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FUZZY LOGIC BASED SMART GRID FOR POWER SYSTEM APPLICATION

A thesis submitted in partial fulfilment of the requirement for the degree of

Master of Technology

In

Electronics and Communication Engineering

Specialization: Electronics and Instrumentation

By

Kartheka Sri Vardhan

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National Institute of Technology Rourkela,

Rourkela, Odisha, 769008, India,

May 2015

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Under the Guidance of

Dr. Samit Ari

Department of Electronics and Communication Engineering

National Institute of Technology Rourkela

Rourkela, Odisha, 769008, India

May 2015

DEPARTMENT OF ELECRTONICS AND COMMUNICATION ENGINEERING, NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA, ODISHA -769008.

CERTIFICATE

This is to certify that the work done in the thesis entitled **Fuzzy Logic Based Smart Grid For Power System Application** by **Kartheka Sri Vardhan** is a record of an original research work carried out by him in National Institute of Technology, Rourkela under my supervision and guidance during 2014-2015 in partial fulfilment for the award of the degree in Master of Technology in Electronics and Communication Engineering (Electronics and Instrumentation), National Institute of Technology, Rourkela.

Place: NIT Rourkela

Date: 28th May, 2015.

Dr. Samit Ari

Assistant Professor

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DECLARATION

I certify that,

a. The work presented in this thesis is an original content of the research done by myself under the general supervision of my supervisor.

b. The project work or any part of it has not been submitted to any other institute for any degree or diploma.

c. I have followed the guidelines prescribed by the Institute in writing my thesis.

d. I have given due credit to the materials (data, theoretical analysis and text) used by me from other sources by citing them wherever I used them and given their details in the references.

e. I have given due credit to the sources (written material) used by quoting them where I used them and have cited those sources. Also their details are mentioned in the references.

Kartheka Sri Vardhan

ACKNOWLEDGEMENT

This research work is one of the significant achievements in my life and is made possible because of the unending encouragement and motivation given by so many in every part of my life. It is immense pleasure to have this opportunity to express my gratitude and regards to them.

Firstly, I would like to express my gratitude and sincere thanks to **Prof. Samit Ari**, Department of Electronics and Communication Engineering for his esteemed supervision and guidance during the tenure of my project work. His invaluable advices have motivated me a lot when I feel saturated in my work. His impartial feedback in every walk of the research has made me to approach a right way in excelling the work. I would also like to thank him for providing best facilities in the department.

I would like to express my gratitude and respect to Prof. K.K.Mahaptra, Prof. S.K.Patra, Prof.A.K. Sahoo, Prof. L.P.Roy, Prof. Samit Ari, Prof. S. Maiti, Prof. A.K. Swain, Prof. D.P.Acharya, Prof.T.K.Dan, Prof.U.C.Pati, for their guidance and suggestions throughout the M.Tech course. I would also like thank all the faculty members of the EC department, NIT Rourkela for their support during the tenure spent here.

I would like to express my sincere thanks to the Ph.D. scholar Mr. Deepak for his valuable suggestions throughout my project work which inspired me a lot. I would like to express my heartfelt wishes to my brothers, friends and classmates whose company and support made me feel much better than what I am. I would like to mention my special wishes to my juniors whose queries made my basics strong.

Lastly, I would like to express my love and heartfelt respect to my parents and sister for their consistent support, encouragement in every walk of my life without whom I would be nothing.

Kartheka Sri Vardhan

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Abstract

Smart grid manages the innovation for modernizing power flow frameworks by exploitation circulated and PC based remote detecting, administration and robotization, and two-way correspondences. Potential edges of the innovation region unit that the great grid's focal administration can right now have the capacity to administration and work a few remote station, streamline the general quality use and operational speedily. Amid this paper, there is an inventive methodology for the great framework to handle vulnerability emerging from condition perception and support of force plant. The mentality utilizes optional versatile support advisor and a framework upkeep analyser for outlining/executing streamlined condition-based protection happenings, and together handles [2] operational dissimilarities happening in every station. The framework upkeep enhancer creates the starting support anticipates each station with multiobjective enhancement by taking into consideration just the look or normal operational conditions.[2] Amid methodology, the station can experience ageing, administration movements, moving climate and payload components, and shaky estimations. Living on every host station, the upkeep advisor can survey the capacity of beginning support arranges; and gauge the obligation changes created by effective dissimilarities on the substation utilizing a hierarchal fuzzy framework. The consultant determination caution the preservation streamlining agent on regardless of whether a reoptimization of its support exercises should be started for meeting the general framework dependability request.[7].

