function for training and testing data.
2. The results of the calculation system for the value of structural lightning strikes in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.
3. From this research we can make it suitable to calculate the value of the lightning density (Nd) by using ANFIS which is then programmed in the form of a GUI. This GUI makes it easy to find out the lightning density (Nd) value on the tower.

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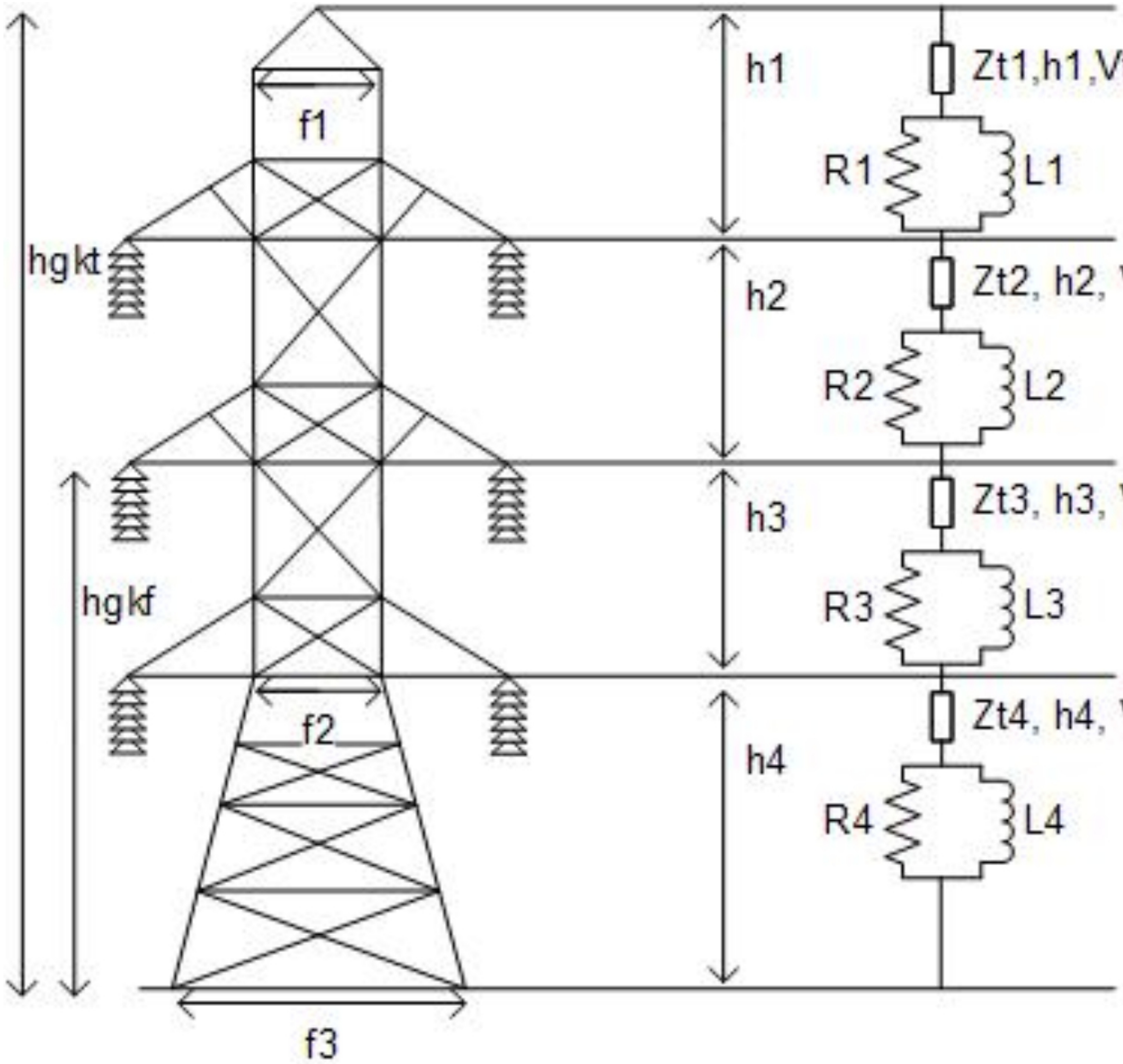

Figure 2
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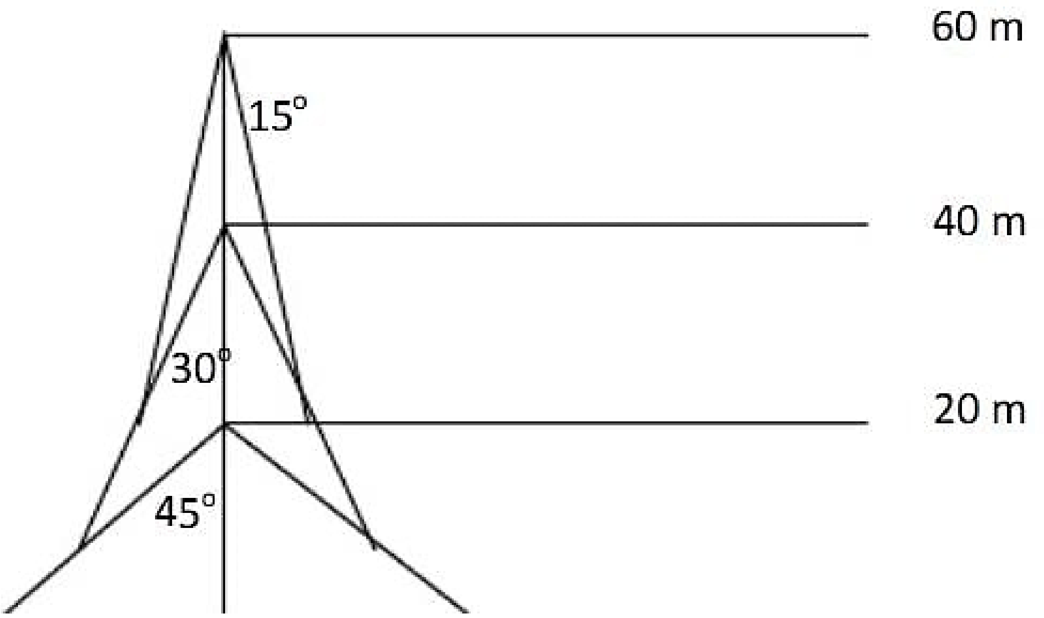

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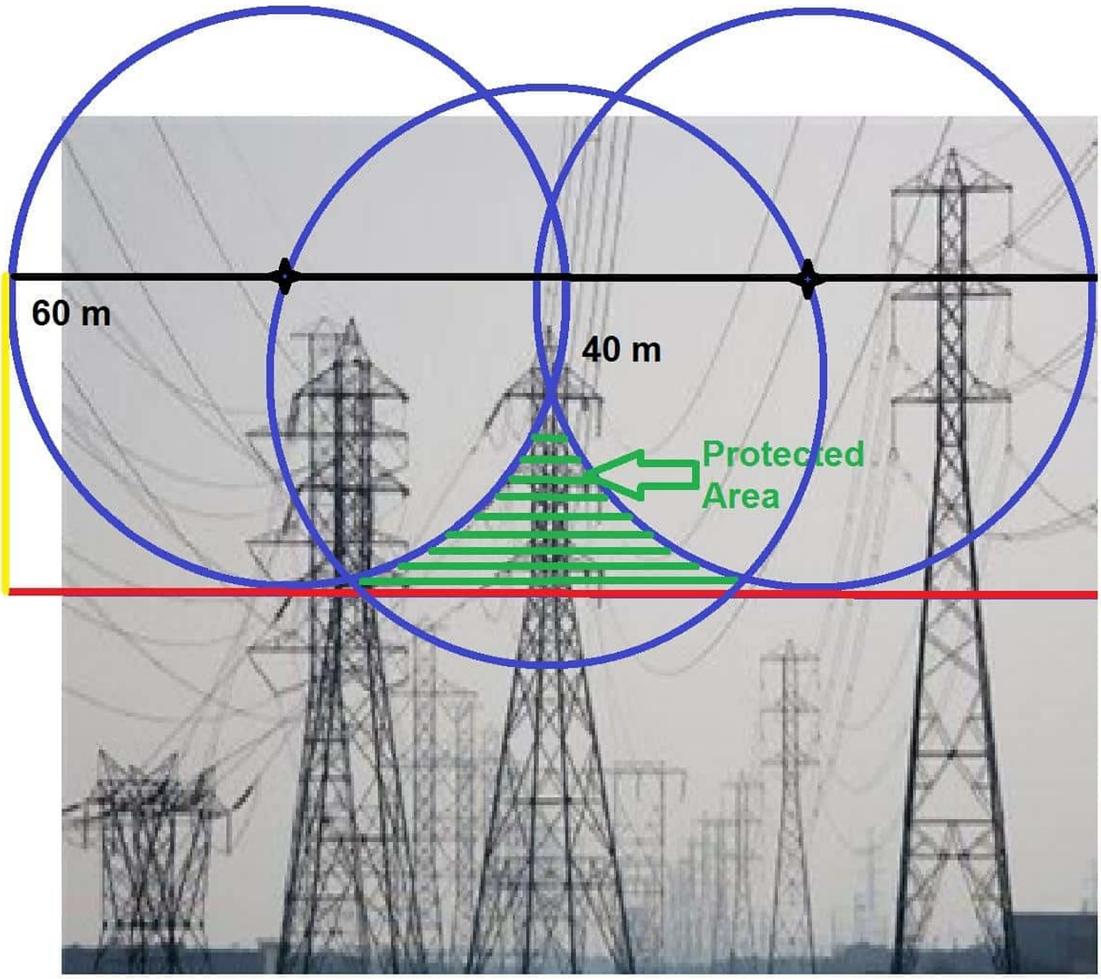

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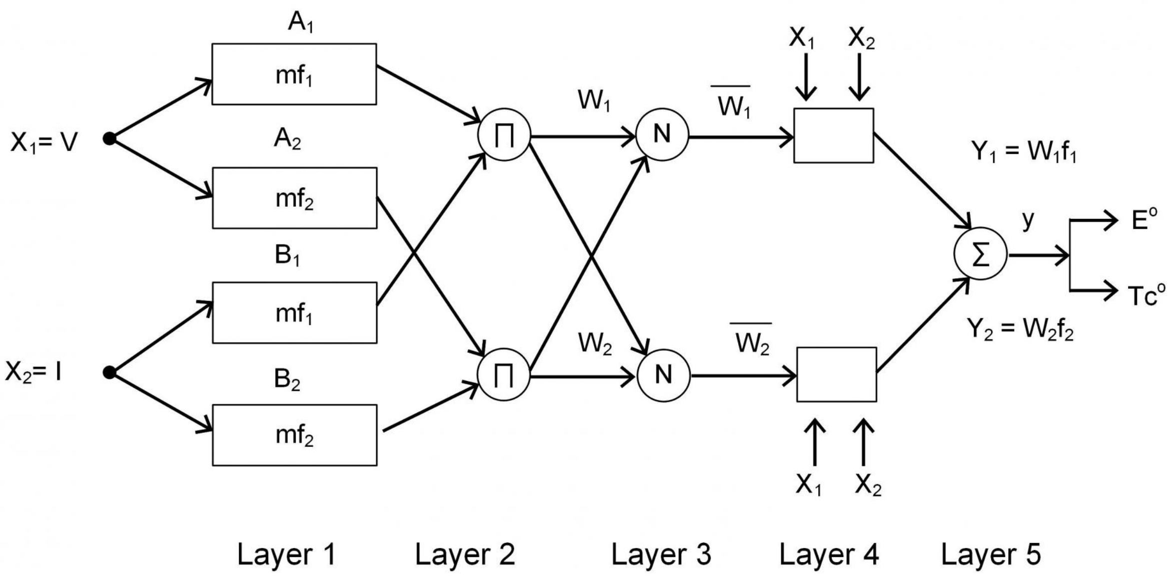

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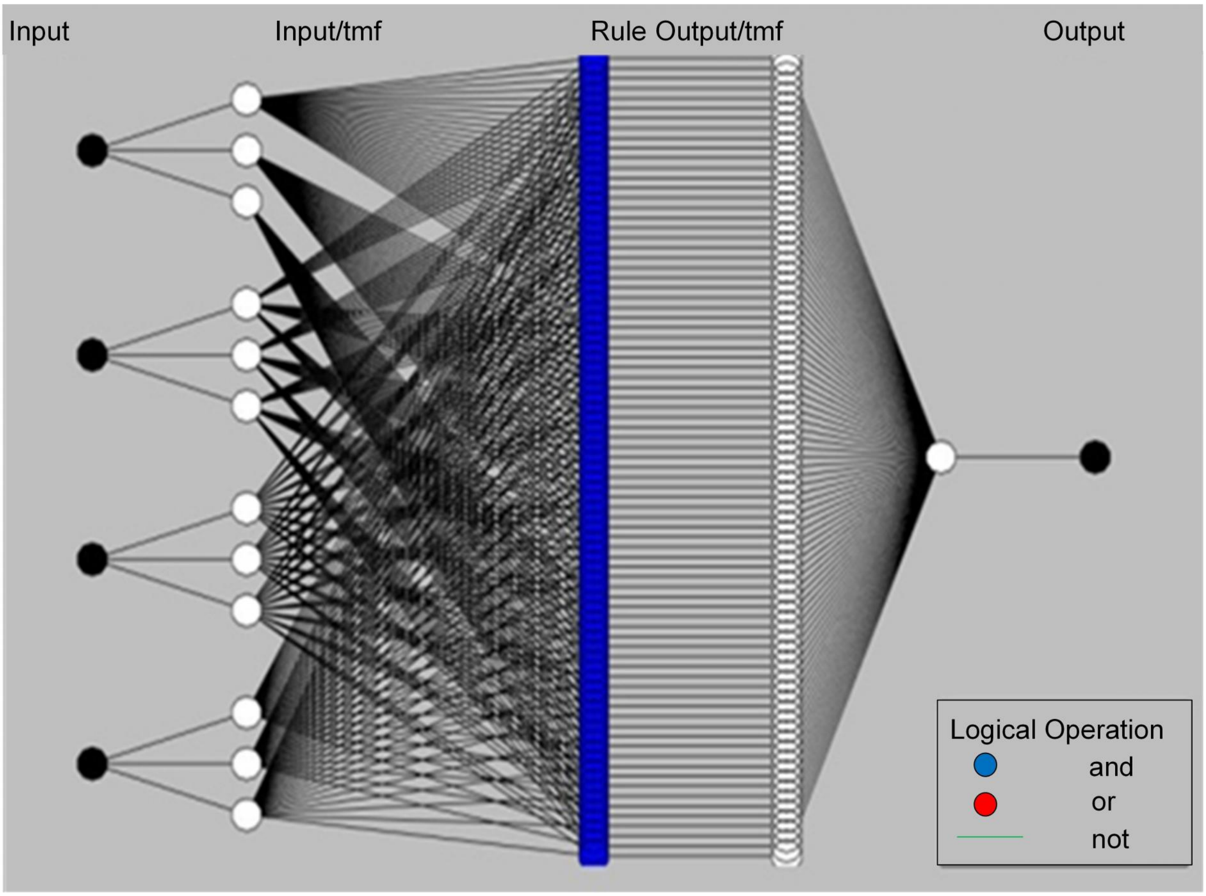

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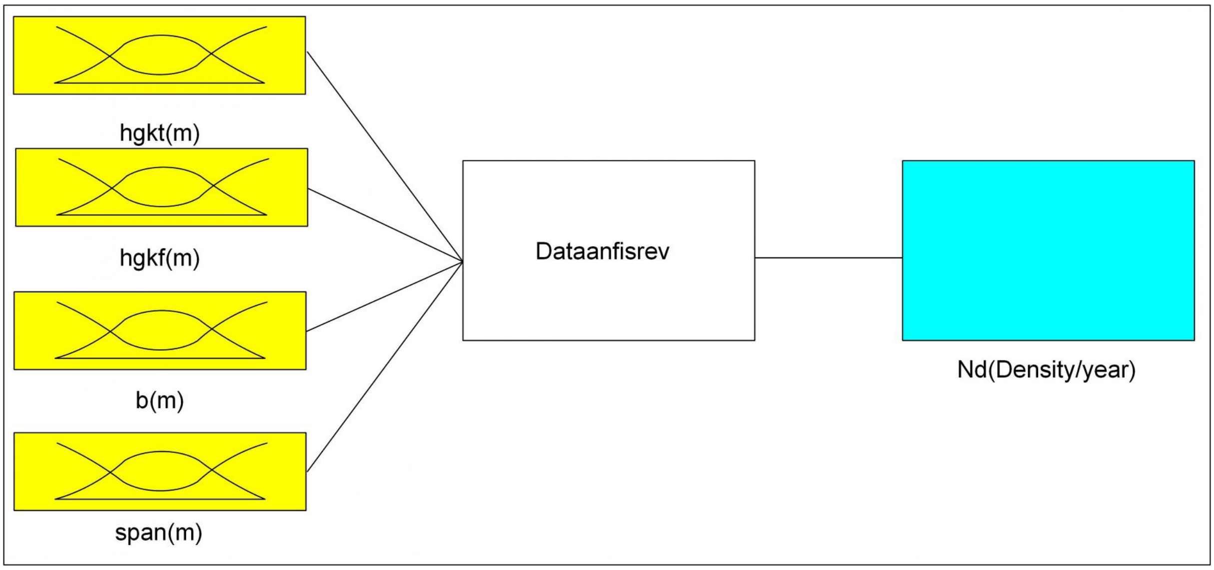

Figure 7

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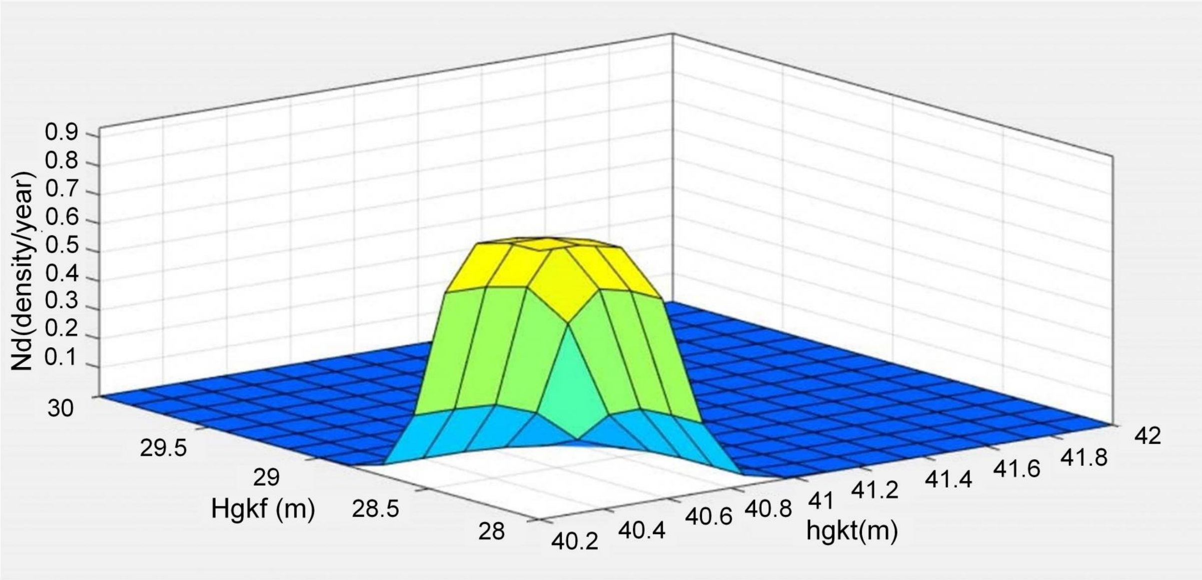

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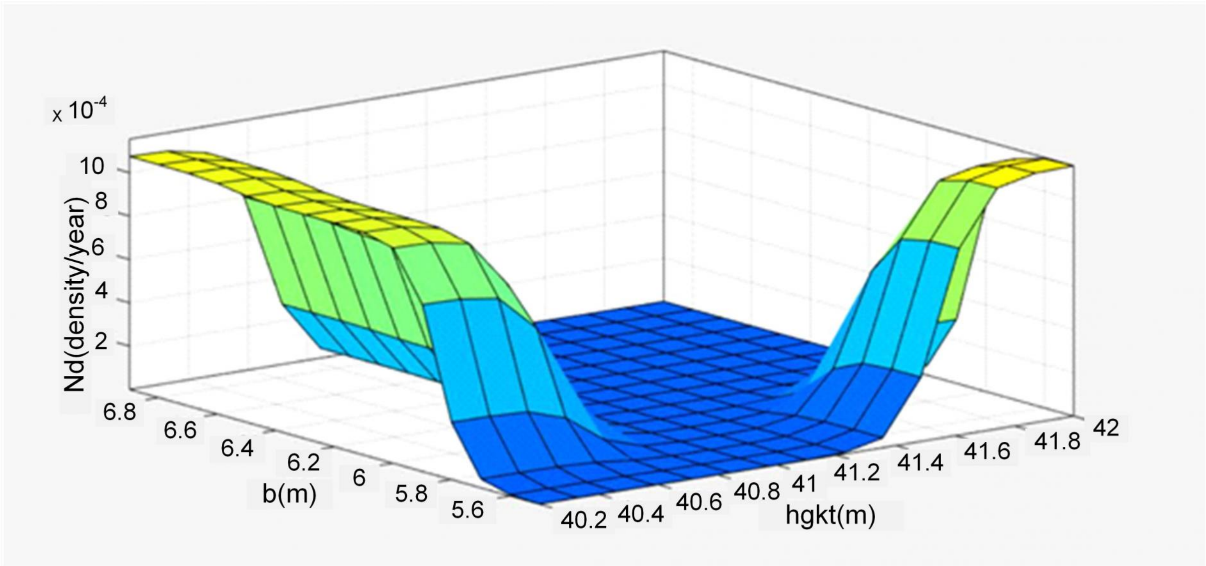

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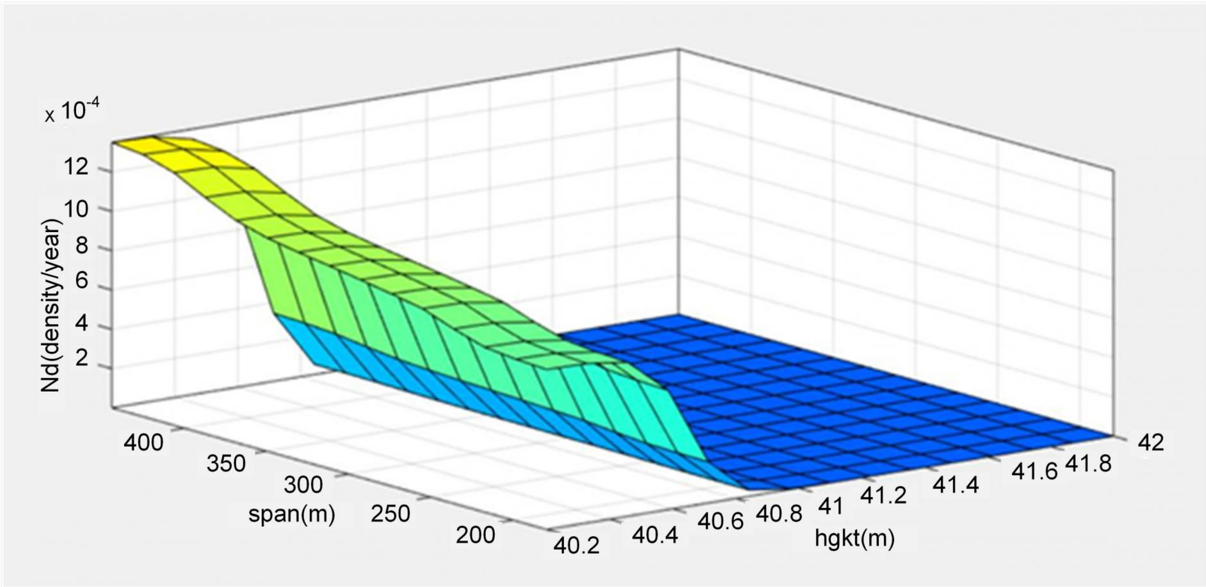