Mean time between failure (MTBF) and mean time to failure (MTTF) are studied in this thesis and fuzzy logic is generate to find he MTTF and MTBF, such that the components that present in the grid may be maintained from time to time without any failure in the system. It can also be useful to find the life of a particular component and to estimate the time taken between to successive failure of component such that it will aid in maintenance of the system.

CHAPTER 1: INTRODUCTION

1.1Introduction

Smart grid is very complex construction.it consists of several section in the production and generation of electricity .there will be a complexity in the transmission of the electricity to the households and industries. The problem in the transmission is corrected with the help of smart meter. Whereas, the problems arise because of problems created by different components in the substation due to their respective problems must be rectified by a good class of maintain ace .In this project, the maintenance techniques by using fuzzy logic are developed. The problems are caused by different uncertainties**. [3]** The substation will experience getting old, regulator shifts, shifting climate and load features. Possible welfares of the expertise are that the smart grid's dominant regulator will presently be able to manager and trigger countless inaccessible power plant, improve the complete strength operation and operative expertly.

Maintenance is kept by considering optimizer and advisor. With the help of fuzzy logic controller the advisor and optimizer are made to work according to change in the transformer.

There will be a failure time for every component in the transformer .Those failure time is calculated by means of Mean time to failure (MTTF) and mean time between failures (MTBF)Mean time between failure or Interim between disappointments (MTBF) is that the prognosticated period between innate disappointments of a framework all through operation. MTBF are frequently figured in light of the fact that the normal worth (normal) time between disappointments of a framework. The MTBF is frequently a piece of a model that expect the unsuccessful framework is immediately repaired (interim to repair, or MTTR), as a region of a replenishment technique. MTBF is the most prevalent dependability term of the item produced by any organization. It gives measure of measure of disappointments per million hours of the item. This is essential in discriminating applications, for example, phone systems, information correspondence system where because of disappointment whole framework will be down and administrations to the buyers will be hampered. Components which are maufactured by considering MTBF are sensors .where as the components which are manufactured by considering MTTF are generators ,tranformers. so , a design is generated for MTBF and MTTF using fuzzy logic .

1.2. An Synopsis of Smart Grid Technology

The combination of information technology engineering in combination with electric grid presents the beginning of smart power system. The digital equipment that enables for two-way message system among the effectiveness and its clients, and therefore the recognising on the communication lines is whatever varieties the grid sensible. Hardly comparable the web, the sensible Grid can comprise controls, information processing systems, computerisation, and new technologies and instrumentality operating, yet during this instance, these technologies can operate with the electrical grid to retort digitally to our rapidly dynamic electric claim.

Renovation of the power circulation organization so that it displays, guards and robotically adjusts the functioning of its interrelated fundamentals since the chief and dispersed generator finished the high-voltage system and circulation arrangement, engineering employers and building mechanization organizations, energy packing connections and to end-use customers besides their regulators, electric automobiles, applications besides extra home strategies.

1.3 Infrastructure of Smart Grid

Infrastructure of smart grid contains the following important section in the generation of power[4]. They are