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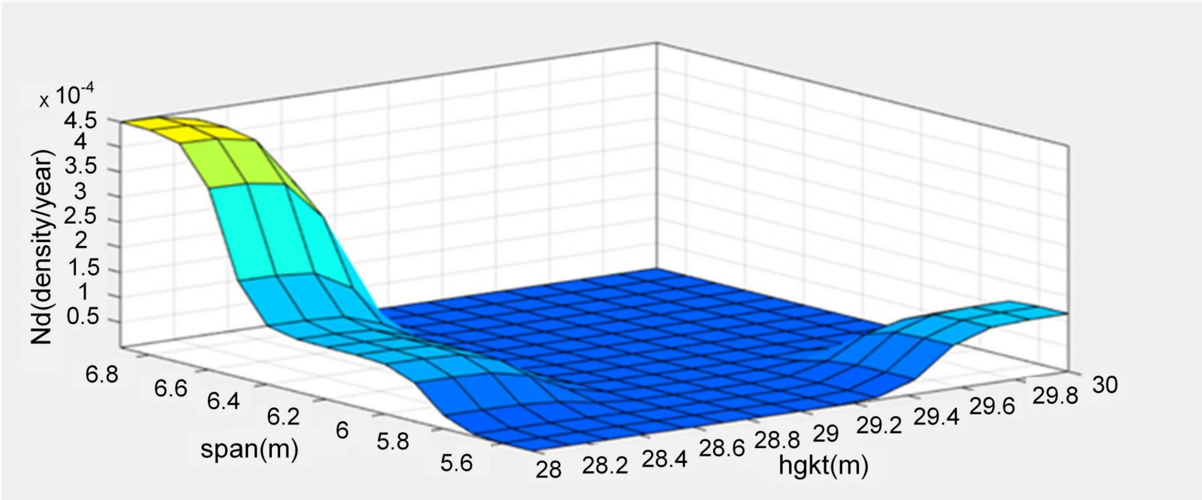

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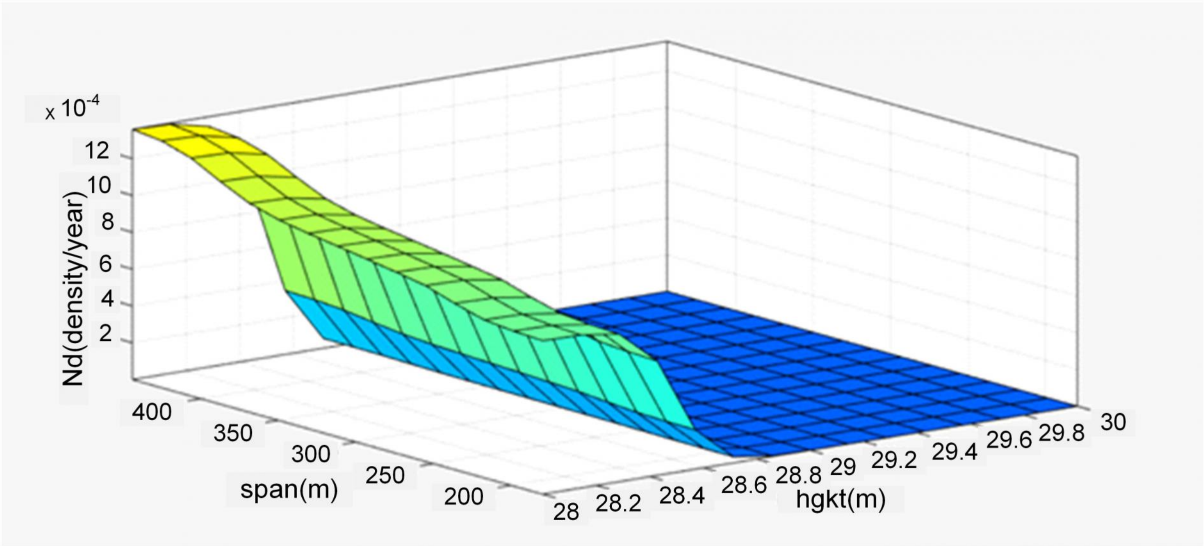

Figure 12

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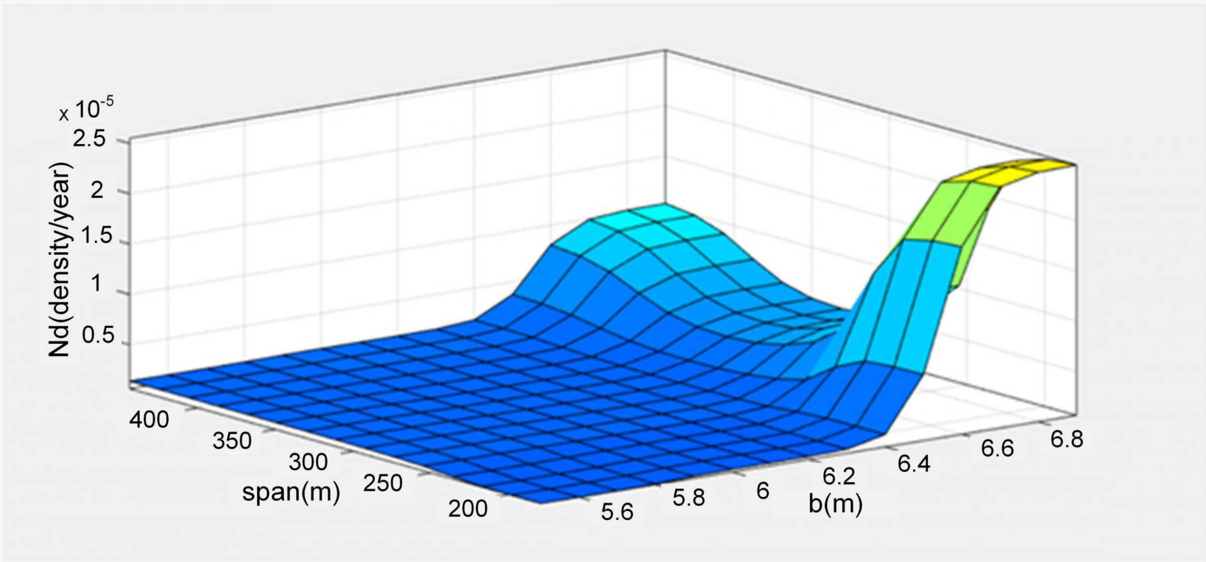

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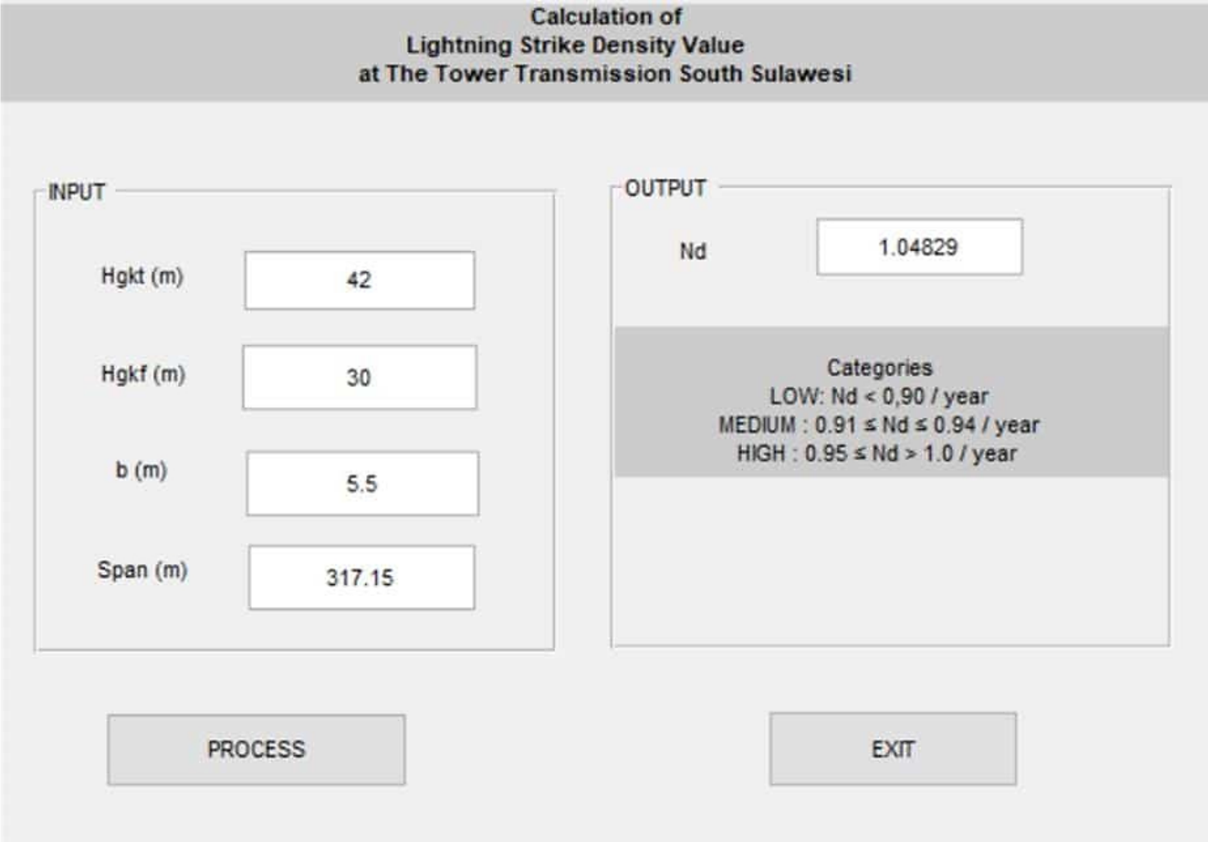

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Figures

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Figure 4 - Download source file (202.97 kB)

Figure 5 - Download source file (685.54 kB)

Figure 6 - Download source file (346.28 kB)

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Figure 8 - Download source file (384.44 kB)

Figure 9 - Download source file (391.71 kB)

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Authors:
Sri Sri, Muhammad Bachtiar, Andarini Rini, Bayu Bayu

Decision letter:
December 08, 2020
AEE-01257-2020-03
Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System

Dear Dr. Sri Sri,

We have carefully evaluated your manuscript, entitled: Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System, and feel that as it stands we cannot accept it. We might, however, be able to accept it if you could respond adequately to the points that have been raised during the review process (see below).

Please revise your manuscript strictly according to the attached Reviewers' comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Editors of the AEE intend to strengthen the position of the Archives of Electrical Engineering. Therefore, we would appreciate it if you will rely on the papers published in our journal. As a result, it will increase the rank of the journal, and thus raised by your papers.

In the interest of the journal's further development and strengthening its position, the editors of the Archives of Electrical Engineering (AEE) quarterly request that the submitted paper quote at least one article that has been published in AEE during the last 2 years.

Thank you for submitting your paper to our journal.

Yours sincerely,
Dr Mariusz Baranski
Scientific Secretary
aee@put.poznan.pl
on behalf of
Prof. Andrzej Demenko
Editor-in-Chief
Archives of Electrical Engineering

Review 1:

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Dear Authors,

thank you for your comprehensive response to all my questions and remarks. In my opinion, the quality of the manuscript has been improved, all changes suggested by the reviewers have been taken into account by the Authors.

Review 2:

I understand the effort done by the authors to improve the manuscript and attend all the reviewers' requirements. Some modifications were implementes, mainly on the presentation of the formulation and figures. However, the text still needs several improvements on the use of English that is very poor. The text still presents several repetition of sentences (please, check again the introduction), leading to misunderstandings along the manuscript.
The content related to the Adaptive Neuro-Fuzzy tool looks fine but the physical and engineering aspects of the problem under investigation (the lightning attractiveness of the tower, the model adopted in simulations, advantages and drawbacks of the model, etc) are completely dismissed.

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Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System

Keywords

Adaptive Neuro-Fuzzy Inference System, Lightning Density Prediction Tower, Transmission Line Arrester

Abstract

Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in the susceptibility of lightning disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The results of the calculation system for the value of structural lightning strikes in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Explanation letter

Reviewer 1 has no more revisions. We only revise from reviewer 2. Thank you so much.

DOI 10.24425/aee./..

Prediction of Lightning Density Value Tower based on Adaptive Neuro-Fuzzy Inference System

Abstract: Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in lightning susceptibility of disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The calculation system results for the value of structural lightning struck in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Keywords: Lightning Density Prediction Tower, Adaptive Neuro-Fuzzy Inference System, and Transmission Line Arrester

1. Introduction

With the growth of technology, electricity demand is increasing, and an improvement must follow this development in the quality of the electricity produced, namely the electric power system's quality and reliability [1]. *PT. Perusahaan Listrik Negara* (PLN) is a company tasked with planning, making, and maintaining an electric power system in Indonesia. This company guarantees the electric power system and the quality of electricity to consumers [2].

South Sulawesi is located in the equatorial region with a tropical climate and high humidity [3]. The condition causes South Sulawesi to have a higher level of lightning strikes, and a bolt of higher lightning strikes level. This lightning strike can disrupt the distribution area (transmission and distribution) of electric power. One of the causes of interference among the many disruptions in the electric power system occurs lightning strikes.

Previous research has discussed several research titles concerning disorder research causes of lightning and arrester placement. A lightning strike and the performance of the arrester input it between GI Bone and GI Sinjai [4]. The earthing value is due to a lightning strike in the 150 kV transmission line system, especially the GI transmission line Sungguminasa- GI Tallasa [5]. Research on modeling 132 kV transmission tower simulated using ATP-EMTP by placing various arrester including, IEEE Model, Pincetti Model, and Fernandez model [6]. And this research on how to get determines the lighting structure's strike value accurately using the ANFIS method. ANFIS is used to get the value of the structure's lightning strike on the tower transmission. Then we can determine which towers are included in the critical

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category on the transmission line. The results of grouping the critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to lightning in the transmission line. The critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to the lightning transmission line.

In this paper, a study will be conducted on obtaining accurate lightning strike density values using the ANFIS method[7][8]. ANFIS is a method that is often used for predictions and forecasting, with good accuracy. ANFIS is a combination of the backpropagation neural network concept with the fuzzy logic concept. Backpropagation neural network has the advantage of recognizing a data/object based on a set of features that are input to the system. Meanwhile, fuzzy-based systems can be expressed with knowledge in the form of "if-then," which provides the advantage of not requiring mathematical analysis for modeling. Besides, fuzzy systems can also process human reasoning and knowledge-oriented to qualitative aspects.

ANFIS is an adaptive neural network based on a fuzzy inference system using a hybrid learning procedure. ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with the right membership function. Fuzzy conclusion systems that utilize fuzzy if-then rules can model qualitative human knowledge aspects and provide reasoning processes without utilizing appropriate quantitative [9][10]. In this paper, the ANFIS is used to get the value of the structure of lightning density in the transmission tower. ANFIS is used to obtain the value of critical tower lightning density. The tower is in critical condition due to the tower's high lightning strike value, which will be input in the installation of the Transmission Line Arrester (TLA).

2. Transmission System

An electric power system consists of three main parts of a central power plant, transmission line, and distribution system. The transmission line is a link between power centers and distribution systems. The connection between systems can also lead to other power systems. A distribution system connects all loads separated from each other to the transmission line [11].

2.1. Transmission Tower

The electric power channeled through the transmission system generally uses bare wire to rely on-air as a media of insulation between the conductive wire with surrounding objects. The tower is sturdy building construction whose function is to support/span the connecting wire with height and distance sufficient to be safe for humans and the surrounding environment.

There are three different transmission tower models examined. One of them we know is the multistory model designed [6]. A multistory tower is a composition of parameter distributions with parallel RL [12].

Several tower structures are modeled, in research [13], tower structures at a voltage of 150 kV, as shown in Figure 1.

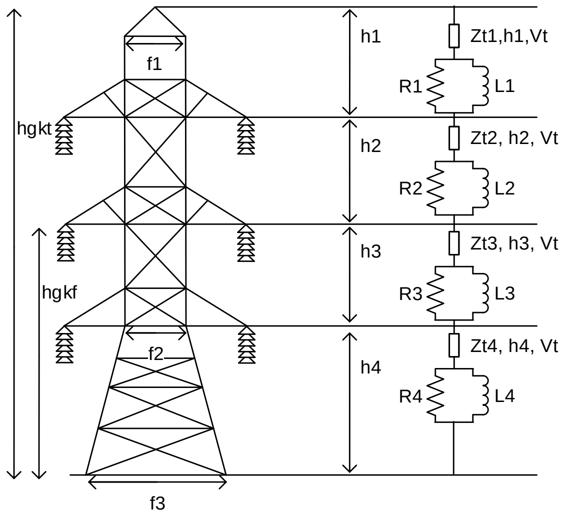

Fig.1. Tower Transmission 150 kV

In this paper, a study has used a 150 kV tower because generally electricity in Indonesia uses a 150 kV tower. The data that has been researched is data from PLN and PLN uses a 150 kV tower in the South Sulawesi area. The disadvantage of 150 kV towers is that the short distance, but one of the advantages of a 150 kV tower is that with a voltage of 150 kV it is still possible to distribute 400 MVA of power/circuit.

2.2. Transmission Line Protection from Lightning Strikes

The conventional protection system commonly used is the cone protection system, which is a simple method of making a protected area by an upright conductor called the 1st method. The second way is the Faraday Cage used for lightning protection against buildings or buildings. The third method will be discussed later by using a rolling ball. For the 4th way, similar to the 3rd way, the drawing model uses a *satellite dish method*. The Cone protection method (existing design) and the Rolling sphere method (design improvement) are selected by selecting several methods.

The existing design (Cone protection method) method is used to facilitate the determination of a good protection angle. Determining the magnitude of the angle that can provide good protection against interference, especially in lightning strikes, can be seen in Figure 2.

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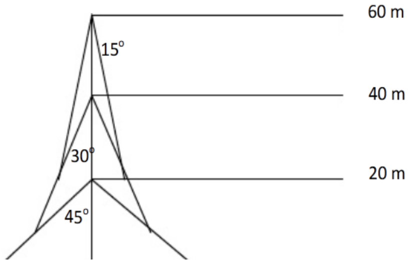

Fig.2. Cone Model Lightning Protection System

The rolling sphere method is an electrometric concept or rolling ball method connecting the distance of lightning to its peak current. This concept says that an imaginary ball with the lead of the leader at the center of the ball is rolled into a structure. All contact points that hit the surface of the ball will then be struck by lightning. This method is straightforward in determining the design of reliable lightning protection. Figure 3 shows a 150 kV SUTT tower using the Rolling sphere method [14][15].

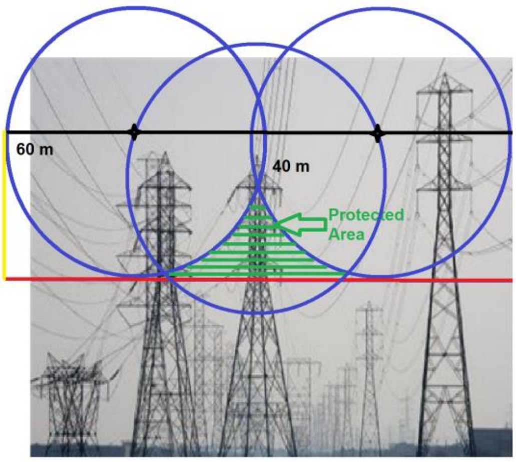

Fig.3. SUTT Tower 150 kV using Rolling Sphere Method

The electrometry concept or the rolling ball method relates the distance of the lightning strike to its peak current. The concept states an imaginary sphere with the leading tip at the center of the ball rolls into a structure. All points of contact that hit the surface of the ball will then be struck by lightning. This method makes it very easy to determine a reliable lightning protection design. The analysis shows that the height of the high-voltage overhead tower affects the disturbance that occurs due to lightning strikes. And to minimize transmission disruption due to lightning strikes, the existing design method (Cone protection method) can be used very well for lightning strike protection, while the rolling sphere method is better because it is more reliable in protecting lightning strikes on transmission lines 150 kV.

2.3. Calculation of Lightning Structure Value of Lightning Tower

An overhead transmission line can form a shadow of electricity on the ground below the transmission line. The width of the electric shadow for a transmission line has been provided [16].

$$hgwkt=hgkt-1/2(hgkt-hgkf) \quad (1)$$

$$hg=hgkt-2/3\,(hgkt-hgwkt) \quad (2)$$

The width of the shadow is formulated:

$$W2=(b+4.hg^{1.09}) \quad (3)$$

The span of tower 2 is the average distance from the tower to tower.
Area of shadows for a transmission span (L) :

$$L2=(span\ 1+span\ 2)/2\ \ meters \quad (4)$$

The span protection area (A2):

$$A2=W2\times L2 \quad (5)$$

The lightning density on the tower (Nd):

$$N_d=0.15\ IKL.A \quad (6)$$

Notes: $\boldsymbol{hgkt}$ is the maximum height of the ground wire; $\boldsymbol{hgkf}$ is the maximum height of phase wire; $\boldsymbol{hg}$ is the heigh of tower; $\boldsymbol{hgwkt}$ is the maximum height of ground wire in span; $\boldsymbol{b}$ is the distance between ground wires; $\boldsymbol{W2}$ is Protection shadow width; $\boldsymbol{L2}$ is Average tower distance; **Span 1** is the distance for tower 1; **Span 2** is the distance for Tower 2 or after the tower before; $\boldsymbol{A2}$ is the area of protection; $\boldsymbol{N_d}$ is the value of strikes on structure (annual strokes).

2.4. Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive network based on a fuzzy inference system. Using a hybrid learning procedure, ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with an appropriate membership function.

Illustration of first-order TSK fuzzy inference mechanism with two inputs x and y [10]. Rule base with two fuzzy if-then rules as below:

Rule 1: *if x is* A_1 *and y is* B_1 then $f_1=p_{1x}+q_{1y}+r_1$

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premise consequent

Rule 2: *if x is* A_2 *and y is* B_2 then f_2=p_{2x}+q_{2y}+r_2

premise consequent

Input: x and y Consequent are f.

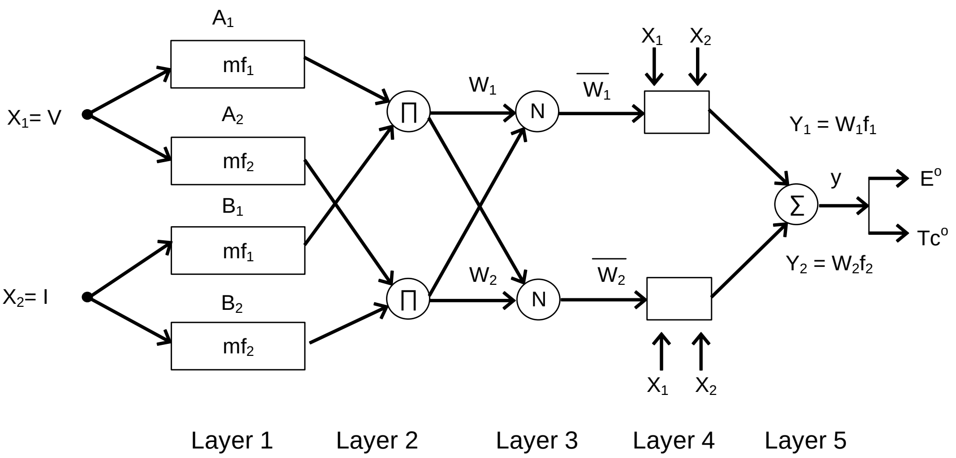

Fig.4. ANFIS structure for the first-order

The ANFIS architecture consists of five layers, each of which has functions that can be explained as follows:

1. Layer 1: Serves as a fuzzy process. The output of node *i* on Layer 1 is denoted as *Oi*. So, each node in Layer 1 functions to generate a degree of membership (part of the premise)
2. Layer 2: Notated π. Each node in this layer functions to calculate the activation strength (firing strength) on each rule as a product of all incoming inputs
3. Layer 3: Denoted by N. Each node in this layer is non-adaptive which functions only to calculate the ratio between firing strength in the I rule to the total firing strength of all rules
4. Layer 4: Each node in this layer is adaptive w_1 ’is the output of layer 3 $(p_{1x} + q_{1y} + r_1)$ is the set of parameters in the first-order Sugeno fuzzy model
5. Layer 5: A single node denoted $\sum$ on this layer functions to aggregate all output from layer 4.

2.6. Strengths and Weakness of ANFIS

The control system will use a system that combines a fuzzy system and an artificial neural network system. This system is known as the neuro-fuzzy system or ANFIS.

The basis of the integration is the advantages and disadvantages of each system. Artificial neural networks can recognize the system through a learning process to improve adaptive parameters. The advantage of fuzzy inference systems is that they can translate knowledge

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from experts in rules. Still, it usually takes a long time to determine the membership function. Therefore it takes learning techniques from artificial neural networks to automate the process so that it can reduce search time; this causes the ANFIS method to be very well applied in various fields. The weakness of this system is the complexity of the structure. The fuzzy system has a concept similar to the concept of human thinking.

The combination of the two will complement each other's strengths and weaknesses. Several studies have been carried out to see the comparison between ANFIS and Fuzzy Logic Controller (FLC), the ANFIS results are better than LFC [17][18]. There are also studies on the comparison of ANFIS and Artificial Neural Network (ANN). The results of this study indicate that ANFIS is better than ANN [19]. And other studies also compared ANFIS with some Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA). The results of this study indicate that ANFIS is better than Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA) [20].

3. Simulation Result and Discussion

Processing calculation data into artificial intelligence makes it easier to get the value of the tower's lightning strike density [21]. The artificial intelligence used is the Adaptive Neuro-Fuzzy Inference System (ANFIS).