1. Substation Automation

2. Advanced Metering Infrastructure

3. Distributed Energy Integrated

Typical components of the smart grid are

1. Smart power meters

2.Smart substation

3.Smart distribution

4.Smart generation

General distribution of a smart grid is shown as follow.it includes

1. Secure communication interface

2. Electric interface

3. Domain

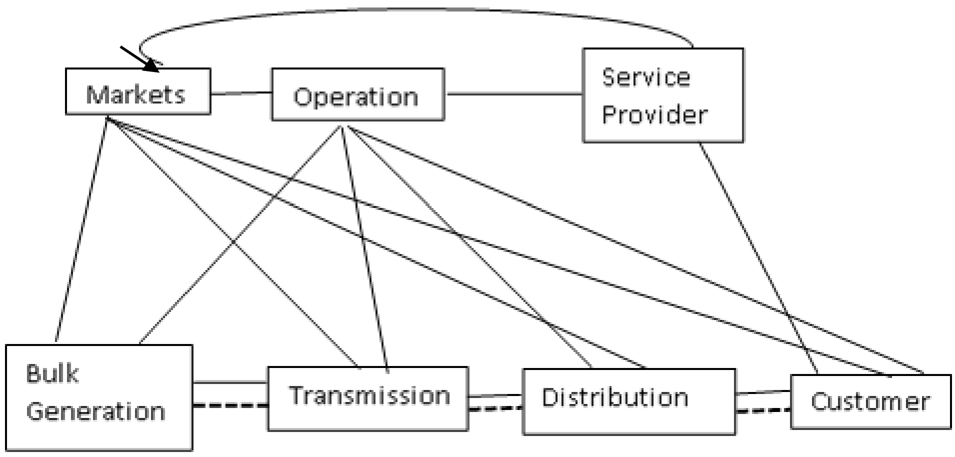


Figure 1 Distribution of smart grid

1.4 Steps elaborated in the Smart Grid

The steps are[5]

- Communication Optimization
- Request Side Administration
- Circulation Optimization
- Quality Optimization

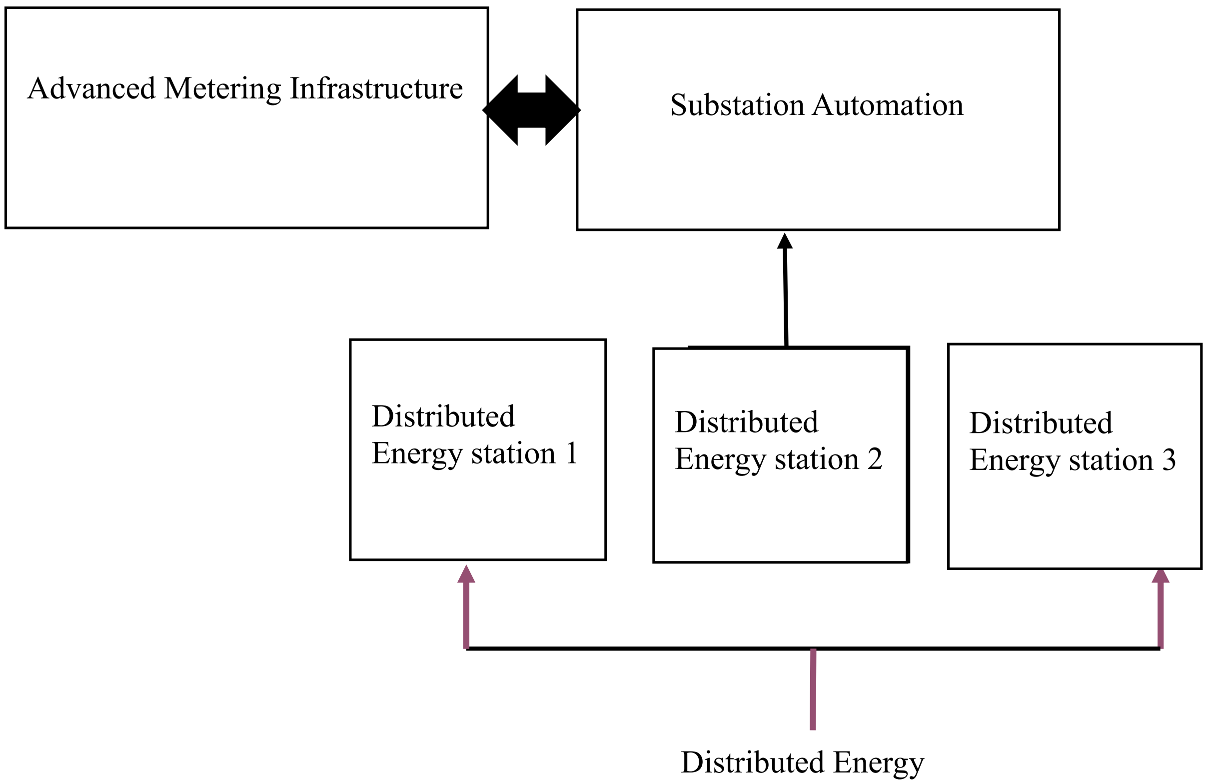


Figure 2 Infrastructure of a smart grid system

1.5. Smart Grid Abilities and Benefits

- Additional well-organized communication of power.
- Faster repair of electricity subsequently control troubles.
- Condensed procedures and supervision prices for conveniences, and eventually lower control prices for clients.
- Condensed top request, which will aid in help minor energy charges.
- Enlarged combination of important renewable energy classifications.
- Enhanced combination of customer-owner power group structures, with renewable. dynamism schemes
- Upgraded safety
- Mechanising care and operation.
- Reducing greenhouse gas discharges.
- Cumulative Distribution of Renewable and Distributed Energy Bases.
- Upgraded Situational Alertness and Infrastructures in the grid.
- Innovative Facilities for End-Users.

1.6 Comparison between Conventional Grid and Smart Grid

Smart grid is way totally dissimilar compared to traditional grid, which is presently a serious half in transmission power offer to households and industries

Table 1difference between smart grid and traditional grid

TRADITIONAL GRID	SMART GRID
1. Electro mechanical metering 2. Only one way directional communication 3. Sensitive(prone to failure and blackouts) 4. No/limited consumer regulator 5. Restricted control over power flows 6. Manual functioning is observed	1. Digital microprocessor metering 2. Two way communication 3. Active 4. Customer can accomplish his energy customs 5. Pervasive control system 6. Semi/full automated(self-healing) is observed in smart grid

1.7 Disadvantages of smart grid

The biggest concern of smart grid is privacy and security. Some of the smart meters used in the metering can be hacked easily. The hackers can gain control on thousands or even millions of meters.it will be dangerous issue. When this situation occurs there will be increase or decrease in the demand of power. Disadvantages problems also arises by the following reasons.

- Overcharging, accuracy, and the Structure Group report
- Fires and electrical problems
- Remote disconnection of power
- Increased metal and infrastructure corrosion

1.8. An Outline of Smart Meters system

A smart meter is a partner degree electrical meter that records the utilization of electrical vitality in the interims of a partner degree hour or less. Brilliant meter imparts the information in any event every day back to the convenience for checking and charging capacities. Shrewd meters empower two- route correspondence between the meter and the focal framework.

Smart Meters are electronic estimation gadgets utilized by services to convey data for charging clients and working their electric frameworks. For more than fifteen years electronic meters, have been utilized viably by utilities as a part of conveying exact charging information for in any event a segment of their client base. At first, the utilization of this innovation was connected to business and mechanical clients because of the requirement for more complex rates and more granular charging information prerequisites.