The results of the calculation of the lightning strike value in the form of whitehead then become input data for data processing in ANFIS, Process Stages of Simulation:

a. Data Load Phase (Data Entering Phase)
b. The Generate FIS Phase (Generating FIS Stage)
c. FIS Training Stage (FIS Learning Stage)
d. FIS Test Stage (FIS Validation Stage)

3.1. Learning Process Model (Training)

Based on the comparison of RMSE (Root Mean Square Error) learning process (training) in Table 5, the most optimal method for this case is:

a. Learning Algorithm: Hybrid method
b. Type of Membership Function (MF): psignmf
c. Epoch: 50
d. Error tolerance: 0
e. Input Parameters: (3 3 3 3) f.

It consists of 81 rules. The method is taken from the lowest error rate.

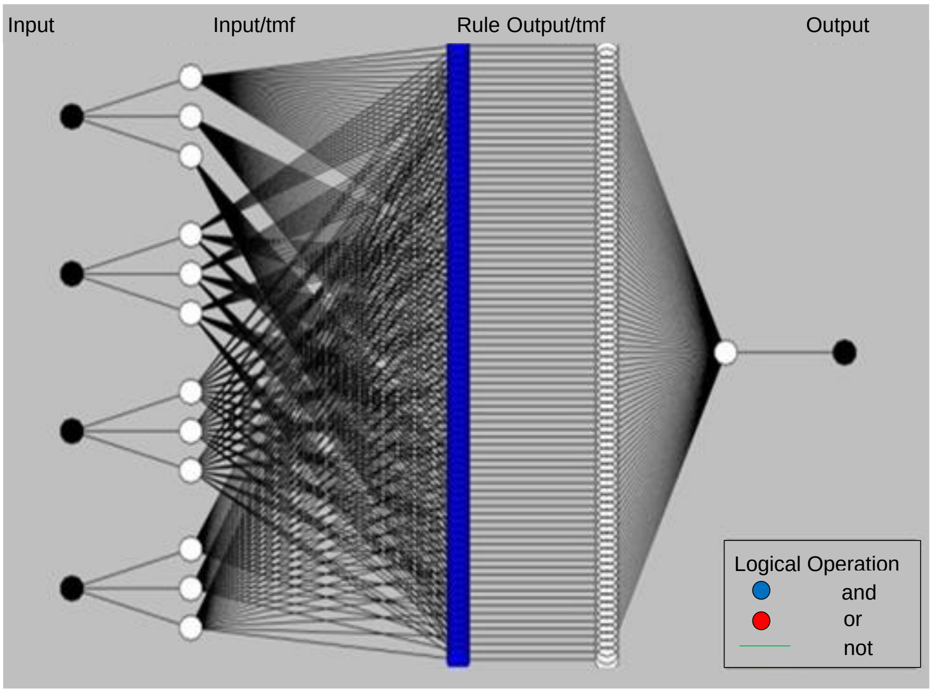

Fig.5. Learning Process Model (Training)

Figure 5 shows ANFIS neurons consisting of 4 inputs and one output, and 81 rules.

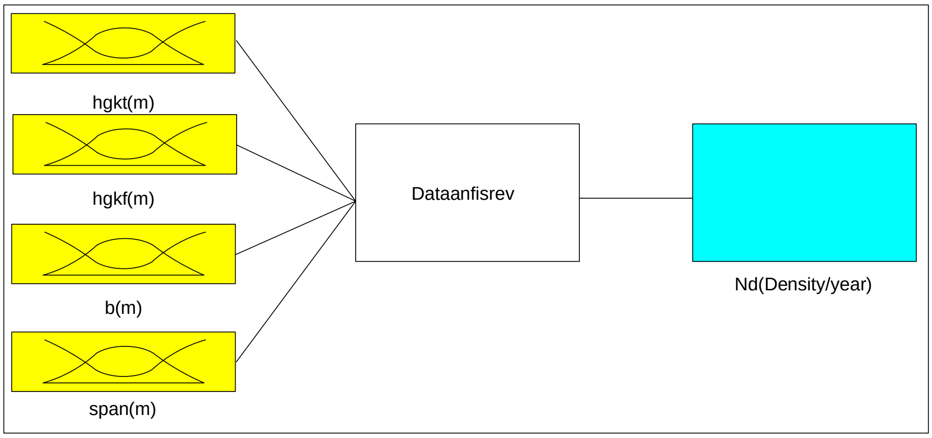

Fig.6. FIS Learning Editor (Training)

To make it easier to see the rule, we can see the surface viewer in Figure 7 through Figure 6 to see the relationship between the four inputs and the output of the ANFIS. Figure 6 shows four inputs (*hgkt , hgkf, b, and span*) and one output (*Nd*). Dataanfisrev is a training process in ANFIS processing to produce the output of the ANFIS .

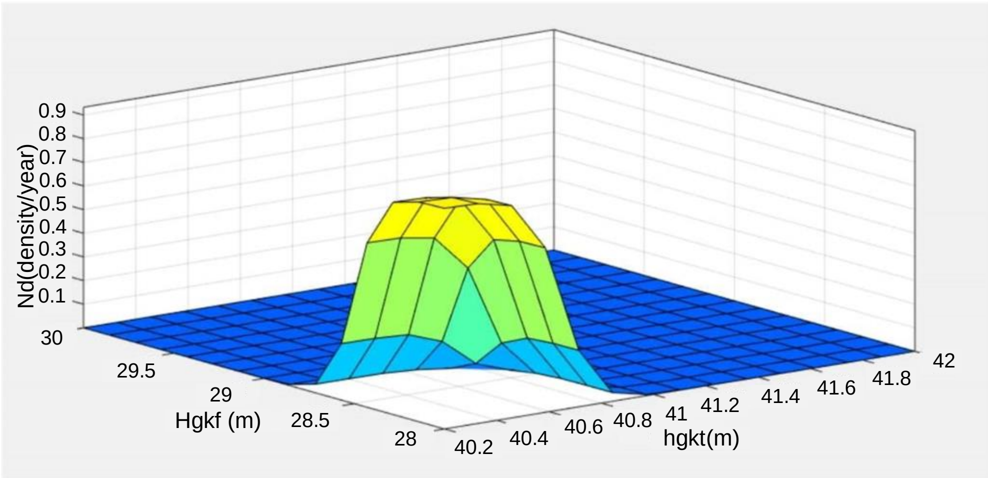

Fig.7. Surface viewer between Hgkt and Hgkf

Figure 7 shows the surface viewer of Hgkt, Hgkf, and Nd where the X-axis is Hgkt Y-axis is Hgkf, and the Z-axis is Nd.

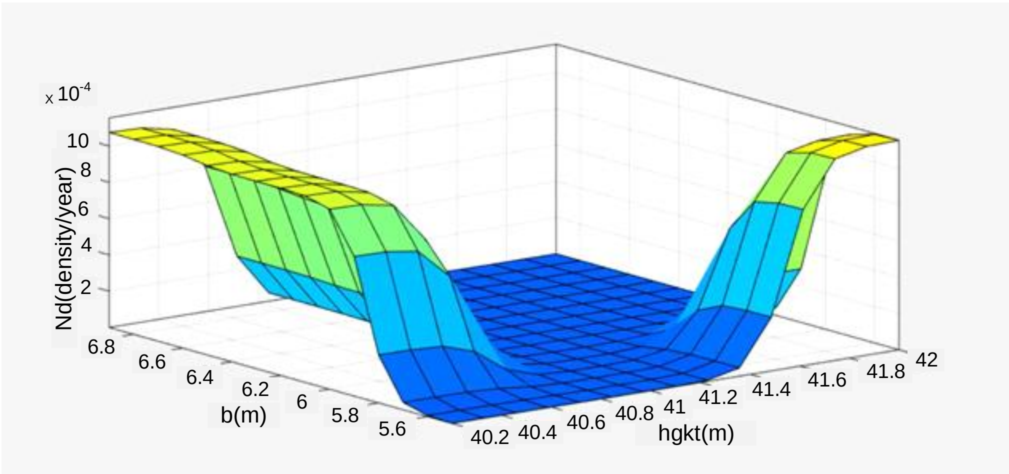

Fig.8. Surface viewer between Hgkt and b

Figure 8 shows the surface viewer of Hgkt, b, and Nd where the X-axis is Hgkt the Y-axis is b and the Z-axis is Nd.

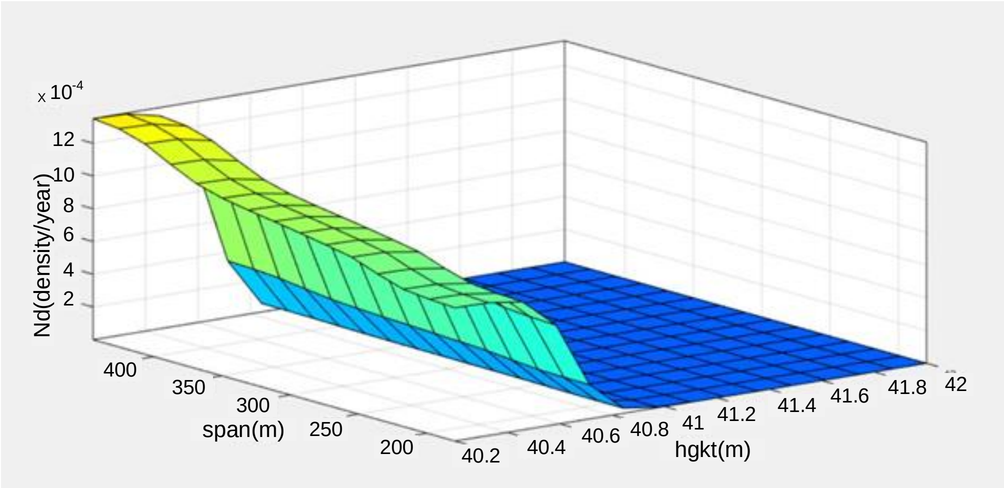

Fig.9. Surface viewer Hgkt and span distance

Figure 9 shows the surface viewer of Hgkt, span, and Nd where the X-axis is Hgkt Y-axis is span distance, and the Z-axis is Nd.

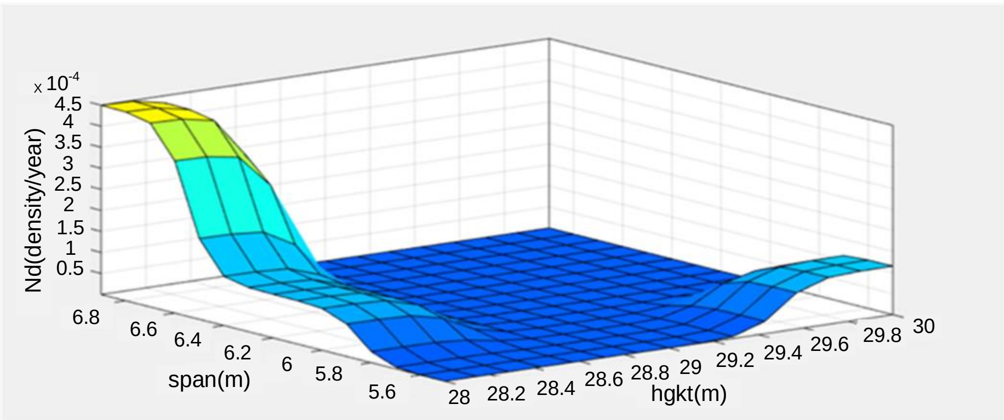

Fig.10. Surface viewer Hgkf and b

Figure 10 shows the surface viewer of Hgkf, b, and Nd where the X-axis is Hgkf the Y-axis is b and the Z-axis is Nd.

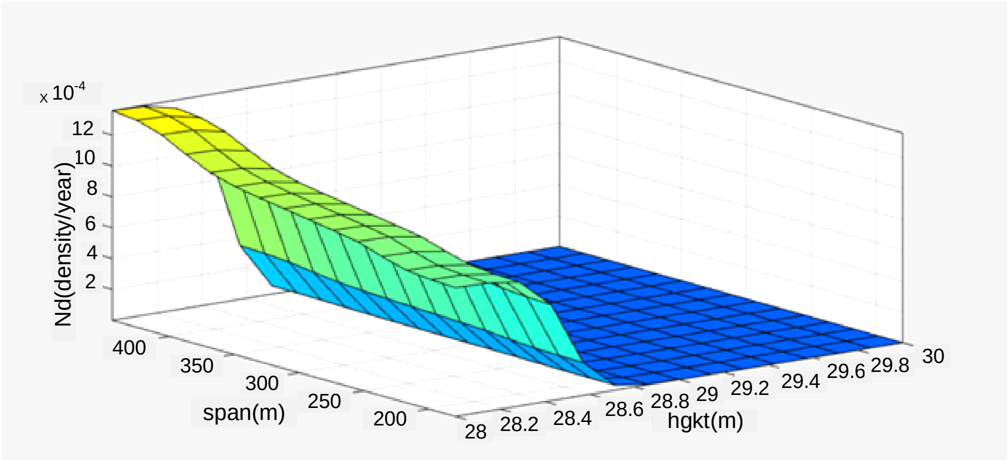

Fig.11. Surface viewer Hgkf and Span Distance

Figure 11 shows the surface viewer of Hgkf, span distance, and Nd where the X-axis is Hgkf the Y-axis is Span distance, and the Z-axis is Nd.

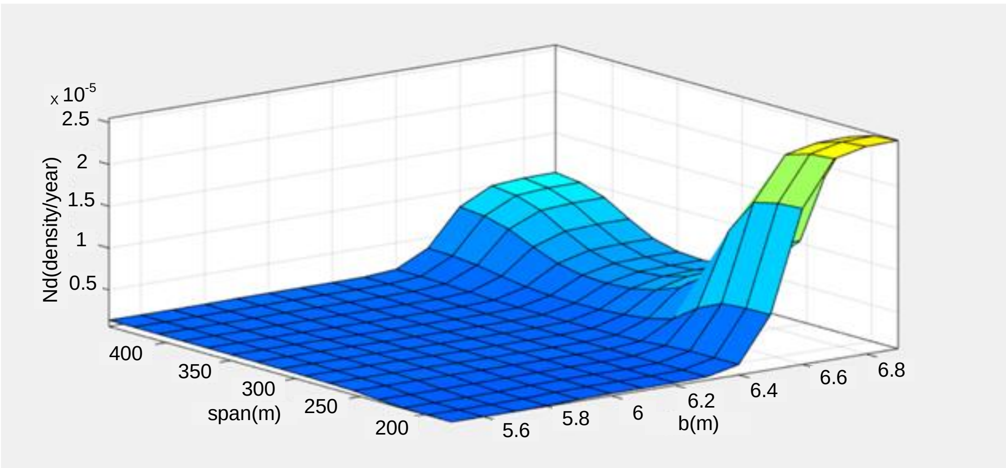

Fig.12. Surface Viewer Span Distance and b

Figure 12 shows a surface viewer of b, span distance, and Nd where the X-axis is b the Y-axis is the span distance, and Z-axis is Nd.

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3.2. The Results of ANFIS

Table 1. RMSE comparison of hybrid and backpropagation methods

RMSE (Root Mean Square Error)				
Membership Function	*Data training*		*Data Testing*	
	Hybrid	*Backpropagation*	*Hybrid*	*Backpropagation*
Trimf	0.07589	0.48271	0.07589	0.47364
Trapmf	0.07886	0.46583	0.07886	0.45786
gbellmf	0.07597	0.51851	0.07597	0.50895
gaussmf	0.07592	0.49996	0.07592	0.49049
gauss2mf	0.07782	0.46550	0.07782	0.45746
pimf	0.07989	0.46534	0.07989	0.45754
dsignmf	0.07588	0.44199	0.07588	0.43343
psignmf	0.07588	0.44181	0.07588	0.43325

Table 1 compares RMSE for the two methods, Hybrid and Backpropagation, in the learning process (training) and the validation process (testing). The lowest RMSE in the learning process is 0.07588 for training data and 0,07588 for testing with *dsignmf* and *psignmf* membership functions.

From the results obtained through ANFIS, the results are loading and testing. ANFIS can predict through the lightning density values that often appear when a lightning strike occurs based on tower input data processed by ANFIS.

3.3. GUI (Graphical User Interface)

The display of the model of determining the value of the structure of lightning strikes based on adaptive neuro-fuzzy inference systems uses the Matlab software, with lightning strike value output. The rule used is from the ANFIS rule with the AND logic function. The display of the lightning strike value structure based on the adaptive neuro-fuzz inference system is shown in Figure 13.

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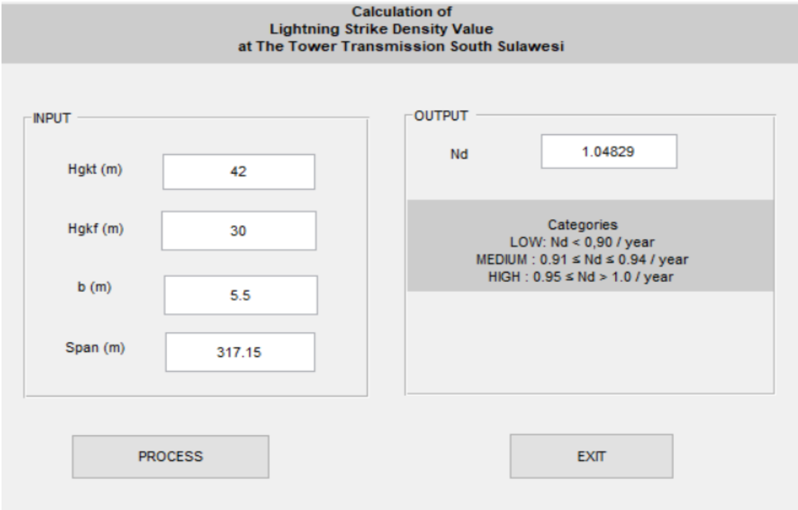

Fig.13. Display GUI Prediction of Lightning Strike Tower Value

3. Conclusions

In this paper, it can be analyzed and concluded several things that are needed to determine the value of the lightning strike structure of the South Sulawesi region:

1. The result shows ANFIS simulation with hybrid algorithm and backpropagation algorithm hybrid. The backpropagation algorithm with *trimf, tramf, gbellmf, and gaussmf* functions shows the comparison of RMSE for the two methods, namely Hybrid and Backpropagation, in the learning process (*training*) and the validation process (*testing*). The lowest RMSE in the learning process is 0.07588 with the *gaussmf* membership function for training and testing data.
2. The calculation system results for the value of structural lightning struck in the South Sulawesi region. They validated manual calculations and ANFIS with an average percentage of 0.0554%.
3. From this research, we can make it suitable to calculate the value of the lightning density (Nd) by using ANFIS, which is then programmed in a GUI. This GUI makes it easy to find out the lightning density (Nd) value on the tower.

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Figure 1

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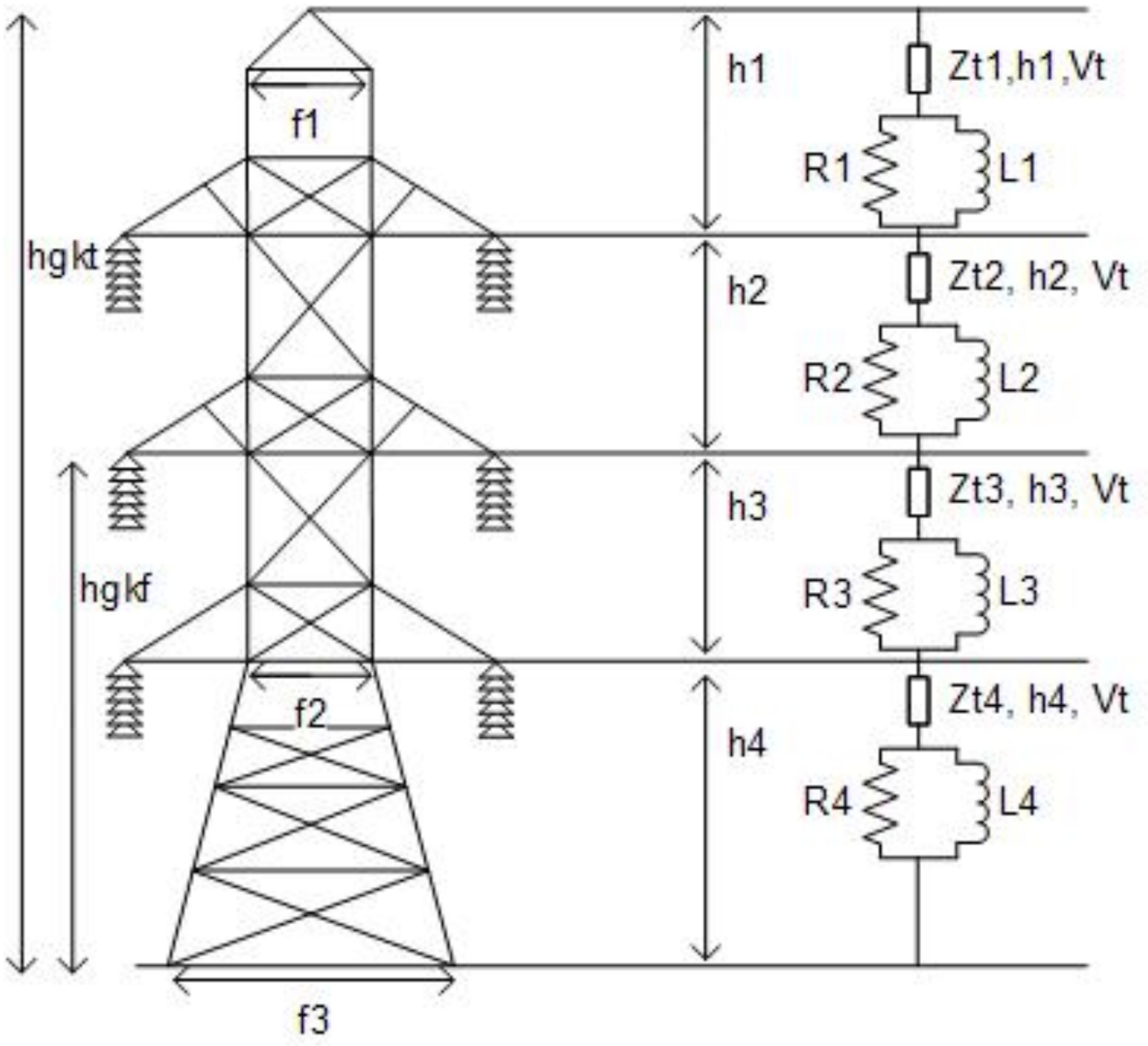

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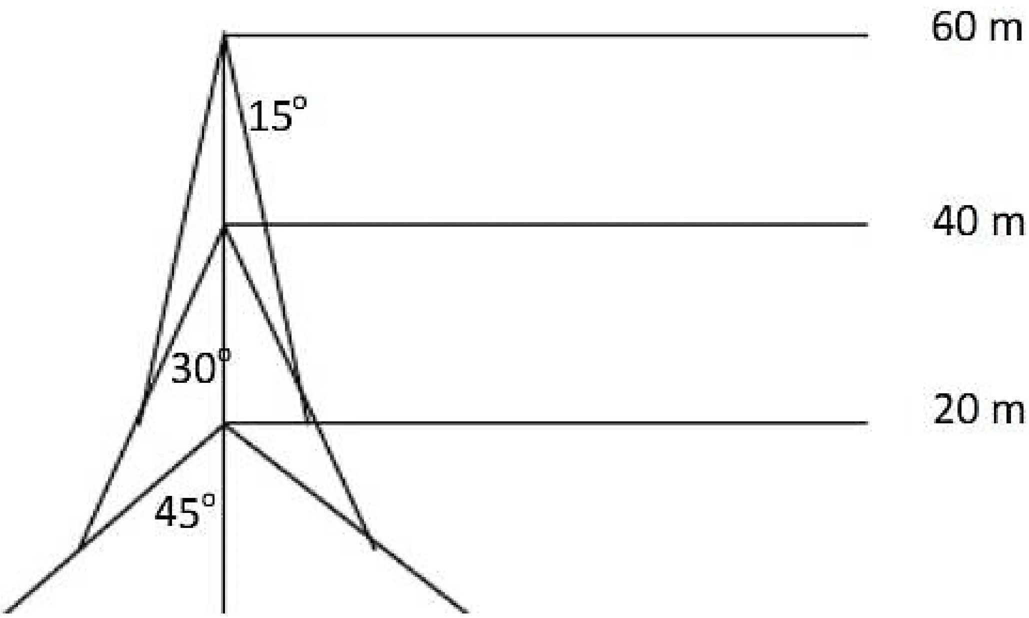