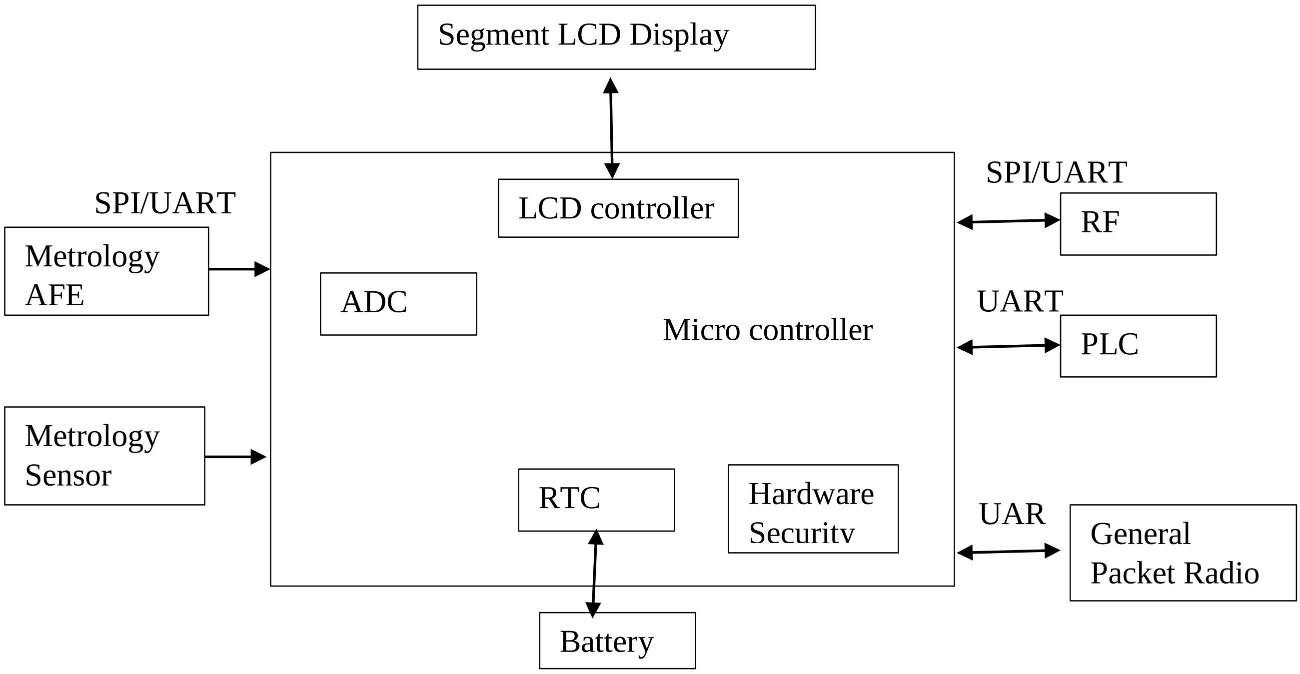


Figure 3 Smart Meter Block Diagram

The combination of the electronic meters with two-way interchanges innovation for data, screen, and control is generally mentioned to as Advanced Metering foundation (AMI). Past frameworks, which used restricted interchanges to gather meter information were suggested to as AMR (Automated Meter Reading) Systems. AMI has grown over the long pull, from its roots as a metering perusing substitute (AMR) to today's two-way correspondence and statistics framework.

1.9 Smart Meter System Profits

The advantages of Smart Metering establishments are various for a wide range of partners of the frameworks.

Table 2 Smart meter system profits

Sponsor	Profits
Value Customers	Well access and data to achieve energy use More accurate and timely Enhanced billing Improved rate options Enhanced outage
Customer Deal & Field Actions	Reduced cost of Metering analysis Compressed collections and connects/separates Removes handheld meter reading apparatus Reduced call centre relations
Revenue Cycle Facilities - Billing, Accounting, Revenue Guard	Early recognition of meter damaging Reduced valued billing and billing blunders
Communication and Supply	Enhanced transformer load administration Better capacitor bank transferring Data for upgraded efficiency, consistency of service, losses, and charging
Advertising & Load Estimating	Condensed costs for gathering load research statistics
Efficiency General	Condensed regulatory objections Upgraded customer principle safety & risk profile

1.10 Smart Meter Architecture

Smart Meter Systems are differed in innovation and outline yet work through a straightforward general methodology. The Smart Meters gather information generally and transmit through a Local Area Network (LAN) to an information authority. [31]This transmission can happen as regularly as 15 minutes or as occasionally as day by day as indicated by the utilization of the information.

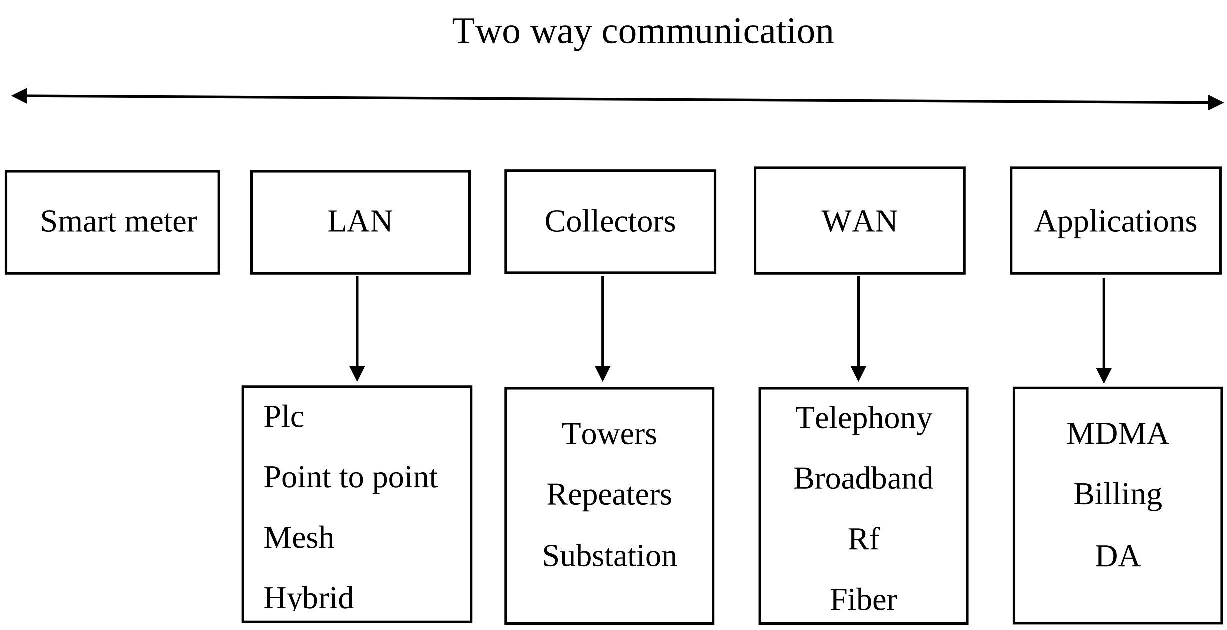


Figure 4 Smart Meter System Elementary Design

The authority recovers the information and could conceivably complete any handling of the information. Information is transmitted through a Wide Area Network (WAN) to the utility focal gathering point for handling and use by business applications. Since the interchanges was two -way, flags or summons can be sent specifically to the meters.