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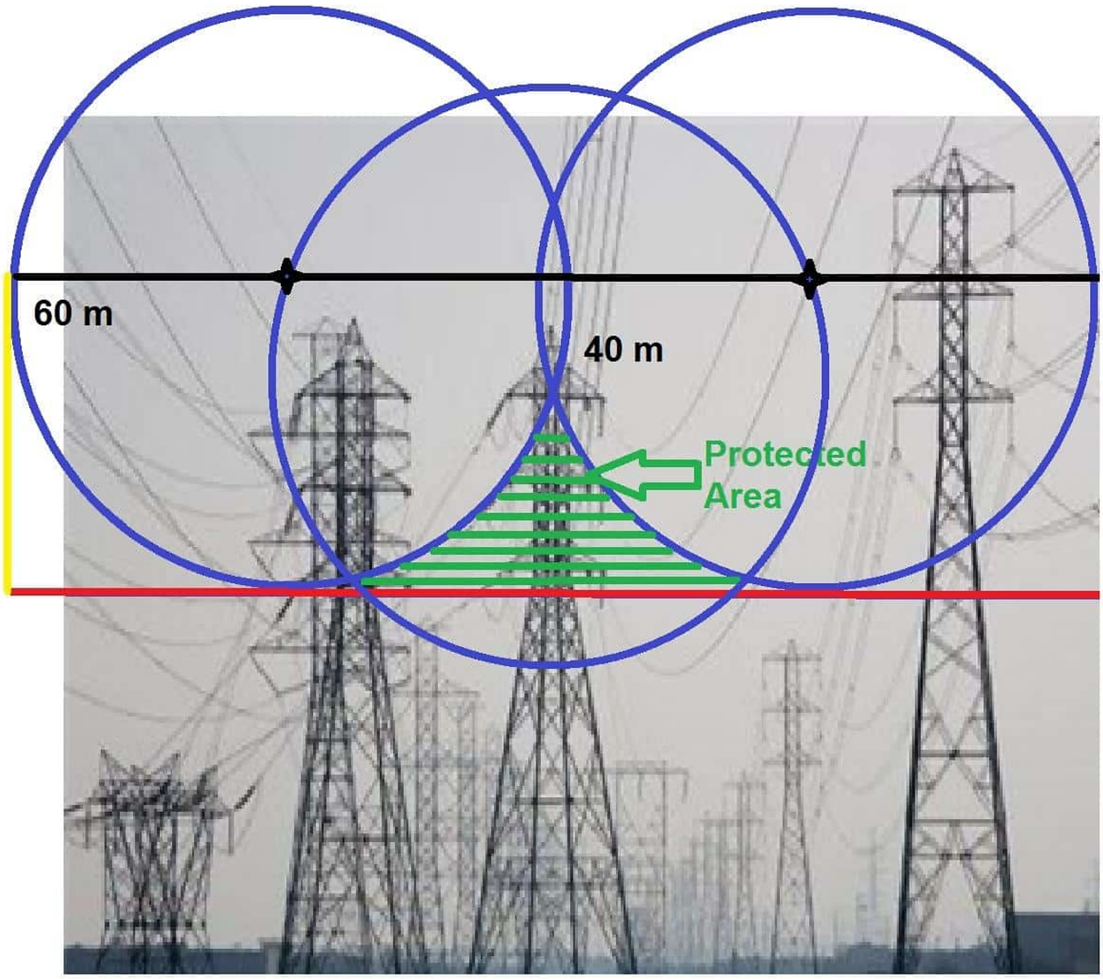

Figure 4

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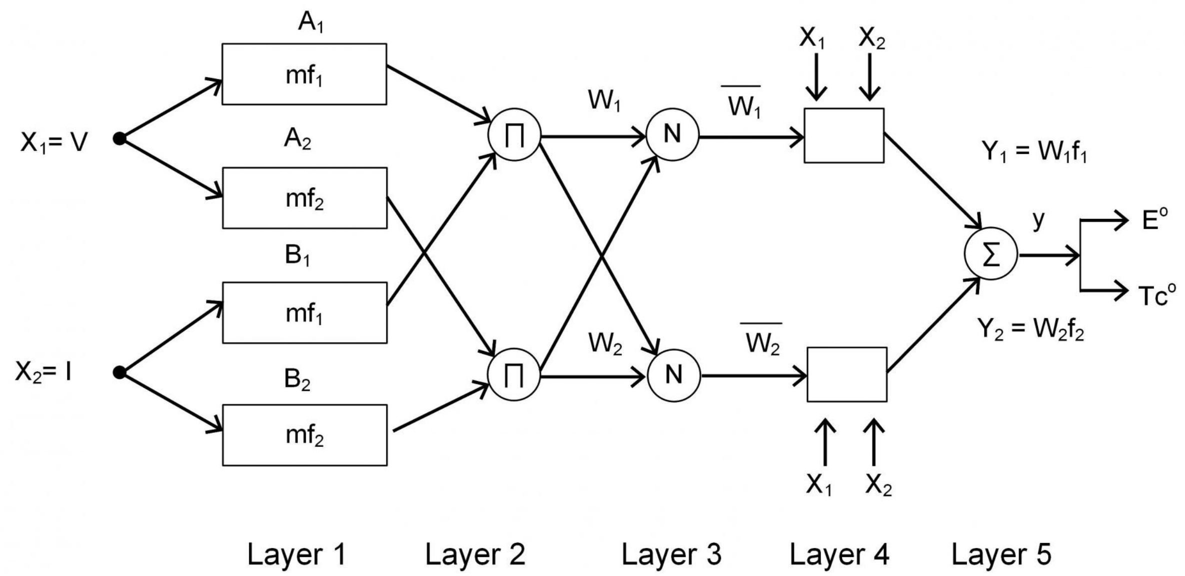

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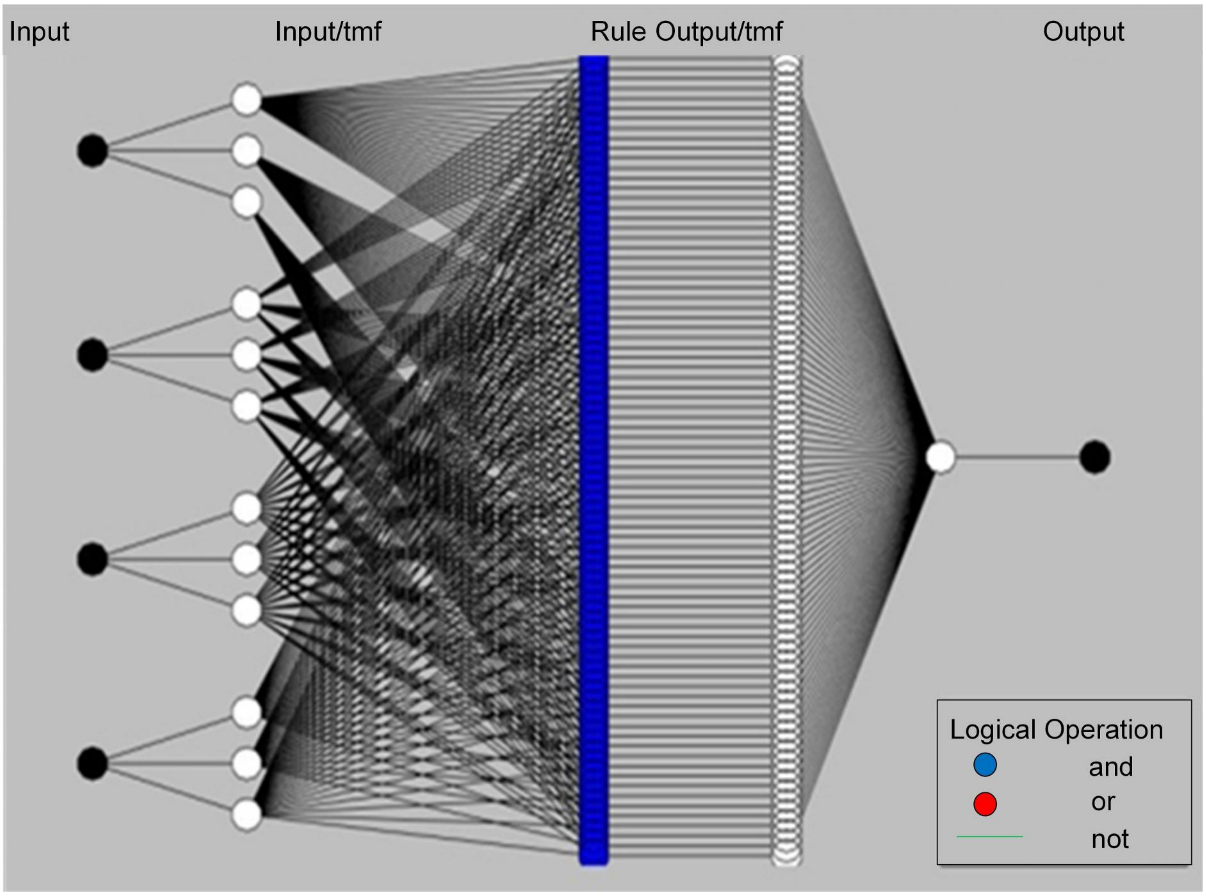

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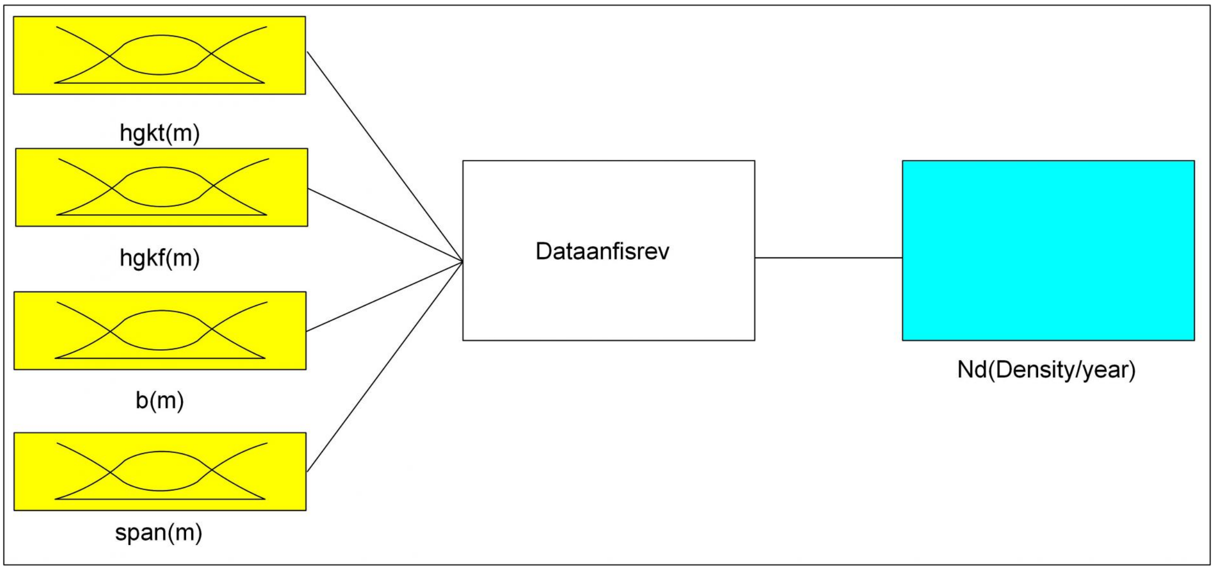

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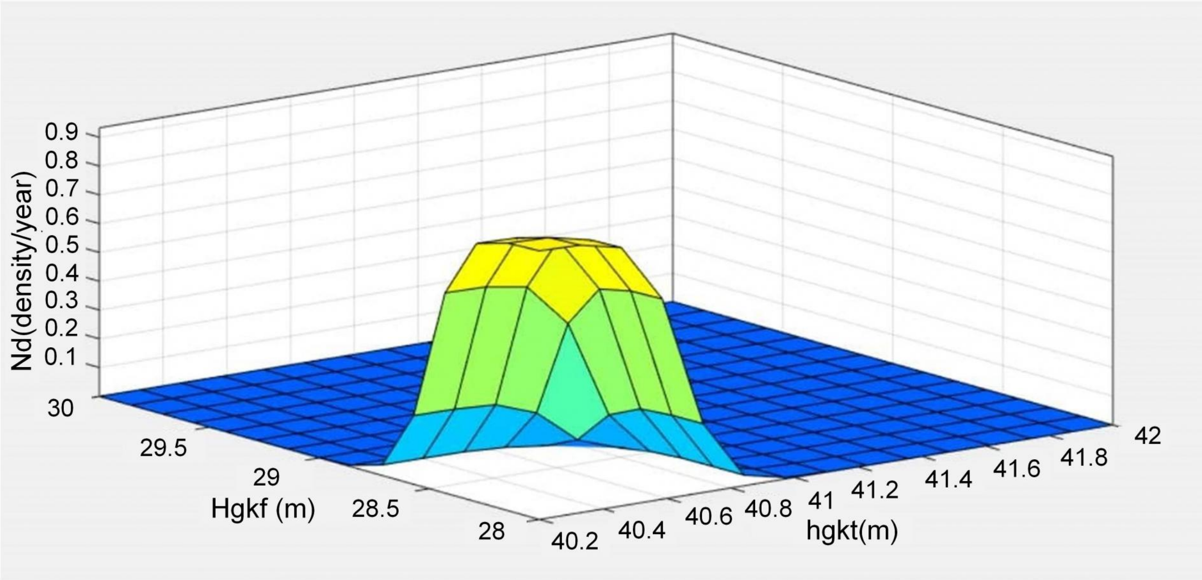

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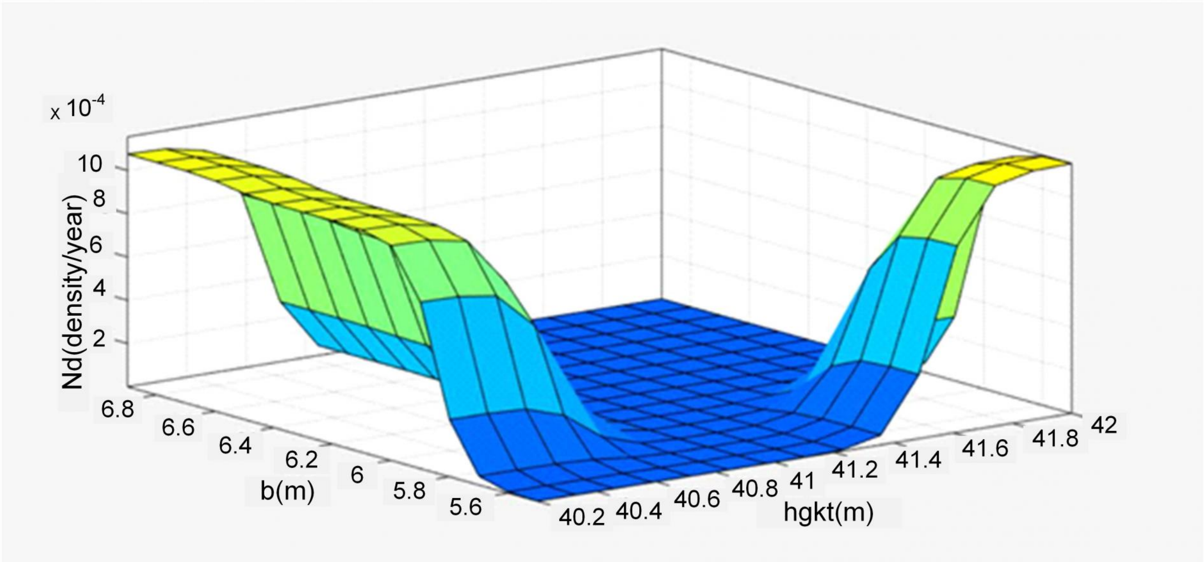

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Figure 9

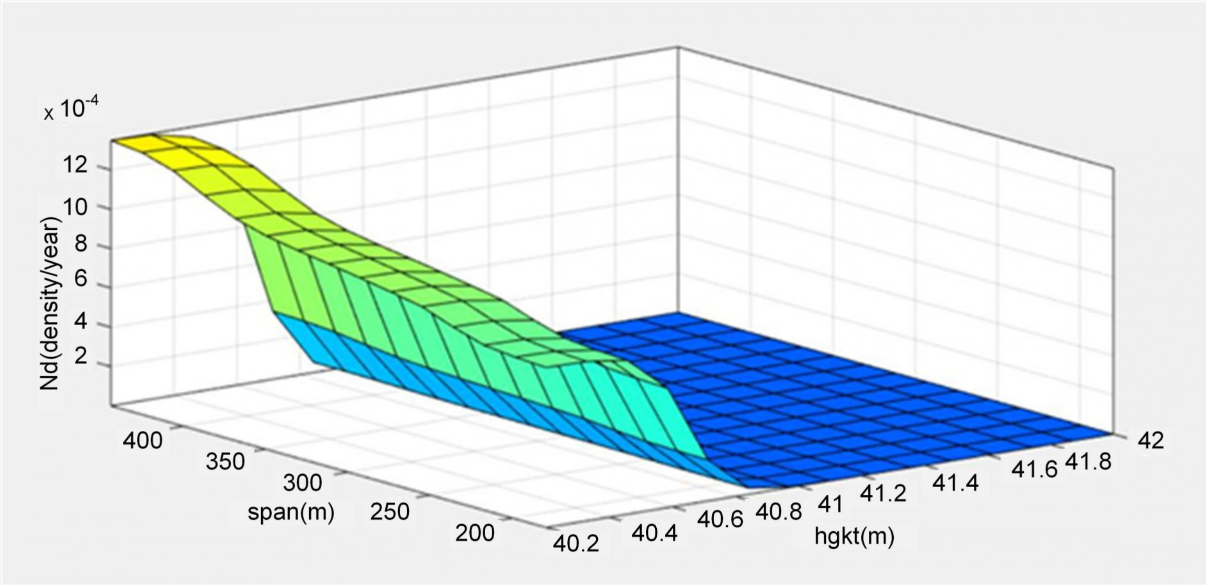

Figure 10

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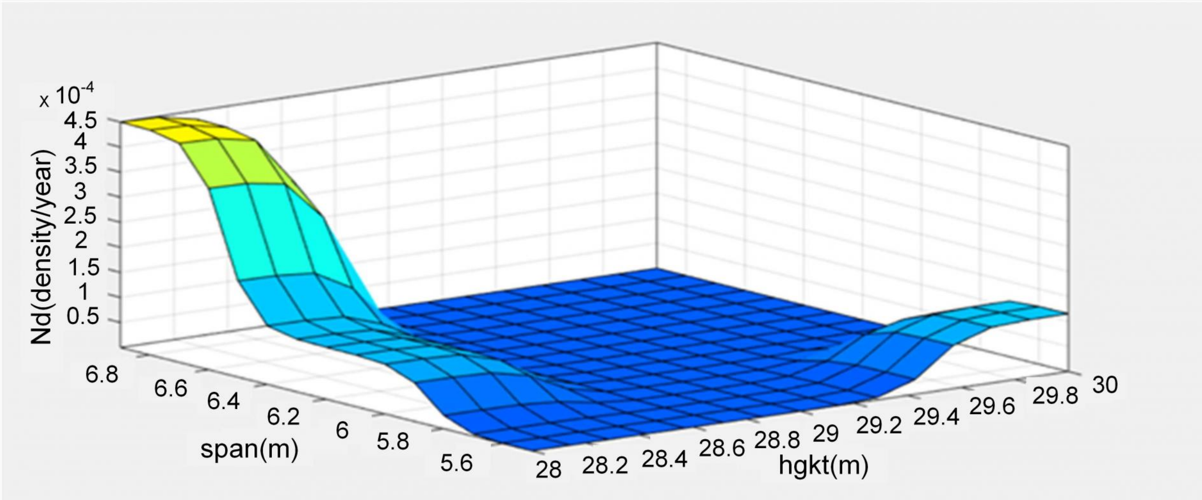

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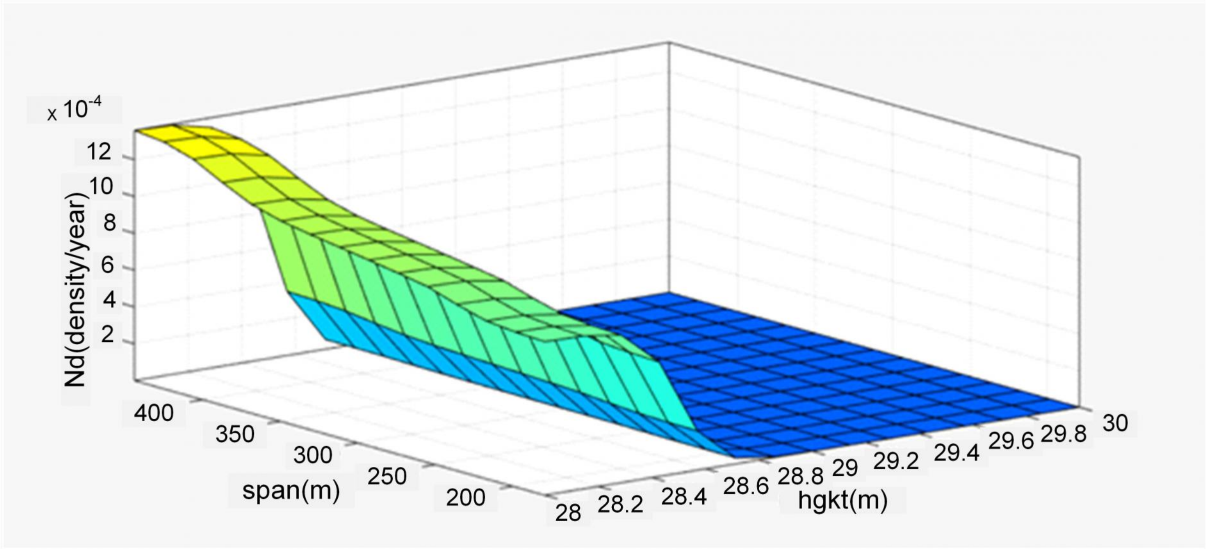

Figure 12

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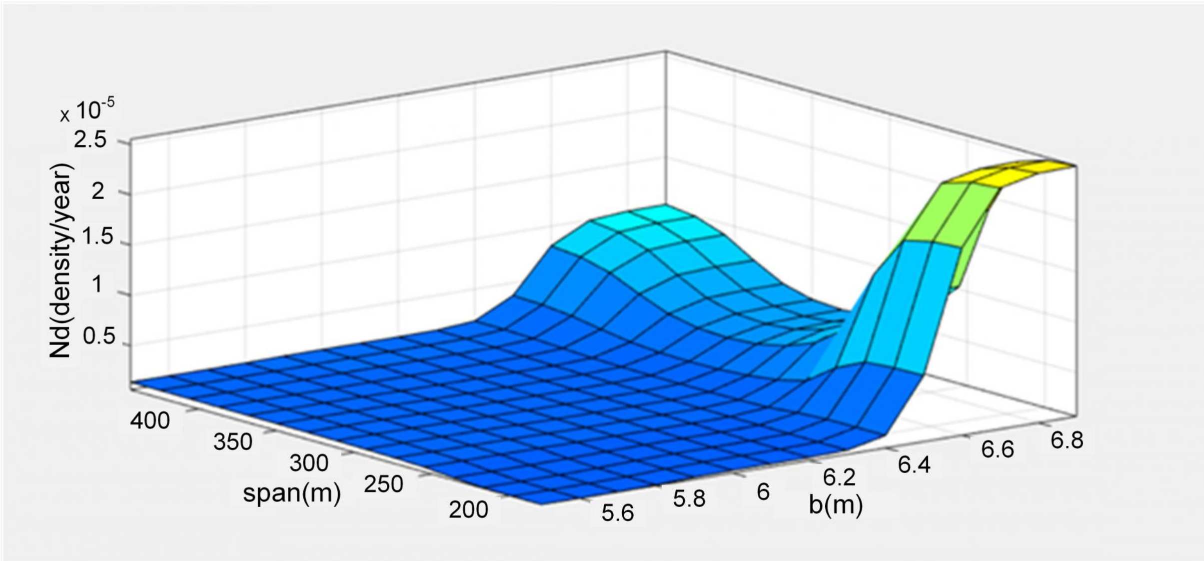

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Figure 13

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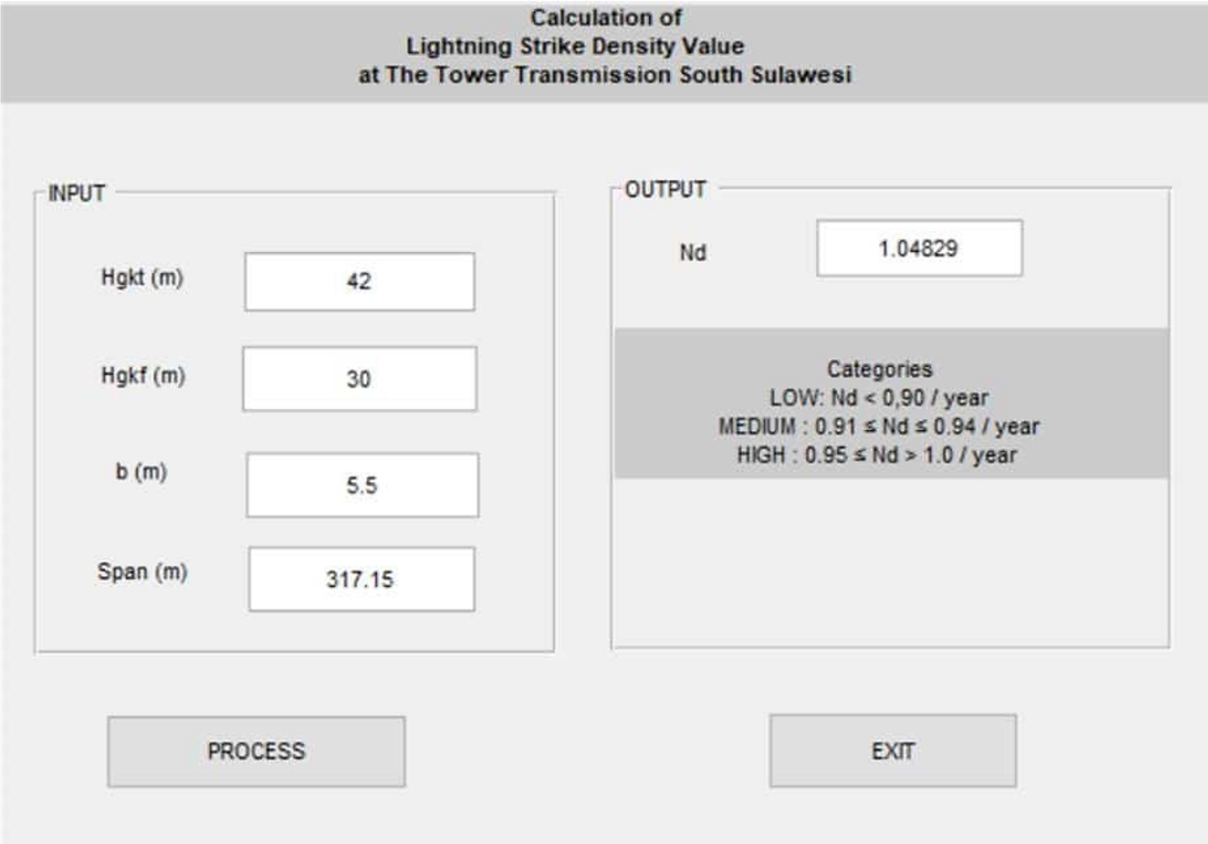

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Authors:
Sri Sri, Muhammad Bachtiar, Andarini Rini, Bayu Bayu

Decision letter:
January 18, 2021
AEE-01257-2020-05
Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System

Dear Dr. Sri Sri,

I am pleased to inform you that your manuscript, entitled: Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System, might be accepted for publication in our journal, pending some minor changes suggested by reviewers (see below).