1.11. Introduction to fuzzy logic Overview

Fuzzy logic may be a method of numerous esteemed rationale that agreement with assessed, marginally than secured and genuine thinking. Joined to antiquated parallel [42] rationale (where variables may battle genuine),[6] numerical rationale variables may have a truth charge that ranges in degree somewhere around zero and one. Fuzzy logic has been reached out to handle the origination of halfway truth,[32] wherever the truth value mass differ between completely genuine and completely false. In addition,[9] when verbal variables are utilized, these degrees may be overseen by particular capacities The expression "fuzzy logic" was acquainted with proposition of fluffy unadulterated [6]arithmetic by Lotfi A. Zadeh numerical rationale has been utilitarian to a few fields, from organization hypothesis to software engineering. Numerical rationale had, yet, been concentrated on since the Nineteen Twenties, as limitless esteemed rationale amazingly by Łukasiewicz and Tarsk.

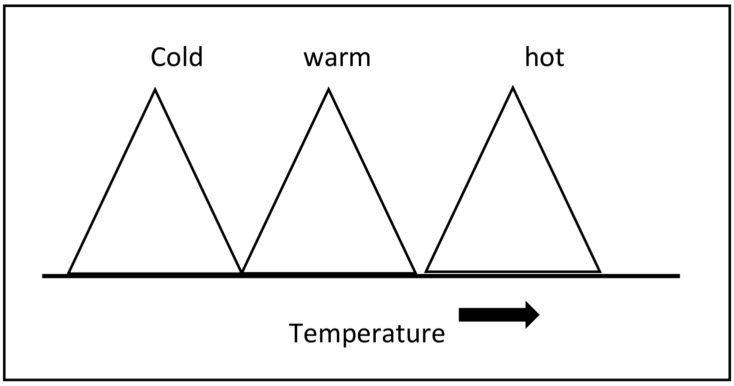
Classical logic solely permits propositions having a worth of truth or falsity. The notion of whether or not 1+1=2 is Associate in nursing absolute, changeless and mathematical truth. However, there exist sure propositions with variable answers, like asking numerous folks to spot a colour. The notion of truth does not fall by the edge, however rather on a method of representing and reasoning over partial information once afforded, by aggregating all doable outcomes into a dimensional spectrum.[9] Each degrees of truth and possibilities vary between zero and one and thence could seem similar initially. [20]As an example, let a hundred millilitre glass contain thirty millilitre of water. Then we have a tendency to could take into account 2 ideas: unfilled and full. That which means of both of them will be diagrammatic by an exact uncertain set. Then one may outline the glass as being zero.7 empty and zero.3 full. Memo that the idea of blankness would be particular and [6] therefore would rely upon the witness or style. Another exclusive might, just as well, style a gathering participation perform wherever the glass would be thought-about full for completely values the distance down to fifty millilitre. its key to appreciate that formal rationale utilizes truth degrees as a numerical model of the lack of clarity advancement though probability could be a scientific model of mental article.

1.12 Applying truth values and membership function used

A fundamental accommodation may portray fluctuated sub-scopes of an endless changeable.

For instance, a temperature action for non-freezing stopping devices may require numerous scattered participation occupations forming express temperature assortments needed to deal with the brakes legitimately. Each work maps indistinguishable temperature worth to a truth worth inside of the zero to one shift. These truth qualities will then be acclimated affirm however the brakes should be controlled.

In this image, the denotations of the terms cold, warm, and hot are characterized by occupations



recording a temperature measure. An idea scheduled that scale has three "truth values" one for individual of the three occupations. The upright line in the image characterises a certain temperature that the three arrows gauge. Meanwhile the red arrow points to zero, this temperature might be taken as "not hot". The orange dart may designate it as "somewhat warm" and the blue arrow "impartially cold".

While variables in number-crunching now and again take numerical qualities, in typical rationale applications, the non-numeric are normally acclimated empower the presence of principles and truths. A semantic variable like age may have a value like youthful or its pledge past. Be that as it may, the decent utility of etymological variables is that they'll be changed through verbal fences helpful to essential terms.[6]

A fuzzy set is totally considered by its involvement function (MF). Meanwhile most fuzzy sets in use take a world of discourse X involving of the real line R, it would be unworkable to list all the pair major a involvement function. A more suitable and brief way to express an MF is to direct it as a mathematical formulation. In the fuzzy logic system, the most frequently used membership function in repetition are

(a). Triangles

(b). Trapezoids

(c). Bell curves

(d). Gaussian

- The function are given as

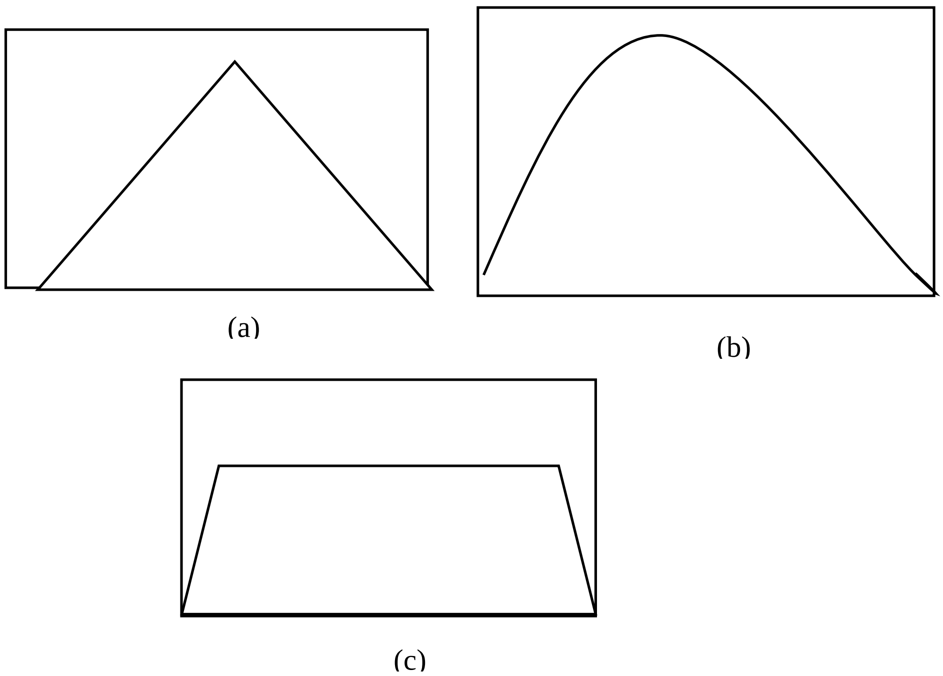


Figure 5 Different types of MF’s a) Triangular, b) Gaussian, c) Trapezoidal,

1.13 objective

Smart grid is exceptionally construction.It comprises of a few segment in the generation and era of power .there will be an intricacy in the transmission of the power to the family units and commercial enterprises. The issue in the transmission is revised with the assistance of smart meter. Though, the issues emerge on account of issues made by distinctive parts in the substation because of their separate issues must be corrected by a decent class of look after pro .In this venture, the upkeep methods by utilizing fuzzy rationale are produced. The issues are created by diverse vulnerabilities Maintenance is kept by considering optimizer and advisor.

With the help of fuzzy logic controller the advisor and optimizer are made to work according to change in the transformer. There will be a failure time for every component in the transformer .Those failure time is calculated by means of Mean time to failure (MTTF) and mean time between failures (MTBF) Mean time between failures.

1.14 Thesis outline

- Chapter 1 contains the information about the introduction of the smart grid. Infrastructure of a smart grid is studied. The difference between the smart grid and conventional grid is noticed. Smart meter architecture is studied and the working of smart meter is studied .fuzzy logic introduction is studied and the way to implement the fuzzy logic is noticed.
- Chapter 2 contains the procedure foe the maintenance of a substation. The working of advisor and optimizer is studied. Fuzzy logic is implemented on unplanned operational variations. Fuzzy logic is also used to find the failure time of a transformer .MTTF is find by failure time of a transformer.
- Chapter 3 contains information about the customer, how to select the power line from the substation which is providing low cost at a particular interval of time.it is implemented by fuzzy logic.
- Chapter 4 contains information about the conclusion and future work.