Please revise your paper strictly according to the attached Reviewers comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Please make sure that you have addressed ALL the comments in a detailed covering letter as an additional file.

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Scientific Secretary
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Review 1:

I congratulate the authors by the efforts to improve the manuscript

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Prediction of Lightning Density Value Tower based on The Adaptive Neuro-Fuzzy Inference System

Keywords

Adaptive Neuro-Fuzzy Inference System, Lightning Density Prediction Tower, Transmission Line Arrester

Abstract

Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in the susceptibility of lightning disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The results of the calculation system for the value of structural lightning strikes in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Explanation letter

Thank you for the corrections from editors and reviewers. I have corrected points that need improvement.

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ARCHIVES OF ELECTRICAL ENGINEERING VOL. XX(Y), pp. XXX-YYY (YEAR)
DOI 10.24425/aee./...

Prediction of Lightning Density Value Tower based on Adaptive Neuro-Fuzzy Inference System

SRI MAWAR SAID1, MUHAMMAD BACHTIAR NAPPU1, ANDARINI ASRI2, BAYU TRI UTOMO1

1 Hasanuddin University, Indonesia

2Ujung Pandang State Polytechnic, Indonesia

e-mail: srimawarsaid@gmail.com

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Abstract: Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in lightning susceptibility of disturbances to electrical system lines, especially in high-voltage airlines and substations. Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The calculation system results for the value of structural lightning struck in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Keywords: Lightning Density Prediction Tower, Adaptive Neuro-Fuzzy Inference System, and Transmission Line Arrester

1. Introduction

With the growth of technology, electricity demand is increasing, and an improvement must follow this development in the quality of the electricity produced, namely the electric power system's quality and reliability [1]. *PT. Perusahaan Listrik Negara* (PLN) is a company tasked with planning, making, and maintaining an electric power system in Indonesia. This company guarantees the electric power system and the quality of electricity to consumers [2].

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South Sulawesi is located in the equatorial region with a tropical climate and high humidity [3]. The condition causes South Sulawesi to have a higher level of lightning strikes, and a bolt of higher lightning strikes level. This lightning strike can disrupt the distribution area (transmission and distribution) of electric power. One of the causes of interference among the many disruptions in the electric power system occurs lightning strikes.

Previous research has discussed several research titles concerning disorder research causes of lightning and arrester placement. A lightning strike and the performance of the arrester input it between GI Bone and GI Sinjai [4]. The earthing value is due to a lightning strike in the 150 kV transmission line system, especially the GI transmission line Sungguminasa- GI Tallasa [5]. Research on modeling 132 kV transmission tower simulated using ATP-EMTP by placing various arrester including, IEEE Model, Pincetti Model, and Fernandez model [6]. And this research on how to get determines the lighting structure's strike value accurately using the ANFIS method. ANFIS is used to get the value of the structure's lightning strike on the tower transmission. Then we can determine which towers are included in the critical category on the transmission line. The results of grouping the critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to lightning in the transmission line. The critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to the lightning transmission line.

In this paper, a study will be conducted on obtaining accurate lightning strike density values using the ANFIS method[7][8]. ANFIS is a method that is often used for predictions and forecasting, with good accuracy. ANFIS is a combination of the backpropagation neural network concept with the fuzzy logic concept. Backpropagation neural network has the advantage of recognizing a data/object based on a set of features that are input to the system. Meanwhile, fuzzy-based systems can be expressed with knowledge in the form of "if-then," which provides the advantage of not requiring mathematical analysis for modeling. Besides, fuzzy systems can also process human reasoning and knowledge-oriented to qualitative aspects.

ANFIS is an adaptive neural network based on a fuzzy inference system using a hybrid learning procedure. ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with the right membership function. Fuzzy conclusion systems that utilize fuzzy if-then rules can model qualitative human knowledge aspects and provide reasoning processes without utilizing appropriate quantitative [9][10]. In this paper, the ANFIS is used to get the value of the structure of lightning density in the transmission tower. ANFIS is used to obtain the value of critical tower lightning density. The tower is in critical condition due to the tower's high lightning strike value, which will be input in the installation of the Transmission Line Arrester (TLA).

2. Transmission System

An electric power system consists of three main parts of a central power plant, transmission line, and distribution system. The transmission line is a link between power centers and distribution systems. The connection between systems can also lead to other

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power systems. A distribution system connects all loads separated from each other to the transmission line [11].

2.1. Transmission Tower

The electric power channeled through the transmission system generally uses bare wire to rely on-air as a media of insulation between the conductive wire with surrounding objects. The tower is sturdy building construction whose function is to support/span the connecting wire with height and distance sufficient to be safe for humans and the surrounding environment.

There are three different transmission tower models examined. One of them we know is the multistory model designed [6]. A multistory tower is a composition of parameter distributions with parallel RL [12].

Several tower structures are modeled, in research [13], tower structures at a voltage of 150 kV, as shown in Figure 1.

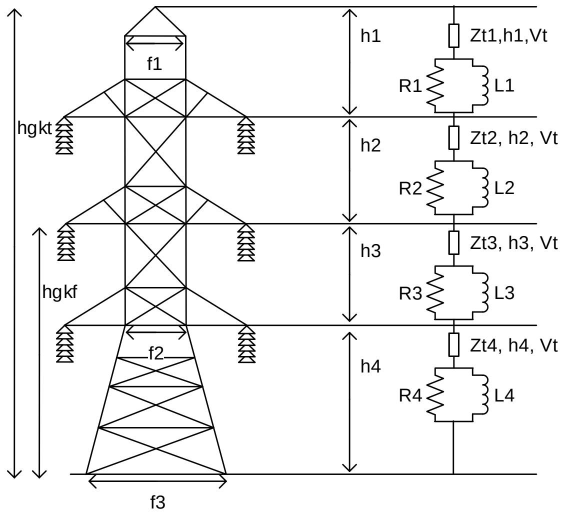

Fig.1. Tower Transmission 150 kV

In this paper, a study has used a 150 kV tower because generally electricity in Indonesia uses a 150 kV tower. The data that has been researched is data from PLN and PLN uses a 150 kV tower in the South Sulawesi area. The disadvantage of 150 kV towers is that the short distance, but one of the advantages of a 150 kV tower is that with a voltage of 150 kV it is still possible to distribute 400 MVA of power/circuit.

2.2. Transmission Line Protection from Lightning Strikes

The conventional protection system commonly used is the cone protection system, which is a simple method of making a protected area by an upright conductor called the 1st method. The second way is the Faraday Cage used for lightning protection against buildings or buildings. The third method will be discussed later by using a rolling ball. For the 4th way, similar to the 3rd way, the drawing model uses a *satellite dish method*. The Cone protection method (existing design) and the Rolling sphere method (design improvement) are selected by selecting several methods.

The existing design (Cone protection method) method is used to facilitate the determination of a good protection angle. Determining the magnitude of the angle that can provide good protection against interference, especially in lightning strikes, can be seen in Figure 2.

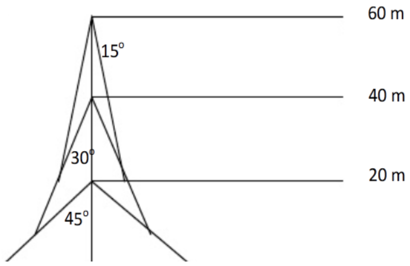

Fig.2. Cone Model Lightning Protection System

The rolling sphere method is an electrometric concept or rolling ball method connecting the distance of lightning to its peak current. This concept says that an imaginary ball with the lead of the leader at the center of the ball is rolled into a structure. All contact points that hit the surface of the ball will then be struck by lightning. This method is straightforward in determining the design of reliable lightning protection. Figure 3 shows a 150 kV SUTT tower using the Rolling sphere method [14][15].

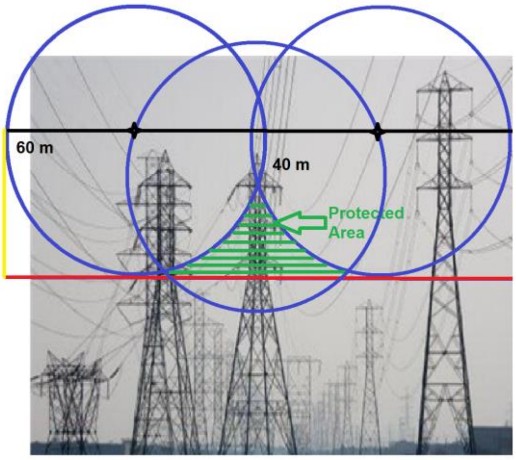

Fig.3. SUTT Tower 150 kV using Rolling Sphere Method

The electrometry concept or the rolling ball method relates the distance of the lightning strike to its peak current. The concept states an imaginary sphere with the leading tip at the center of the ball rolls into a structure. All points of contact that hit the surface of the ball will then be struck by lightning. This method makes it very easy to determine a reliable lightning protection design. The analysis shows that the height of the high-voltage overhead tower affects the disturbance that occurs due to lightning strikes. And to minimize transmission disruption due to lightning strikes, the existing design method (Cone protection method) can be used very well for lightning strike protection, while the rolling sphere method is better because it is more reliable in protecting lightning strikes on transmission lines 150 kV.

2.3. Calculation of Lightning Structure Value of Lightning Tower

An overhead transmission line can form a shadow of electricity on the ground below the transmission line. The width of the electric shadow for a transmission line has been provided [16].

$$hgwkt = hgkt - 1/2(hgkt - hgkf) \quad (1)$$

$$hg = hgkt - 2/3\,(hgkt - hgwkt) \quad (2)$$

The width of the shadow is formulated:

$$W2 = \left(b + 4.hg^{1.09}\right) \quad (3)$$

The span of tower 2 is the average distance from the tower to tower.
Area of shadows for a transmission span (L) :

$$L2 = (span\ 1 + span\ 2)/2 \ \text{meters} \quad (4)$$

The span protection area (A2):

$$A2 = W2 \times L2 \quad (5)$$

The lightning density on the tower (Nd):

$$N_d = 0.15\ IKL.A \quad (6)$$

Notes: *hgkt* is the maximum height of the ground wire; *hgkf* is the maximum height of phase wire; *hg* is the heigh of tower; *hgwkt* is the maximum height of ground wire in span; *b* is the distance between ground wires; *W2* is Protection shadow width; *L2* is Average tower distance; Span 1 is the distance for tower 1; Span 2 is the distance for Tower 2 or after the tower before; *A2* is the area of protection; N_d is the value of strikes on structure (annual strokes).

2.4. Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive network based on a fuzzy inference system. Using a hybrid learning procedure, ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with an appropriate membership function.

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Illustration of first-order TSK fuzzy inference mechanism with two inputs x and y [10]. Rule base with two fuzzy if-then rules as below:

Rule 1: if x is A_1 and y is B_1 then $f_1=p_{1x}+q_{1y}+r_1$

Premise consequent

Rule 2: if x is A_2 and y is B_2 then $f_2=p_{2x}+q_{2y}+r_2$

Premise consequent

Input: x and y Consequent are f.

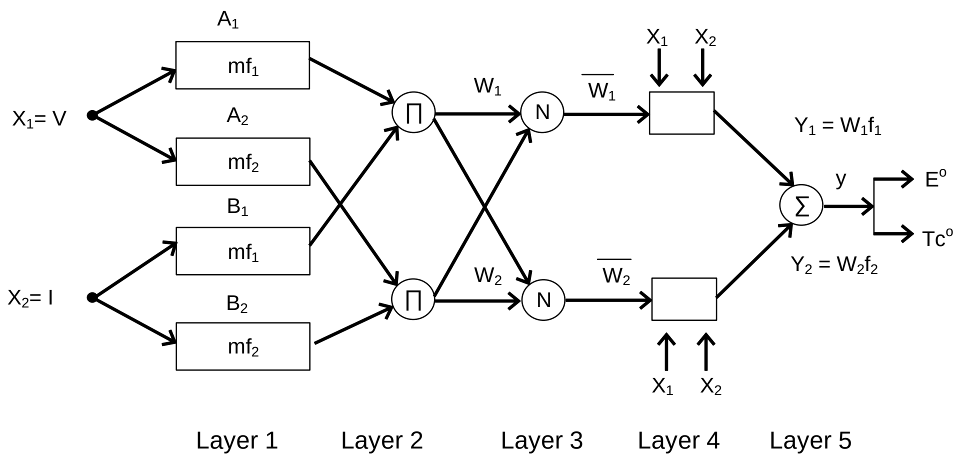

Fig.4. ANFIS structure for the first-order

The ANFIS architecture consists of five layers, each of which has functions that can be explained as follows:

1. Layer 1: Serves as a fuzzy process. The output of node *i* on Layer 1 is denoted as *Oi*. So, each node in Layer 1 functions to generate a degree of membership (part of the premise)
2. Layer 2: Notated π. Each node in this layer functions to calculate the activation strength (firing strength) on each rule as a product of all incoming inputs
3. Layer 3: Denoted by N. Each node in this layer is non-adaptive which functions only to calculate the ratio between firing strength in the I rule to the total firing strength of all rules
4. Layer 4: Each node in this layer is adaptive w_1 'is the output of layer 3 $(p_{1x} + q_{1y} + r_1)$ is the set of parameters in the first-order Sugeno fuzzy model
5. Layer 5: A single node denoted $\sum$ on this layer functions to aggregate all output from layer 4.

2.6. Strengths and Weakness of ANFIS

The control system will use a system that combines a fuzzy system and an artificial neural network system. This system is known as the neuro-fuzzy system or ANFIS.

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The basis of the integration is the advantages and disadvantages of each system. Artificial neural networks can recognize the system through a learning process to improve adaptive parameters. The advantage of fuzzy inference systems is that they can translate knowledge from experts in rules. Still, it usually takes a long time to determine the membership function. Therefore it takes learning techniques from artificial neural networks to automate the process so that it can reduce search time; this causes the ANFIS method to be very well applied in various fields. The weakness of this system is the complexity of the structure. The fuzzy system has a concept similar to the concept of human thinking.

The combination of the two will complement each other's strengths and weaknesses. Several studies have been carried out to see the comparison between ANFIS and Fuzzy Logic Controller (FLC), the ANFIS results are better than LFC [17][18]. There are also studies on the comparison of ANFIS and Artificial Neural Network (ANN). The results of this study indicate that ANFIS is better than ANN [19]. And other studies also compared ANFIS with some Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA). The results of this study indicate that ANFIS is better than Artificial intelligence such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA) [20].

3. Simulation Result and Discussion

Processing calculation data into artificial intelligence makes it easier to get the value of the tower's lightning strike density [21]. The artificial intelligence used is the Adaptive Neuro-Fuzzy Inference System (ANFIS).

The results of the calculation of the lightning strike value in the form of whitehead then become input data for data processing in ANFIS, Process Stages of Simulation:

a. Data Load Phase (Data Entering Phase)
b. The Generate FIS Phase (Generating FIS Stage)
c. FIS Training Stage (FIS Learning Stage)
d. FIS Test Stage (FIS Validation Stage)

3.1. Learning Process Model (Training)

Based on the comparison of RMSE (Root Mean Square Error) learning process (training) in Table 5, the most optimal method for this case is:

a. Learning Algorithm: Hybrid method
b. Type of Membership Function (MF): psignmf
c. Epoch: 50
d. Error tolerance: 0
e. Input Parameters: (3 3 3 3) f.

It consists of 81 rules. The method is taken from the lowest error rate.

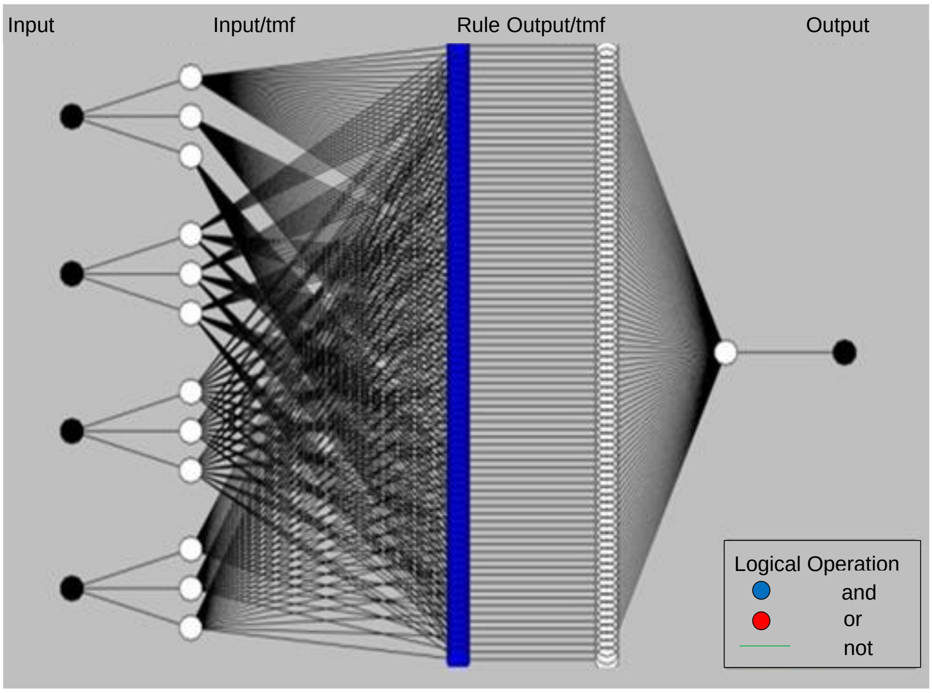

Fig.5. Learning Process Model (Training)

Figure 5 shows ANFIS neurons consisting of 4 inputs and one output, and 81 rules.

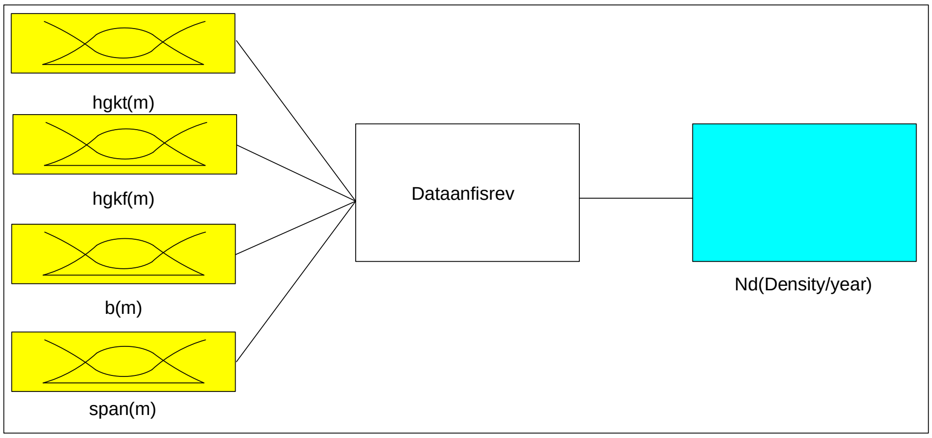

Fig.6. FIS Learning Editor (Training)

To make it easier to see the rule, we can see the surface viewer in Figure 7 through Figure 6 to see the relationship between the four inputs and the output of the ANFIS. Figure 6 shows four inputs (*hgkt* , *hgkf, b, and span*) and one output (*Nd*). Dataanfisrev is a training process in ANFIS processing to produce the output of the ANFIS .

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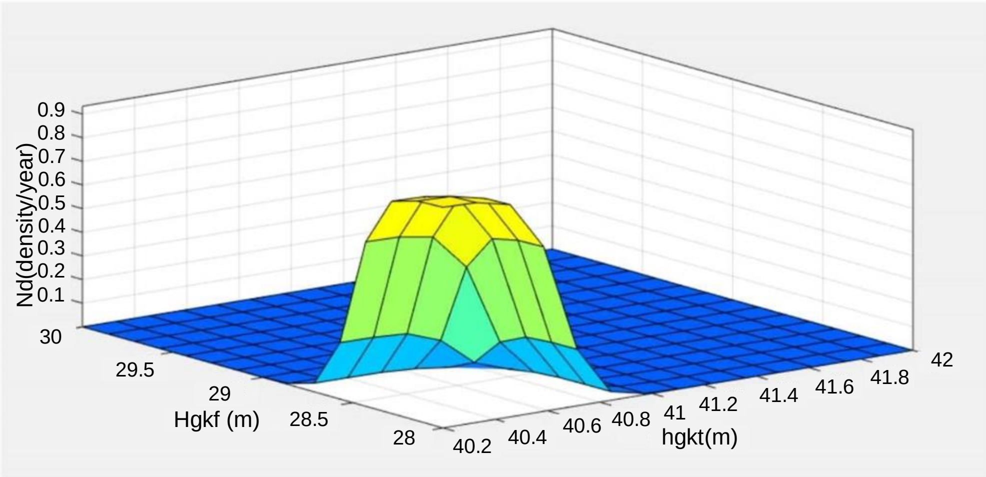

Fig.7. Surface viewer between Hgkt and Hgkf

Figure 7 shows the surface viewer of Hgkt, Hgkf, and Nd where the X-axis is Hgkt Y-axis is Hgkf, and the Z-axis is Nd.

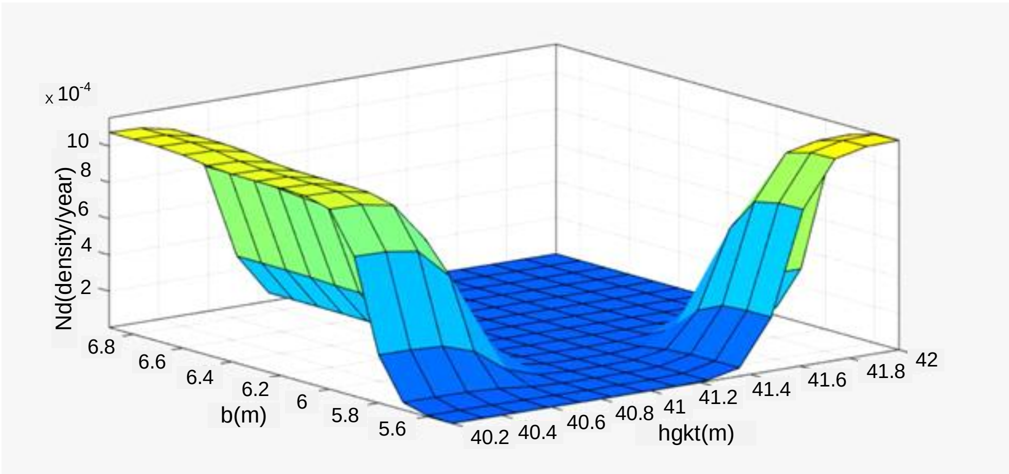

Fig.8. Surface viewer between Hgkt and b

Figure 8 shows the surface viewer of Hgkt, b, and Nd where the X-axis is Hgkt the Y-axis is b and the Z-axis is Nd.

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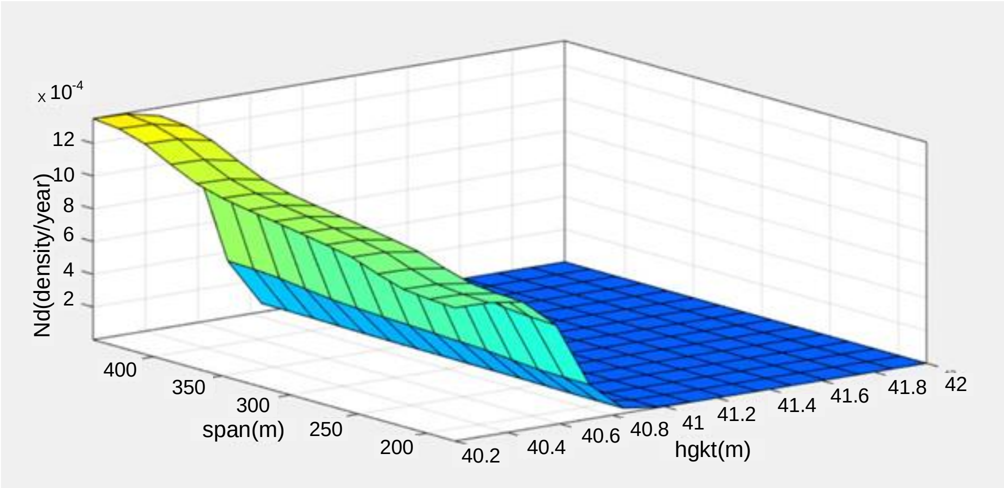

Fig.9. Surface viewer Hgkt and span distance

Figure 9 shows the surface viewer of Hgkt, span, and Nd where the X-axis is Hgkt Y-axis is span distance, and the Z-axis is Nd.

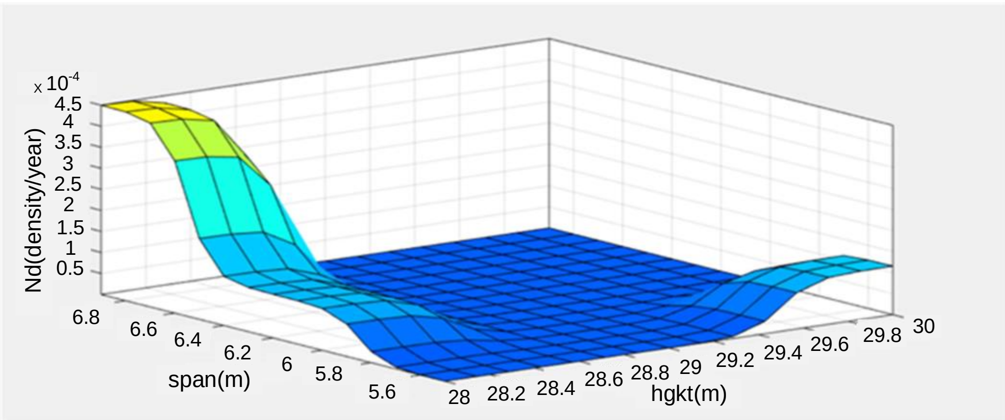

Fig.10. Surface viewer Hgkf and b

Figure 10 shows the surface viewer of Hgkf, b, and Nd where the X-axis is Hgkf the Y-axis is b and the Z-axis is Nd.

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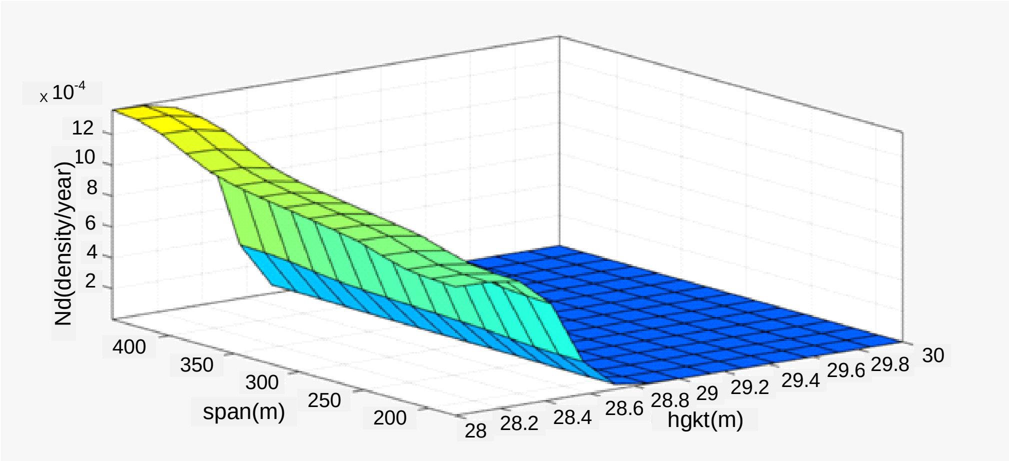

Fig.11. Surface viewer Hgkf and Span Distance

Figure 11 shows the surface viewer of Hgkf, span distance, and Nd where the X-axis is Hgkf the Y-axis is Span distance, and the Z-axis is Nd.

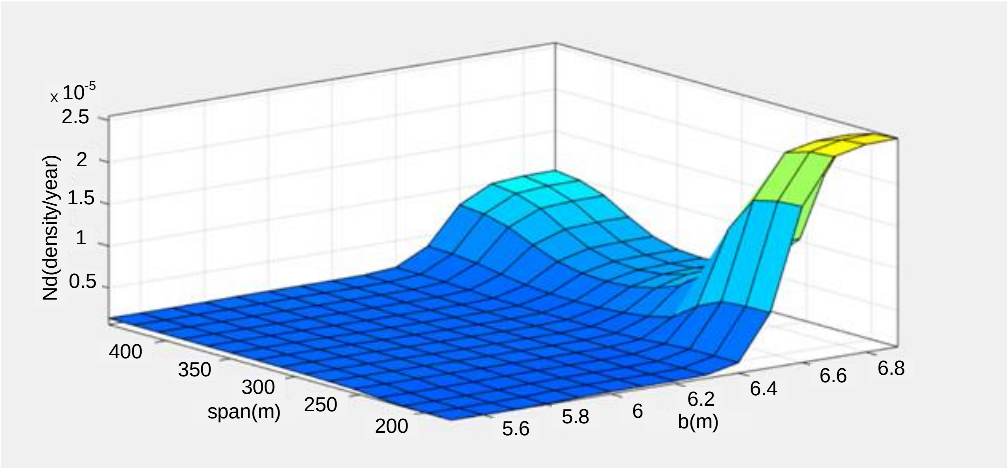

Fig.12. Surface Viewer Span Distance and b

Figure 12 shows a surface viewer of b, span distance, and Nd where the X-axis is b the Y-axis is the span distance, and Z-axis is Nd.

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3.2. The Results of ANFIS

Table 1. RMSE Comparison of Hybrid and Backpropagation Methods

RMSE (Root Mean Square Error)				
Membership Function	*Data Training*		*Data Testing*	
	Hybrid	*Backpropagation*	*Hybrid*	*Backpropagation*
Trimf	0.07589	0.48271	0.07589	0.47364
Trapmf	0.07886	0.46583	0.07886	0.45786
gbellmf	0.07597	0.51851	0.07597	0.50895
gaussmf	0.07592	0.49996	0.07592	0.49049
gauss2mf	0.07782	0.46550	0.07782	0.45746
pimf	0.07989	0.46534	0.07989	0.45754
dsignmf	0.07588	0.44199	0.07588	0.43343
psignmf	0.07588	0.44181	0.07588	0.43325

Table 1 compares RMSE for the two methods, Hybrid and Backpropagation, in the learning process (training) and the validation process (testing). The lowest RMSE in the learning process is 0.07588 for training data and 0,07588 for testing with *dsignmf* and *psignmf* membership functions.

From the results obtained through ANFIS, the results are loading and testing. ANFIS can predict through the lightning density values that often appear when a lightning strike occurs based on tower input data processed by ANFIS.

3.3. GUI (Graphical User Interface)

The display of the model of determining the value of the structure of lightning strikes based on adaptive neuro-fuzzy inference systems uses the Matlab software, with lightning strike value output. The rule used is from the ANFIS rule with the AND logic function. The display of the lightning strike value structure based on the adaptive neuro-fuzz inference system is shown in Figure 13.

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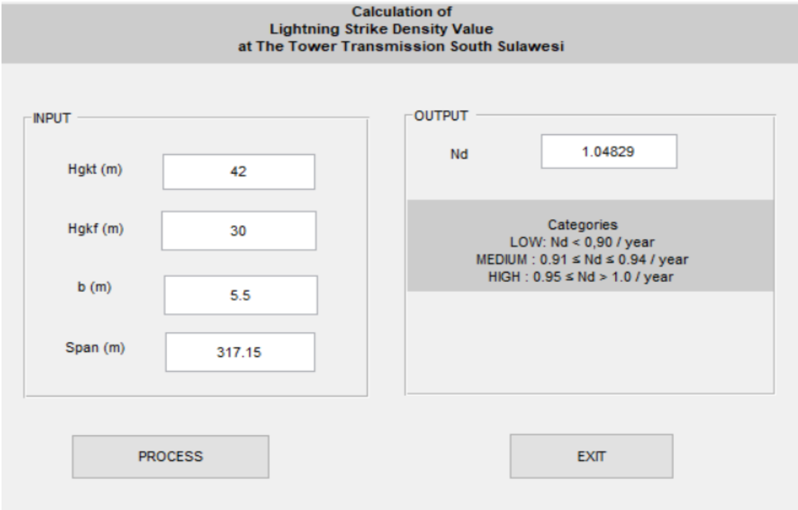

Fig.13. Display GUI Prediction of Lightning Strike Tower Value

3. Conclusions

In this paper, it can be analyzed and concluded several things that are needed to determine the value of the lightning strike structure of the South Sulawesi region:

1. The result shows ANFIS simulation with hybrid algorithm and backpropagation algorithm hybrid. The backpropagation algorithm with *trimf, tramf, gbellmf, and gaussmf* functions shows the comparison of RMSE for the two methods, namely Hybrid and Backpropagation, in the learning process (*training*) and the validation process (*testing*). The lowest RMSE in the learning process is 0.07588 with the *gaussmf* membership function for training and testing data.
2. The calculation system results for the value of structural lightning struck in the South Sulawesi region. They validated manual calculations and ANFIS with an average percentage of 0.0554%.
3. From this research, we can make it suitable to calculate the value of the lightning density (Nd) by using ANFIS, which is then programmed in a GUI. This GUI makes it easy to find out the lightning density (Nd) value on the tower.

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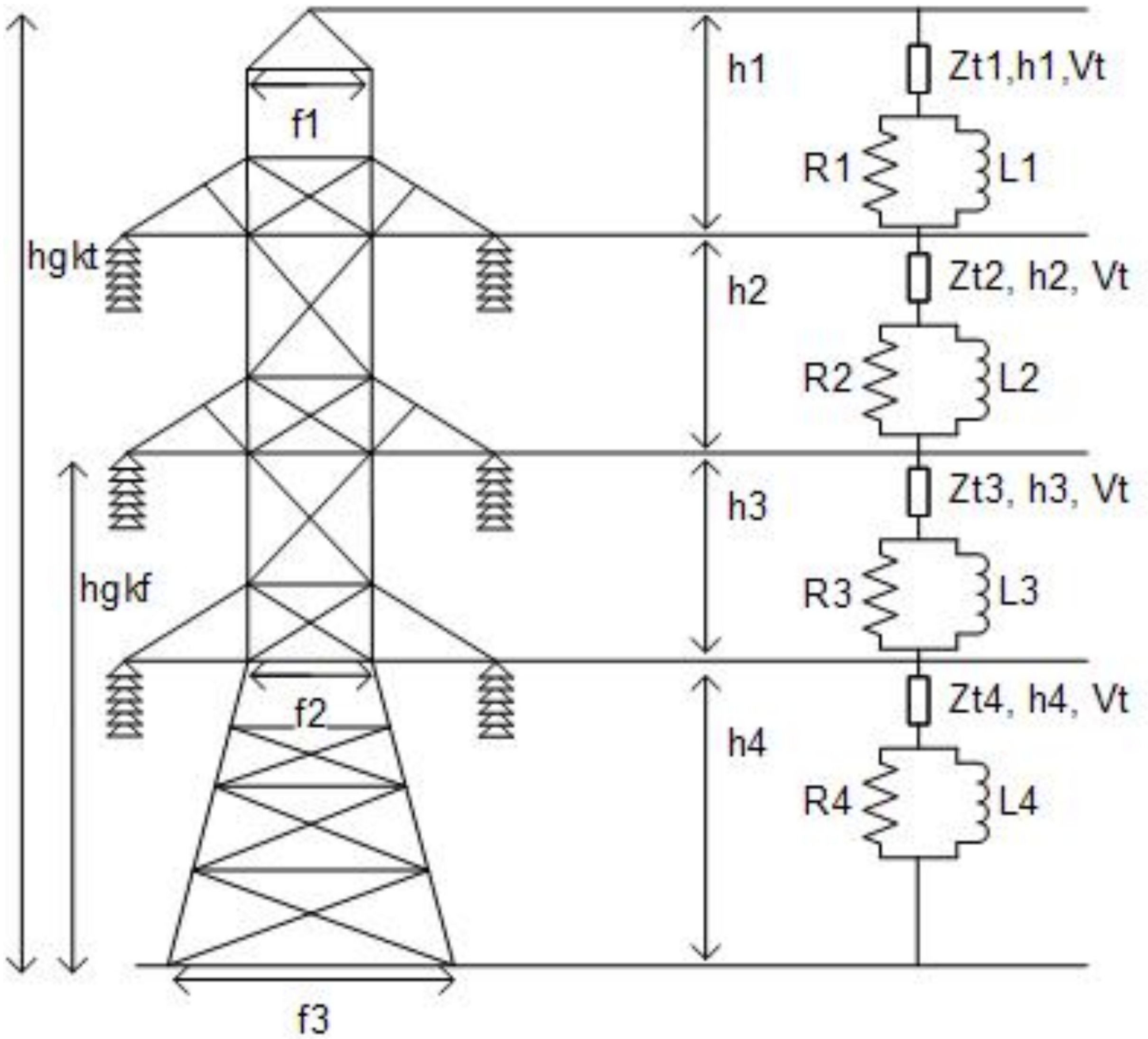

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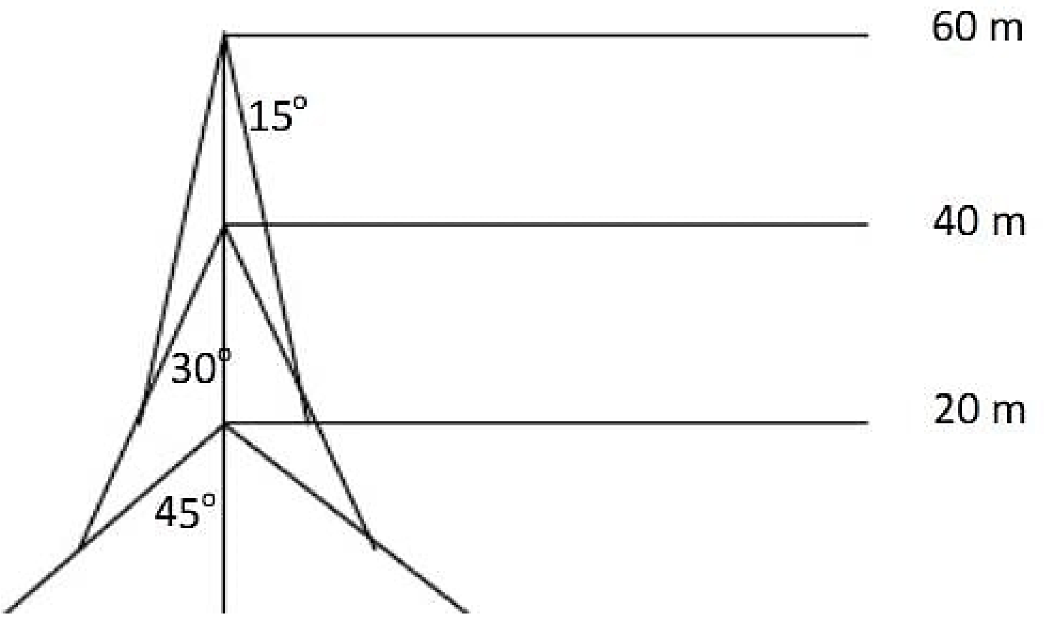

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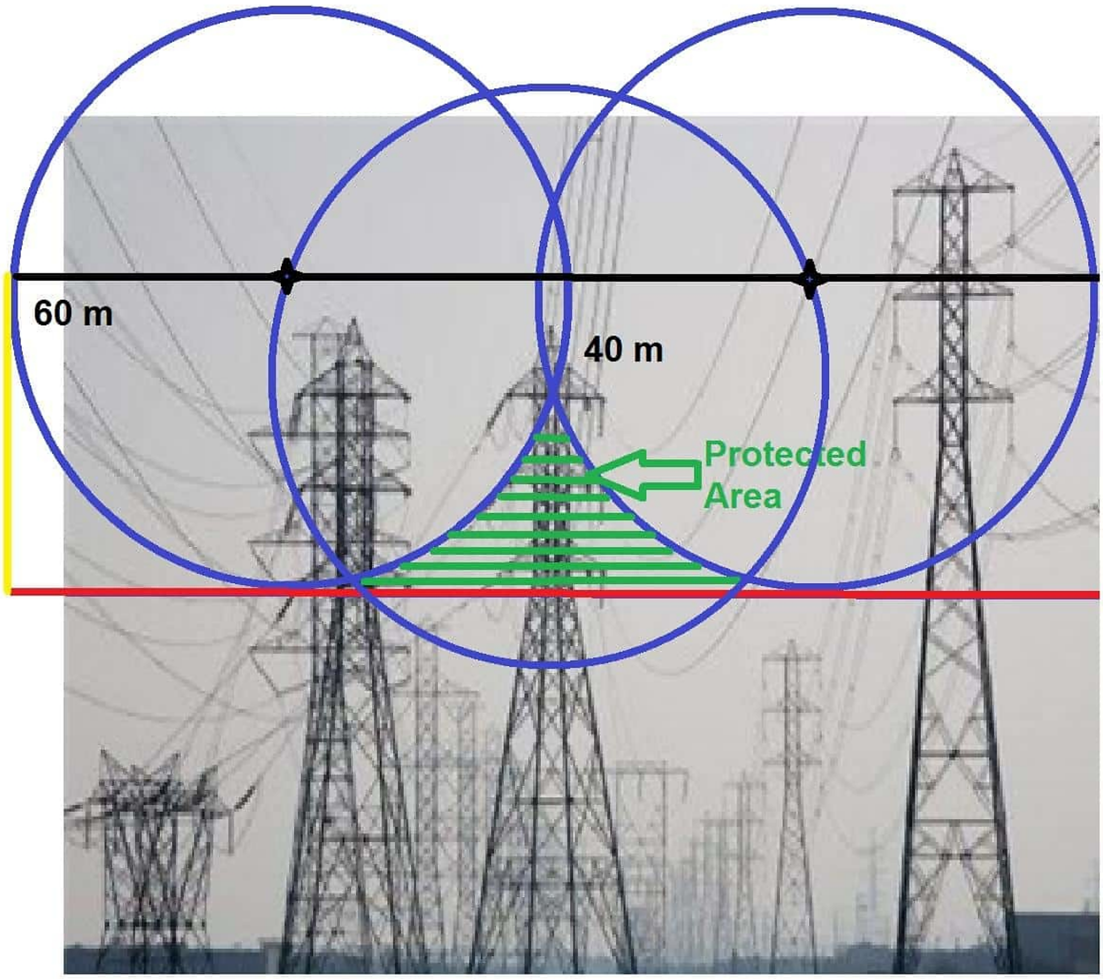

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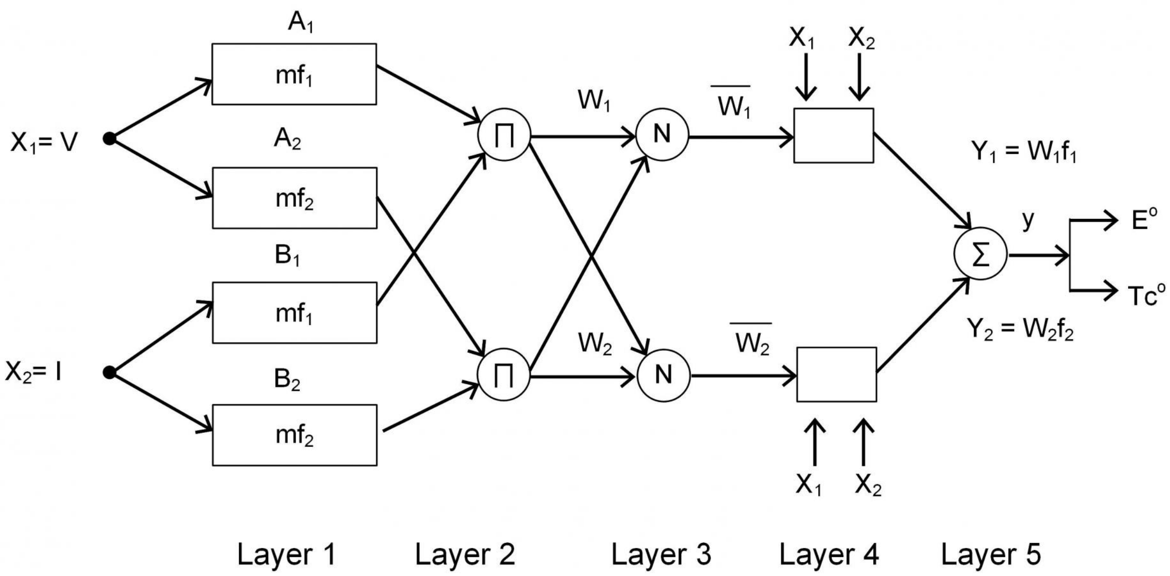

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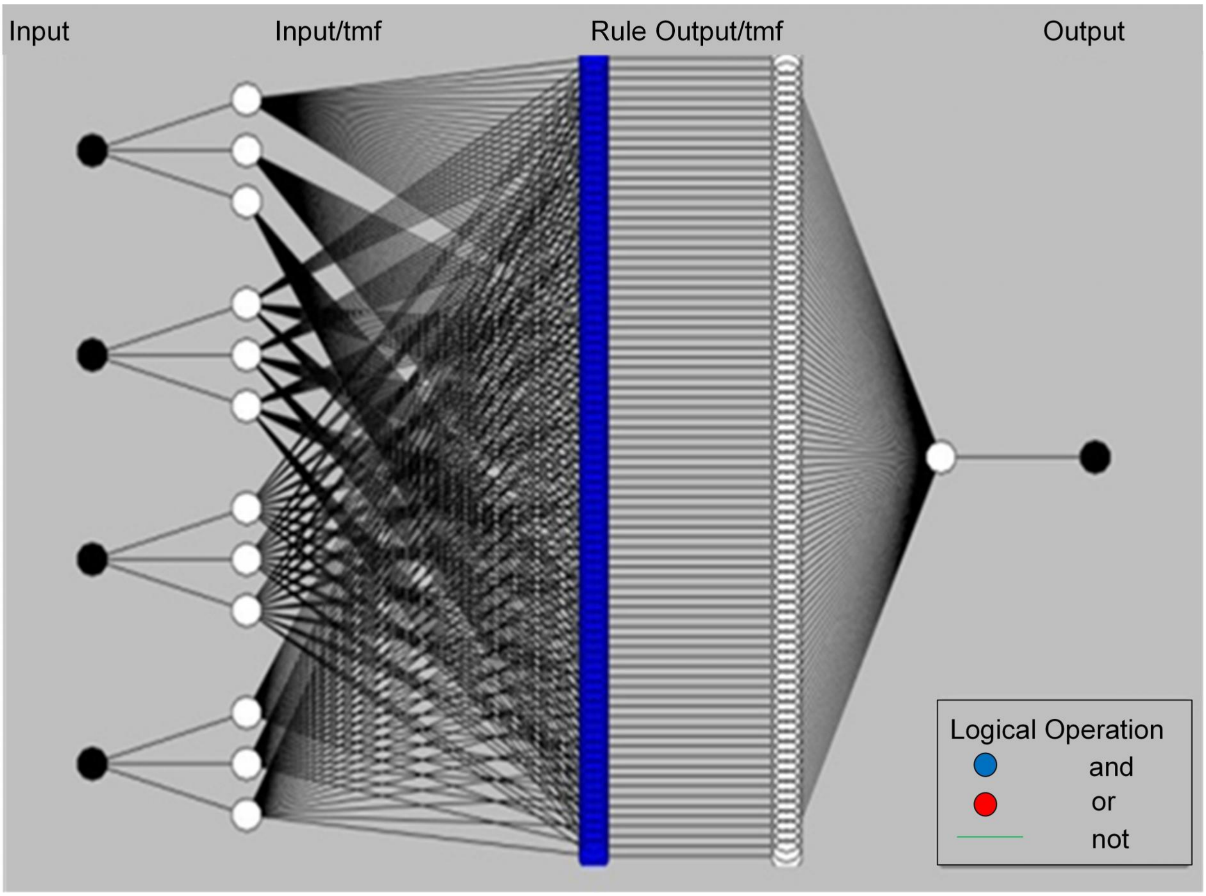
Figure 5



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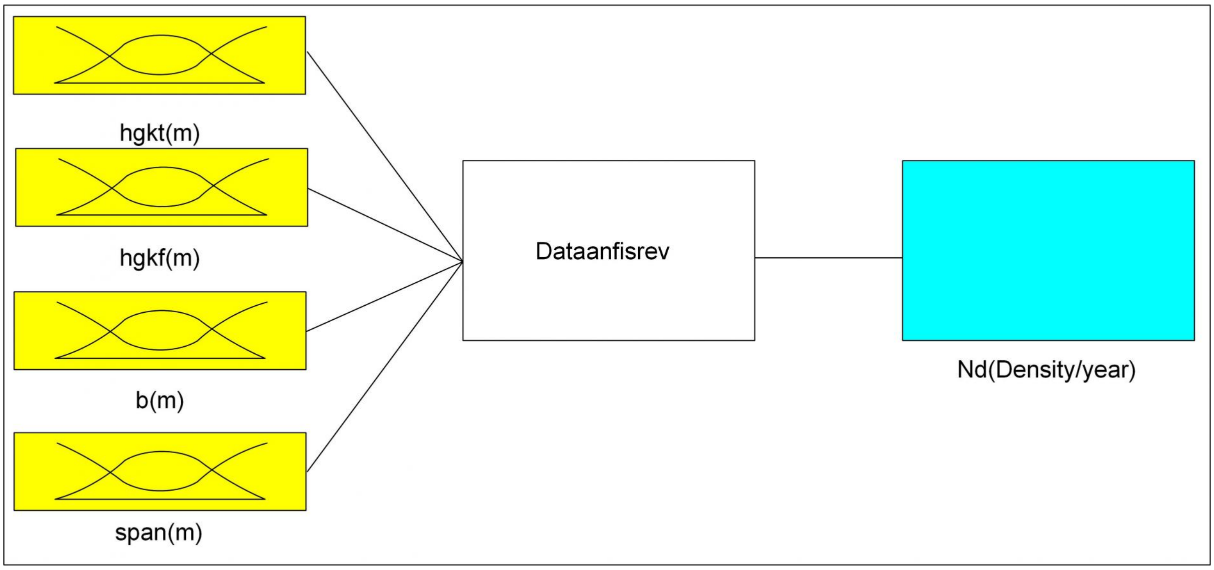

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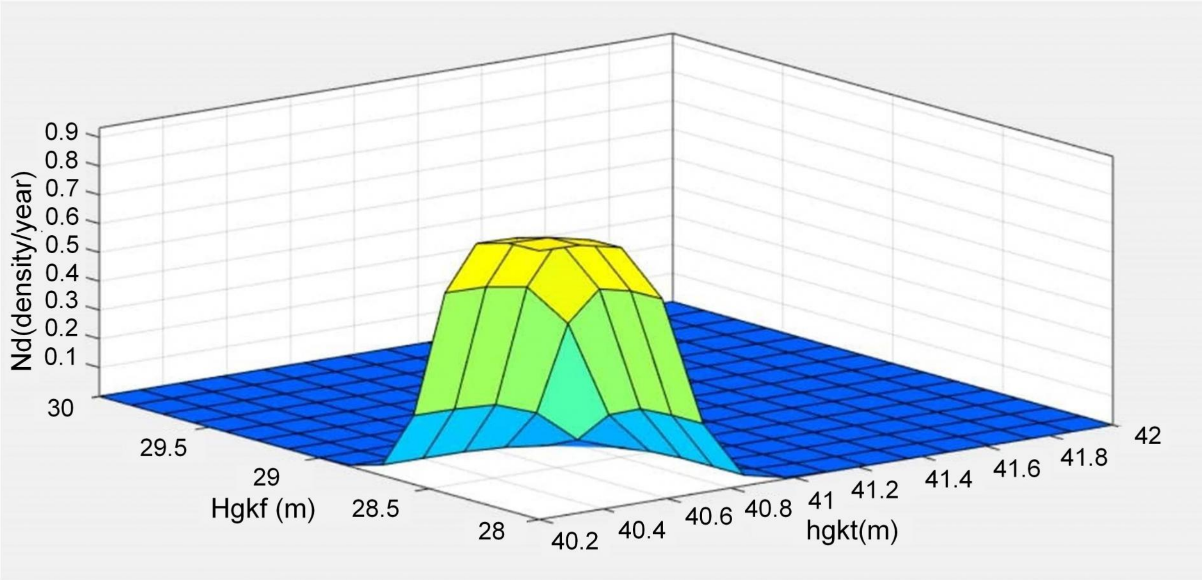

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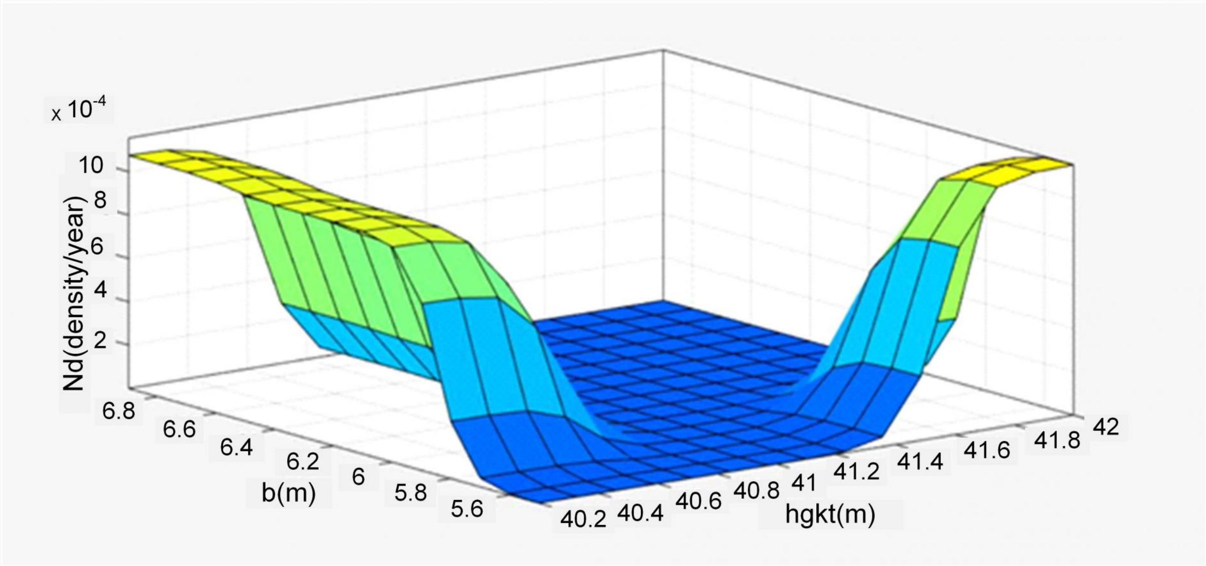

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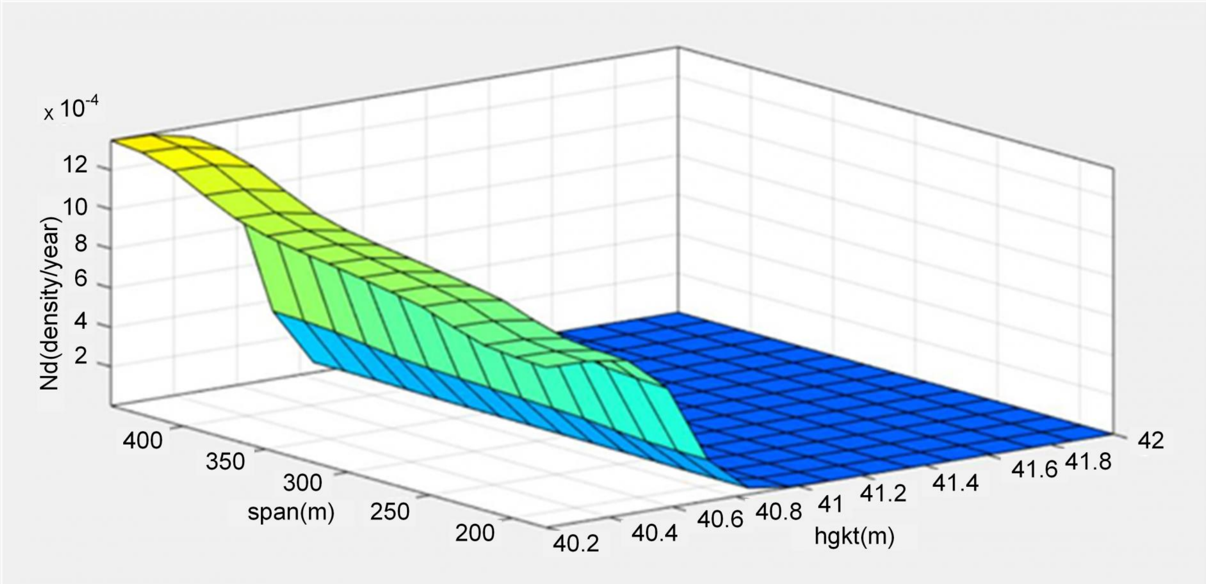

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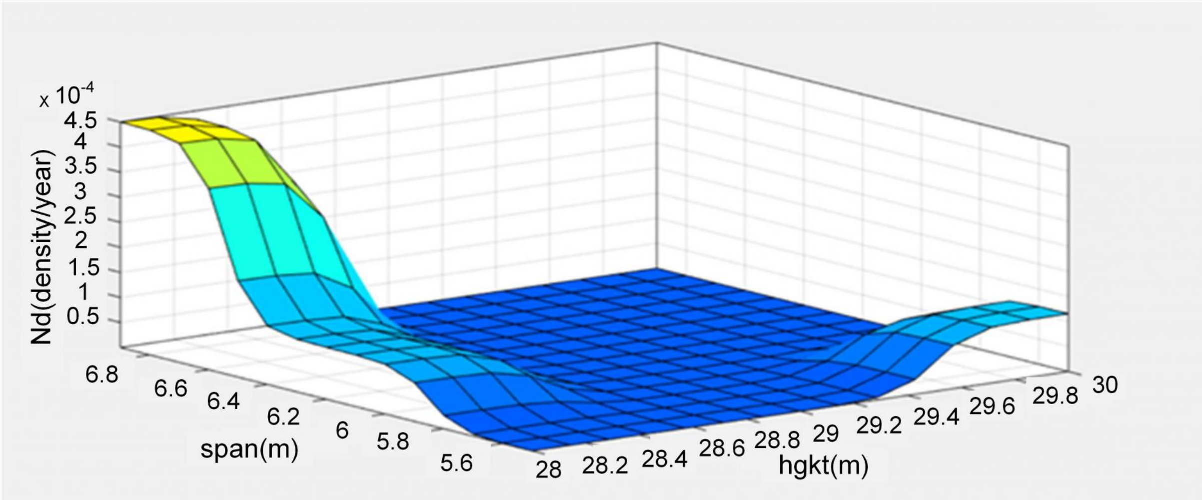

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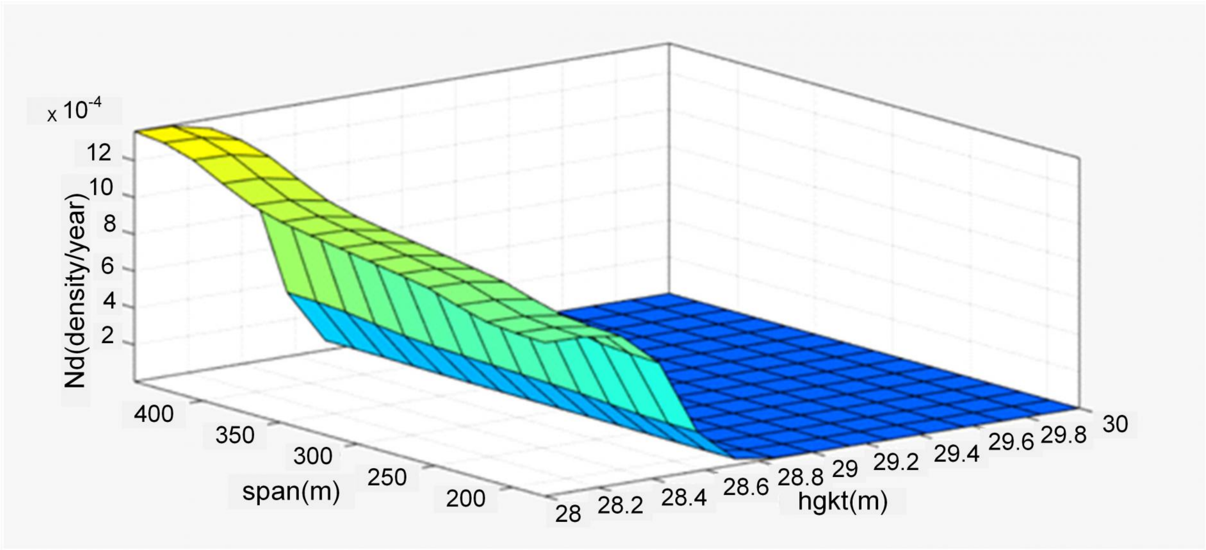

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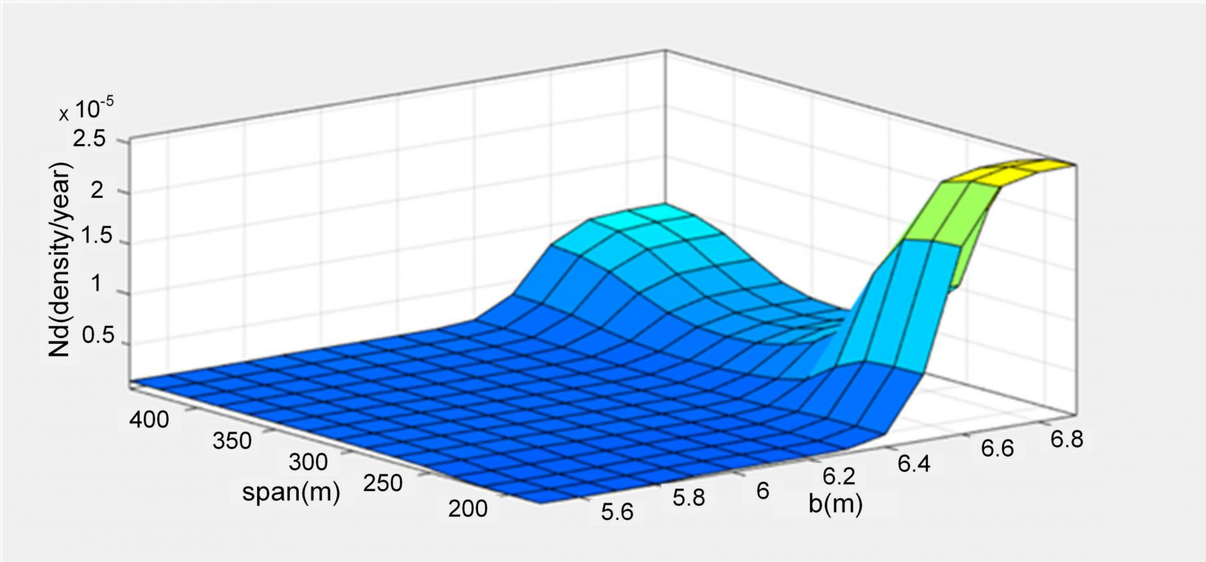

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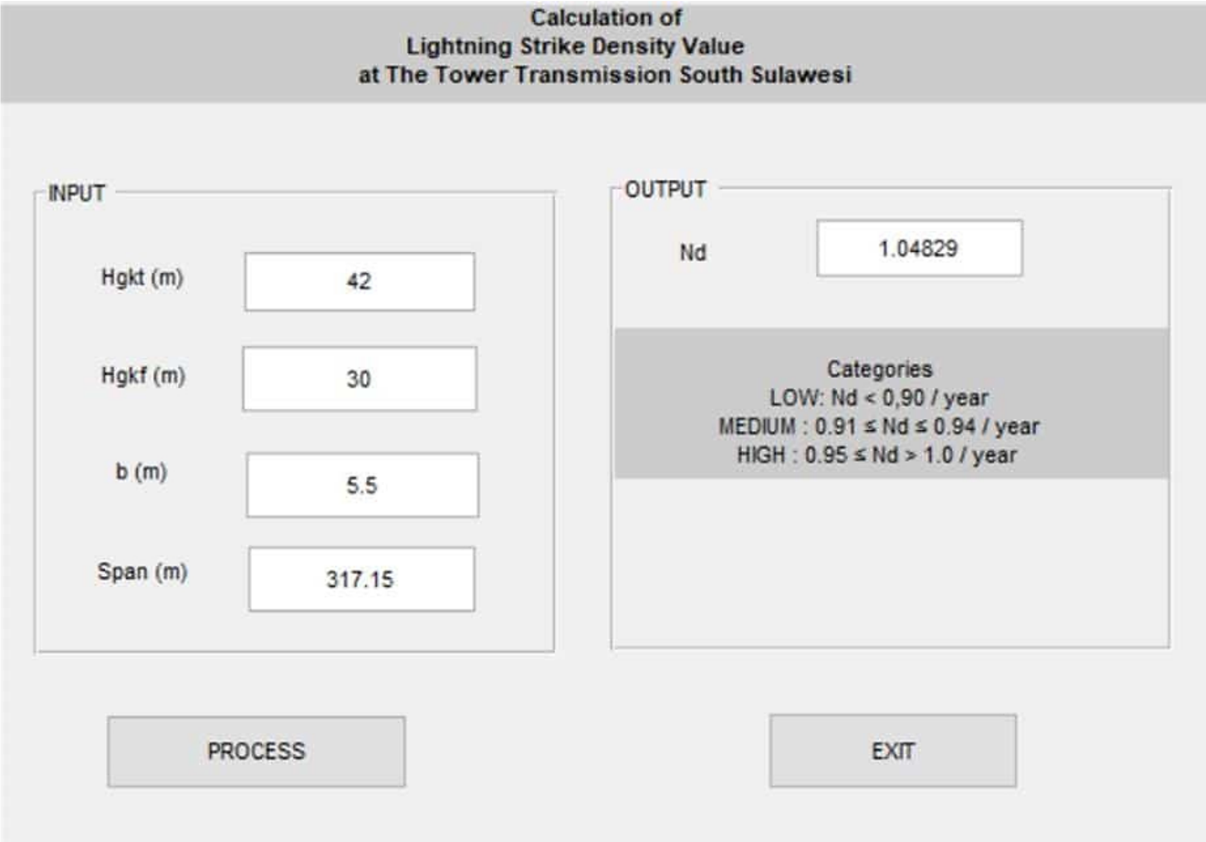

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Prediction of lightning density value tower based on Adaptive Neuro-fuzzy Inference System

SRI MAWAR SAID[1], MUHAMMAD BACHTIAR NAPPU[1], ANDARINI ASRI[2], BAYU TRI UTOMO[1]

[1]*Hasanuddin University*
Indonesia

[2]*Ujung Pandang State Polytechnic*
Indonesia

e-mail: srimawarsaid@gmail.com

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Abstract: Lightning is one of the causes of transmission disorders and natural phenomena that cannot be avoided. The South Sulawesi region is located close to the equator and has a high lightning density. This condition results in lightning susceptibility of disturbances to electrical system lines, especially in high-voltage airlines and substations. An Adaptive Neuro-Fuzzy Inference System (ANFIS) will show the Root Mean Square Error (RMSE) based on the membership function type. This journal is to predict the value of the transmission tower lightning density using the ANFIS method. The value of the lightning strike density index can later be determined based on ANFIS predictions. Analysis of the value calculation system of structural lightning strikes in the South Sulawesi region of the Sungguminasa-Tallasa route can be categorized as three characteristics lightning density (Nd). The calculation system results for the value of structural lightning struck in the South Sulawesi region and validated between manual calculations and ANFIS with an average percentage of 0.0554%.

Key words: Adaptive Neuro-fuzzy Inference System, lightning density prediction tower, Transmission Line Arrester

1. Introduction

With the growth of technology, electricity demand is increasing, and an improvement must follow this development in the quality of the electricity produced, namely the electric power system's quality and reliability [1]. PT. Perusahaan Listrik Negara (PLN) is a company tasked with planning, making, and maintaining the electric power system in Indonesia. This company guarantees the electric power system and the quality of electricity to consumers [2].

South Sulawesi is located in the equatorial region with a tropical climate and high humidity [3]. The conditions cause South Sulawesi to have a higher percentage of lightning strikes, and for those strikes to be higher in power. This lightning strike can disrupt the distribution area (transmission and distribution) of electric power. One of the causes of interference among the many disruptions in the electric power system is occurred by lightning strikes.

Several research titles concerning the disorder caused by lightning and arrester placement have been discussed in the past. A lightning strike and the performance of the arrester input it between GI Bone and GI Sinjai [4]. The earthing value is due to a lightning strike in a 150 kV transmission line system, especially the GI transmission line Sungguminasa-GI Tallasa [5]. Research on modeling a 132 kV transmission tower simulated using ATP-EMTP by placing various arresters including, an IEEE model, Pincetti model, and Fernandez model [6], and this research is on how to get determines the lighting structure's strike value accurately using the ANFIS method. ANFIS is used to get the value of the structure's lightning strike on the tower transmission. Then we can determine which towers are included in the critical category on the transmission line. The results of grouping the critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to lightning in the transmission line. The critical tower is then simulated with an IEEE model arrester to analyze the voltage value impulse that occurs due to the lightning transmission line.

In this paper, a study will be conducted on obtaining accurate lightning strike density values using the ANFIS method [7, 8]. ANFIS is a method that is often used for predictions and forecasting, with good accuracy. ANFIS is a combination of the backpropagation neural network concept with the fuzzy logic concept. The backpropagation neural network has the advantage of recognizing a data/object based on a set of features that are input to the system. Meanwhile, fuzzy-based systems can be expressed with knowledge in the form of "if-then", which provides the advantage of not requiring mathematical analysis for modeling. Besides, fuzzy systems can also process human reasoning and knowledge-oriented towards qualitative aspects.

ANFIS is an adaptive neural network based on a fuzzy inference system using a hybrid learning procedure. ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with the right membership function. Fuzzy conclusion systems that utilize fuzzy if-then rules can model qualitative human knowledge aspects and provide reasoning processes without utilizing appropriate quantitative [9, 10]. In this paper, ANFIS is used to get the value of the structure of lightning density in a transmission tower. ANFIS is used to obtain the value of critical tower lightning density. The tower is in critical condition due to the tower's high lightning strike value, which will be input in the installation of the Transmission Line Arrester (TLA).

2. Transmission system

An electric power system consists of three main parts: a central power plant, transmission line, and distribution system. The transmission line is a link between power centers and distribution systems. The connection between the systems can also lead to other power systems. A distribution system connects all loads separated from each other to the transmission line [11].

2.1. Transmission tower

The electric power channeled through the transmission system generally uses bare wire to rely on-air as a means of insulation between the conductive wire with surrounding objects. The tower is sturdy building construction whose function is to support/span the connecting wire with height and distance sufficient to be safe for humans and the surrounding environment.

There are three different transmission tower models examined. One of them we know is the multistory model designed in [6]. A multistory tower is a composition of parameter distributions with parallel RL [12].

Several tower structures are modeled, in research [13], tower structures at a voltage of 150 kV, as shown in Figure 1.

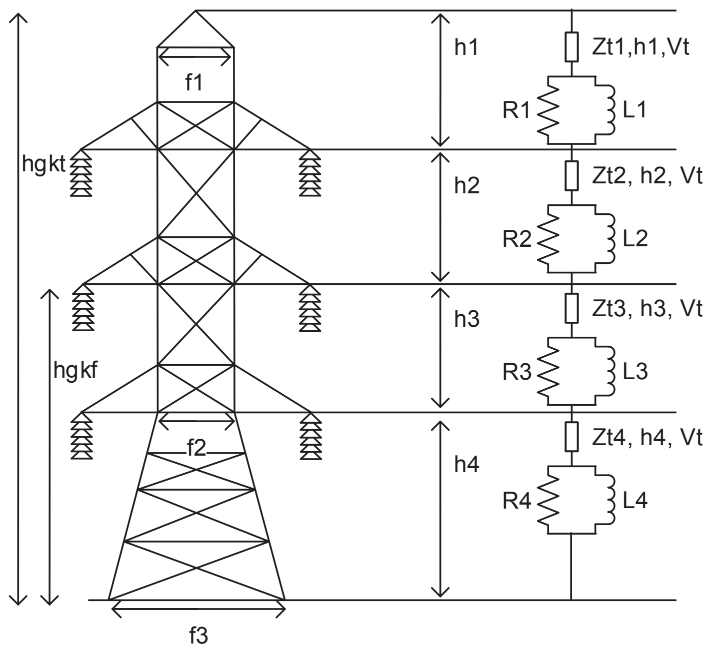

Fig. 1. Tower transmission 150 kV

In this paper, the study has used a 150 kV tower because generally electricity in Indonesia uses a 150 kV tower. The data that has been researched is the data from PLN, and PLN uses a 150 kV tower in the South Sulawesi area. The disadvantage of 150 kV towers is a short distance between them, but one of the advantages of a 150 kV tower is that with a voltage of 150 kV it is still possible to distribute a 400 MVA of power/circuit.

2.2. Transmission line protection from lightning strikes

The conventional protection system commonly used is the cone protection system, which is a simple method of protecting area by using an upright conductor called the 1st method. The second way is the Faraday Cage used for lightning protection of buildings. The third method will be discussed later by using a rolling ball. For the 4th way, similar to the 3rd way, the drawing model uses a satellite dish method. The cone protection method (existing design) and the rolling sphere method (design improvement) were selected by choosing between several methods.

The existing design (cone protection method) method is used to facilitate the determination of a good protection angle. Determining the magnitude of the angle that can provide good protection against interference, especially in lightning strikes, can be seen in Figure 2.

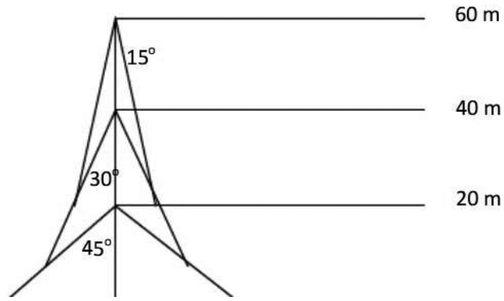

Fig. 2. Cone model lightning protection system

The rolling sphere method is an electrometric concept or rolling ball method connecting the distance of lightning to its peak current. This concept says that an imaginary ball with the lead of the leader at the center of the ball is rolled into a structure. All contact points that hit the surface of the ball will then be struck by lightning. This method is straightforward in determining the design of reliable lightning protection. Figure 3 shows a 150 kV SUTT tower using the rolling sphere method [14, 15].

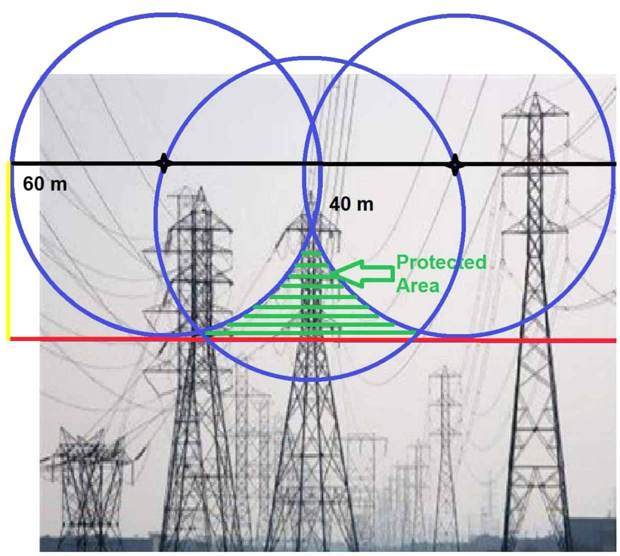

Fig. 3. SUTT tower 150 kV using rolling sphere method

The electrometry concept or the rolling ball method relates the distance of the lightning strike to its peak current. The concept states thet an imaginary sphere with the leading tip at the center of the ball rolls into a structure. All points of contact that hit the surface of the ball will then be struck by lightning. This method makes it very easy to determine a reliable lightning protection design. The analysis shows that the height of the high-voltage overhead tower affects the disturbance that occurs due to lightning strikes. To minimize transmission disruption due to lightning strikes, the existing design method (cone protection method) can be used very well for lightning strike protection, while the rolling sphere method is better because it is more reliable in protecting lightning strikes on 150 kV transmission lines.

2.3. Calculation of lightning structure value of lightning tower

An overhead transmission line can form a shadow of electricity on the ground below the transmission line. The width of the electric shadow for a transmission line has been provided [16].

$$hgwkt = hgkt - 1/2(hgkt - hgkf), \tag{1}$$

$$hg = hgkt - 2/3(hgkt - hgwkf). \tag{2}$$

The width of the shadow is formulated:

$$W2 = \left(b + 4 \cdot hg^{1.09}\right). \tag{3}$$

The span of tower 2 is the average distance from the tower to tower.

Area of shadows for a transmission span (L):

$$L2 = (\text{span1} + \text{span2})/2. \tag{4}$$

The span protection area ($A2$):

$$A2 = W2 \times L2. \tag{5}$$

The lightning density on the tower *(Nd)*:

$$N_d = 0.15IKL \times A2. \tag{6}$$

Notes: *hgkt* is the maximum height of the ground wire; *hgkf* is the maximum height of the phase wire; *hg* is the height of the tower; *hgwkt* is the maximum height of the ground wire in spans; b is the distance between ground wires; $W2$ is the protection shadow width; $L2$ is the average tower distance; span 1 is the distance for tower 1; span 2 is the distance for tower 2 or after the tower before; $A2$ is the area of protection; N_d is the value of strikes on the structure (annual strokes).

2.4. Adaptive Neuro-Fuzzy Inference System (ANFIS)

An Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive network based on a fuzzy inference system. Using a hybrid learning procedure, ANFIS can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with an appropriate membership function.

Illustration of the first-order TSK fuzzy inference mechanism with two inputs x and y [10]. The rule base with two fuzzy if-then rules as below:

Rule 1: if x is A_1 and y is B_1 then $f_1 = p_{1x} + q_{1y} + r_1$.

Premise consequent

Rule 2: if x is A_2 and y is B_2 then $f_2 = p_{2x} + q_{2y} + r_2$.

Premise consequent

Input: x and y consequent are f.

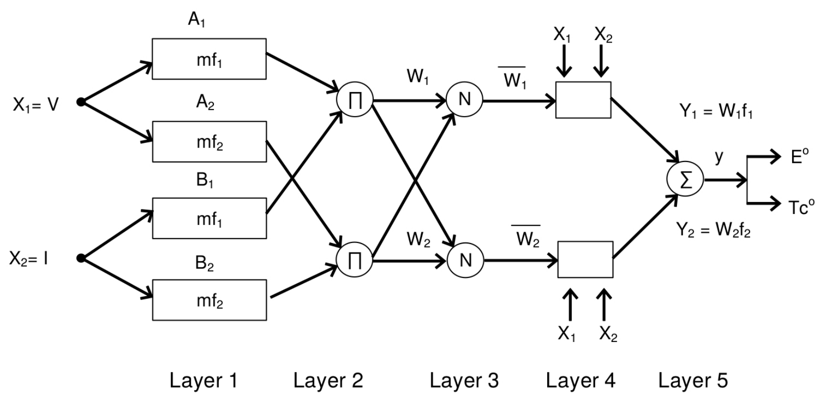

Fig. 4. ANFIS structure for the first-order

The ANFIS architecture consists of five layers, each of which has functions that can be explained as follows.

1. Layer 1: serves as a fuzzy process. The output of node i on Layer 1 is denoted as Oi. So, each node in Layer 1 functions to generate a degree of membership (part of the premise).
2. Layer 2: notated π. Each node in this layer functions to calculate the activation strength (firing strength) on each rule as a product of all incoming inputs.
3. Layer 3: denoted by N. Each node in this layer is non-adaptive which functions only to calculate the ratio between firing strength in the I rule to the total firing strength of all rules.
4. Layer 4: each node in this layer is adaptive w_1, is the output of Layer 3 ($p_{1x} + q_{1y} + r_1$), is the set of parameters in the first-order Sugeno fuzzy model.
5. Layer 5: a single node denoted $\sum$ on this layer functions to aggregate all output from Layer 4.

2.5. Strengths and weakness of ANFIS

The control system will use a system that combines a fuzzy system and an artificial neural network system. This system is known as the neuro-fuzzy system or ANFIS.

The basis of the integration are the advantages and disadvantages of each system. Artificial neural networks can recognize the system through a learning process to improve adaptive parameters. The advantage of fuzzy inference systems is that they can translate knowledge from experts in rules. Still, it usually takes a long time to determine the membership function. Therefore it takes learning techniques from artificial neural networks to automate the process so that it can reduce search time; this causes the ANFIS method to be very well applied in various fields. The weakness of this system is the complexity of the structure. The fuzzy system has a concept similar to the concept of human thinking.

The combination of the two will complement each other's strengths and weaknesses. Several studies have been carried out to see the comparison between ANFIS and a Fuzzy Logic Controller (FLC), the ANFIS results are better than those of an LFC [17, 18]. There are also studies on the comparison of ANFIS and an Artificial Neural Network (ANN). The results of this study indicate that ANFIS is better than an ANN [19]. Other studies also compared ANFIS with some artificial intelligence such as an Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA). The results of this study indicate that ANFIS is better than artificial intelligence such as a Firefly Algorithm (FA), Particle Swarm Optimization (PSO), and Imperialist Competitive Algorithm (ICA) [20].

3. Simulation result and discussion

Processing calculation data into artificial intelligence makes it easier to get the value of the tower's lightning strike density [21]. The artificial intelligence used is the Adaptive Neuro-Fuzzy Inference System (ANFIS).

The results of the calculation of the lightning strike value in the form of whitehead then become input data for data processing in ANFIS, Process Stages of Simulation:

a. Data Load Phase (Data Entering Phase)
b. The Generate FIS Phase (Generating FIS Stage)
c. FIS Training Stage (FIS Learning Stage)
d. FIS Test Stage (FIS Validation Stage).

3.1. Learning process podel (training)

Based on the comparison of the RMSE (Root Mean Square Error) learning process (training) in Table 1, the most optimal method for this case is:

a. Learning algorithm: hybrid method
b. Type of membership function (MF): *psignmf*
c. Epoch: 50
d. Error tolerance: 0
e. Input parameters: (3 3 3 3) f.

It consists of 81 rules. The method is taken from the lowest error rate.

Figure 5 shows ANFIS neurons consisting of 4 inputs_2 one output, and 81 rules.

To make it easier to see the rule, we can see the surface viewer in Figure 7 through Figure 6 to observe the relationship between the four inputs and the output of ANFIS. Figure 6 shows four inputs (*hgkt*, *hgkf*, *b*, and span) and one output (*Nd*). Dataanfisrev is a training process in ANFIS processing to produce the output of ANFIS.

Figure 7 shows the surface viewer of *hgkt*, *hgkf*, and Nd_2, where the X-axis is $hgkt_2$, Y-axis is *hgkf*, and the Z-axis is *Nd*.

Figure 8 shows the surface viewer of *hgkt*, *b*, and Nd_2, where the X-axis is *hgkt*, the Y-axis is *b*, and the Z-axis is *Nd*.

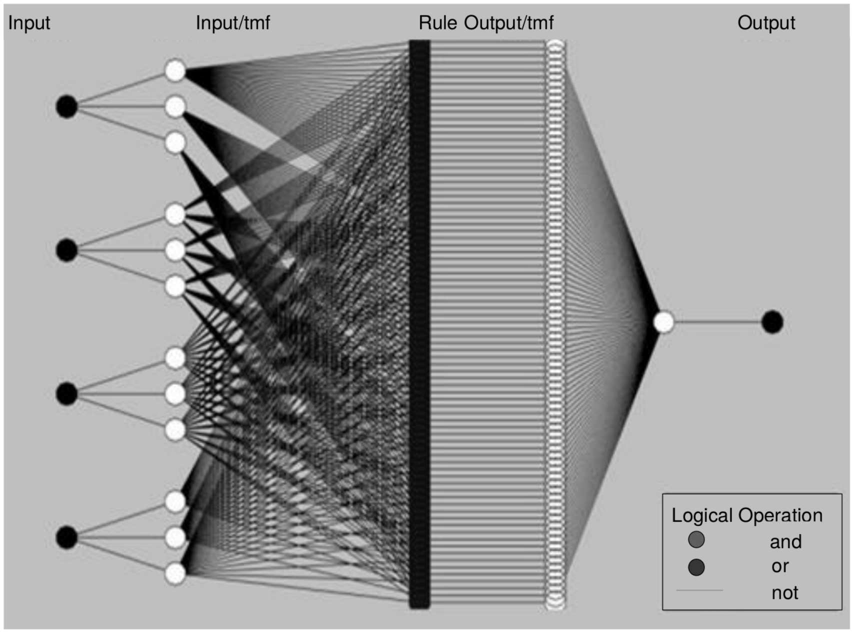

Fig. 5. Learning process model (training)

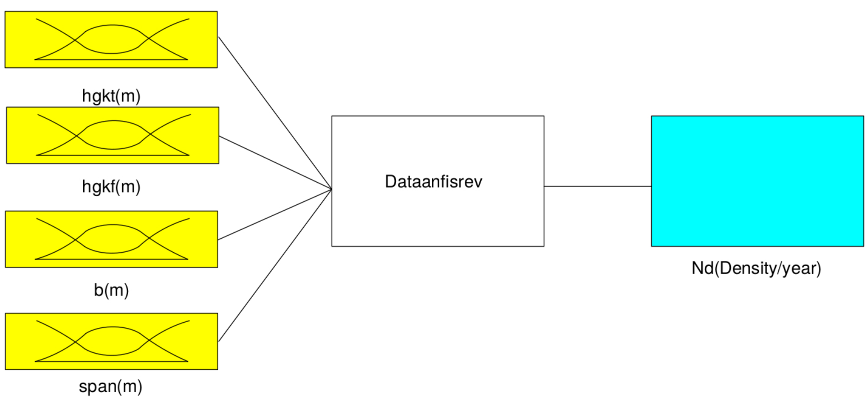

Fig. 6. FIS learning editor (training)

Figure 9 shows the surface viewer of *hgkt*, span, and Nd_2, where the X-axis is $hgkt_2$, Y-axis is the span distance, and the Z-axis is *Nd*.

Figure 10 shows the surface viewer of *hgkf*, *b*, and *Nd*, where the X-axis is $hgkf_2$, the Y-axis is b_2 and the Z-axis is *Nd*.

Figure 11 shows the surface viewer of *hgkf*, span distance, and Nd_2, where the X-axis is $hgkf_2$, the Y-axis is the span distance, and the Z-axis is *Nd*.

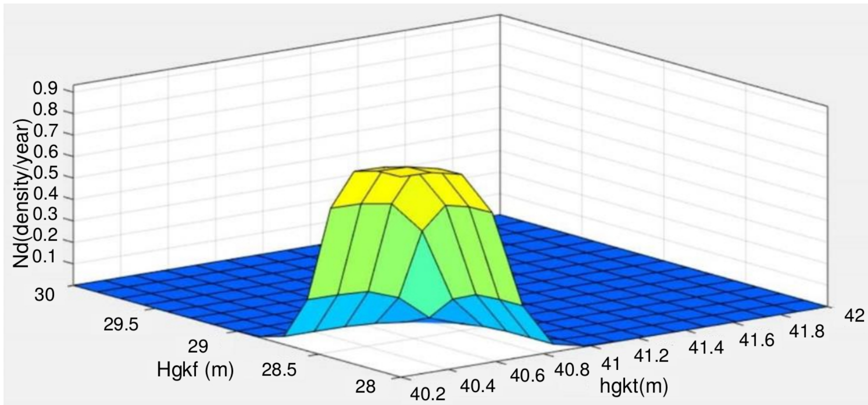

Fig. 7. Surface viewer between *hgkt* and *hgkf*

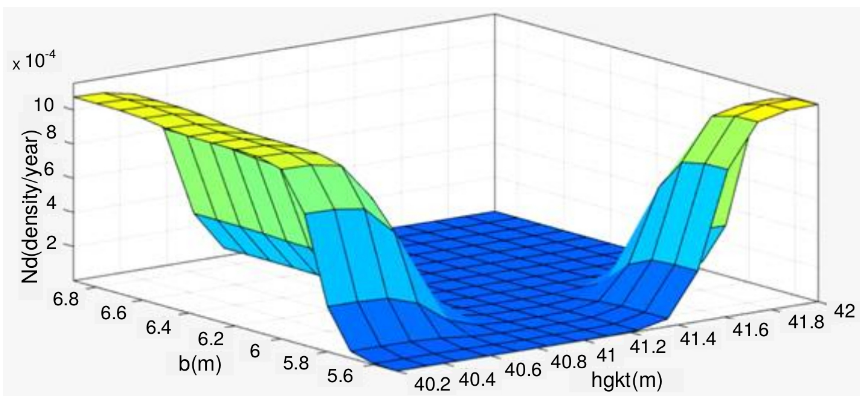

Fig. 8. Surface viewer between *hgkt* and *b*

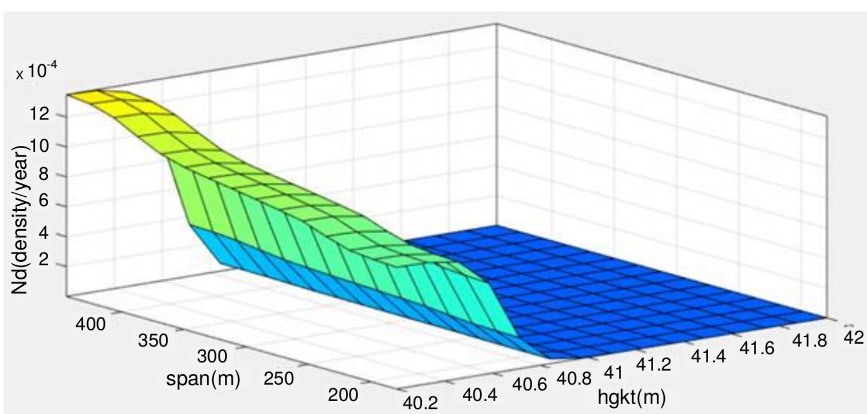

Fig. 9. Surface viewer *hgkt* and span distance

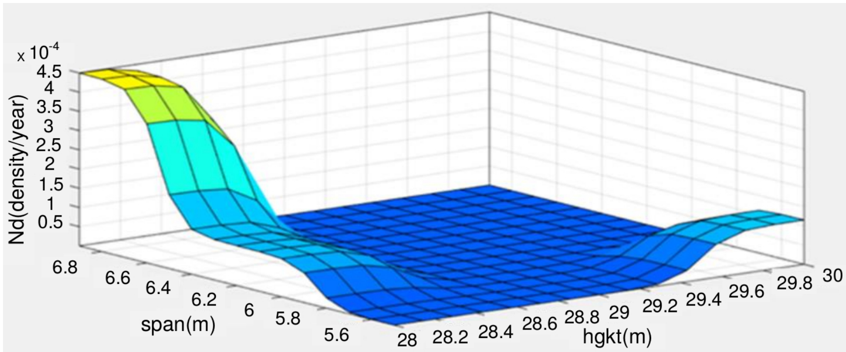

Fig. 10. Surface viewer *hgkf* and *b*

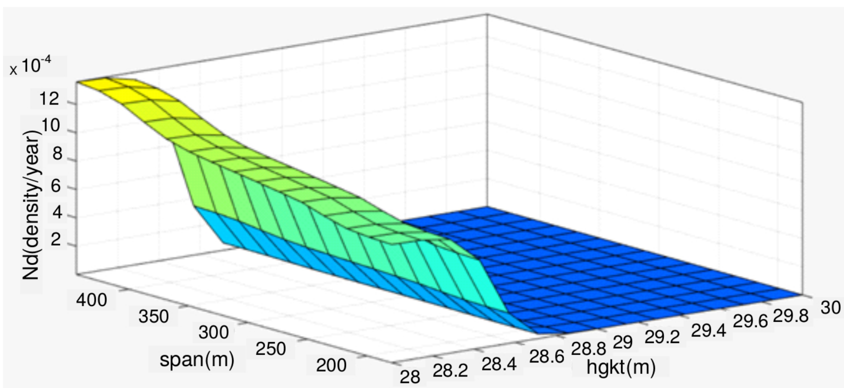

Fig. 11. Surface viewer *hgkf* and span distance

Figure 12 shows a surface viewer of b, span distance, and Nd_2, where the X-axis is b_2, the Y-axis is the span distance, and Z-axis is Nd.

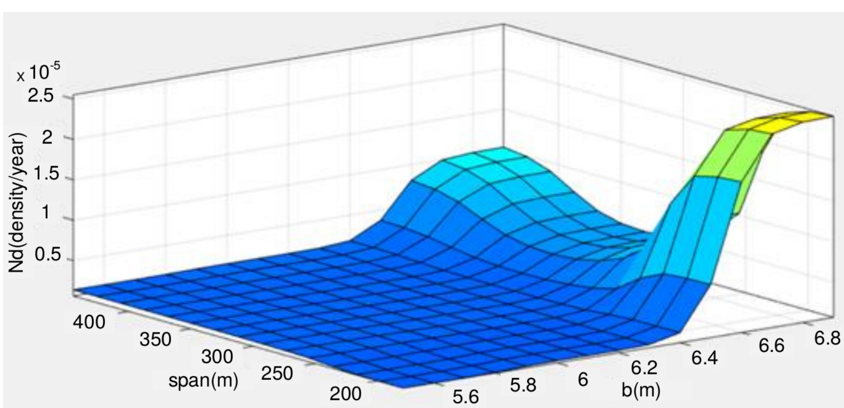

Fig. 12. Surface viewer span distance and *b*

3.2. The results of ANFIS

Table 1 compares RMSE for two methods, Hybrid and Backpropagation, in the learning process (training) and the validation process (testing). The lowest RMSE in the learning process is 0.07588 for training data and 0.07588 for testing with *dsignmf* and *psignmf* membership functions.

Table 1. RMSE comparison of Hybrid and Backpropagation methods

RMSE (Root Mean Square Error)				
Membership Function	**Data Training**		**Data Testing**	
	Hybrid	**Back-propagation**	**Hybrid**	**Back-propagation**
trimf	0.07589	0.48271	0.07589	0.47364
trapmf	0.07886	0.46583	0.07886	0.45786
gbellmf	0.07597	0.51851	0.07597	0.50895
gaussmf	0.07592	0.49996	0.07592	0.49049
gauss2mf	0.07782	0.46550	0.07782	0.45746
pimf	0.07989	0.46534	0.07989	0.45754
dsignmf	0.07588	0.44199	0.07588	0.43343
psignmf	0.07588	0.44181	0.07588	0.43325

From the results obtained through ANFIS, the results are loading and testing. ANFIS can predict through the lightning density values that often appear when a lightning strike occurs based on the tower input data processed by ANFIS.

3.3. GUI (graphical user interface)

The display of the model of determining the value of the structure of lightning strikes based on adaptive neuro-fuzzy inference systems uses the Matlab software, with lightning strike value output. The rule used is from the ANFIS rule with the AND logic function. The display of the lightning strike value structure based on the adaptive neuro-fuzz inference system is shown in Figure 13.

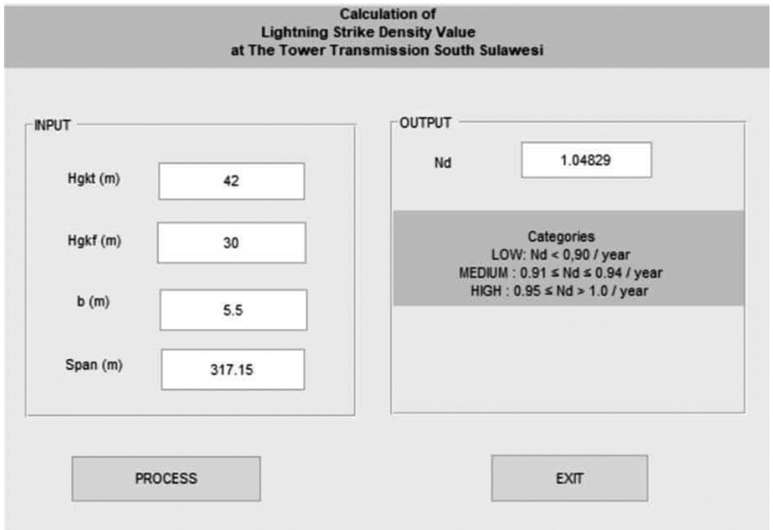

Fig. 13. Display GUI prediction of lightning strike tower value

4. Conclusions

This paper analysis allowed one to conclude that several things are needed to determine the value of the lightning strike structure of the South Sulawesi region:

1. The result shows ANFIS simulation with a hybrid algorithm and backpropagation algorithm hybrid. The backpropagation algorithm with *trimf*, *tramf*, *gbellmf*, and *gaussmf* functions shows the comparison of the RMSE for two methods, namely Hybrid and Backpropagation, in the learning process (training) and the validation process (testing). The lowest RMSE in the learning process is 0.07588 with the *gaussmf* membership function for training and testing data.
2. The calculation system results for the value of structural lightning struck in the South Sulawesi region are shown. They validated manual calculations and ANFIS with an average percentage of 0.0554%.
3. Based on this research, we can calculate the value of lightning density (*Nd*) by using ANFIS, which is programmed in a GUI. This GUI makes it easy to find out the lightning density (*Nd*) value on the tower.

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