CHAPTER 2: FUZZY LOGIC BASED MAINTENANCE OF A SUBSTATION

2.1 Maintenance procedure of substation

Maintenance schedules is a complex method for the sensible grid to switch the uncertainties ascending from complaint [1] observation and conservation of control station

It uses

1. Adaptive maintenance advisor
2. System-maintenance optimizer

System-Maintenance Optimizer: It produces primary maintenance plans for every station with multi-objective improvement by considering average operational conditions or planning.

Station can expertise aging, management shifts, dynamical weather, cargo factors, and unsure measurements throughout the operation [1][5][7]

Adaptive maintenance advisor:

Depending on every host station, the "Maintenance Advisor" measures the capability of initial conservation strategies, estimate the responsibleness variations produced by functioning dissimilarities on the station employing a hierarchal fuzzy organisation [1][10]

For meeting the grid-reliability demand, it alerts the running optimizer for re-optimization of its maintenance activities ought to be initiated [1]

In this paper, three main events are studied which [10] determine the power of the projected method for management operative variations happening in an remote station with controllable machine quality [1]

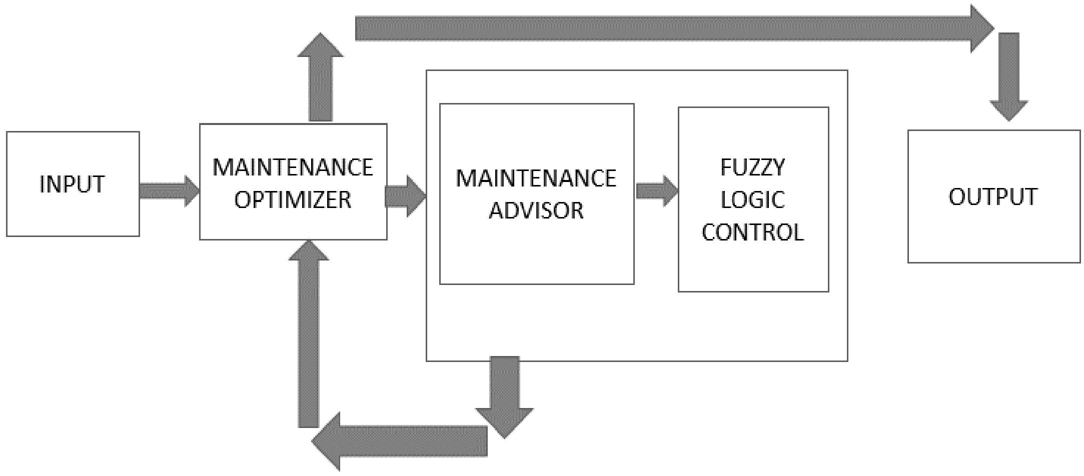


Figure 6 Adaptive Condition Established Maintenance Plan

Generally during a smart grid there'll be prevalence of two sorts of uncertainties happens within the operating. They are

1. Planned Operational Deviations
2. Unplanned Operational Deviations

Our normal fuzzy framework has furthermore a variable structure[35][36], that possesses low-level fuzzy enrolments that connote arranged agent dissimilarities happening in every of remote substation[1] and abnormal state fuzzy connections that guide the unplanned agent dissimilarities as fomentations in parameters[7] handle each few enrollment work of the subordinate framework [1].

The preservation streamlining agent primary acknowledges an arrangement of most prominent perceived or normal compelling circumstances the protection guide acknowledges [1] and outfits the first protection arrangement for absolutely its gear from the association protection analyser, succeeds the requested fuzzy structure [1].

The consultant stays informed regarding the spontaneous varieties climbing from maturing, climate conditions, burden elements [1], and human-judgment hesitations saw from primary types of gear The primary best solutions can become suboptimal, resulting in underneath or over-maintenance all through procedure.

The advice intelligences the indistinguishable deviations of weight point reliableness and any astounding disintegrating [1] inside the station to the analyzer, which can realize reoptimization of upkeep exercises inside the station for levelling the compositions with expenses of backing through system [1].

2.2 Intellectual Maintenance Advisor with Hierarchical Fuzzy Skilled Structure

There are three levels in reaching [4]the identified output inside the method of maintenance. Those three levels are[11][12]

1. Modernising the Reliability Limits for Respective Component[7]
2. Overall Construction of Ranked Fuzzy Logic Organisation[33]
3. Fuzzy Demonstration of Planned and Unplanned
   Working Differences and Fuzzy Interpretation Procedure

Consistency keys, like mean time to failure (MTTF) [1] and failure likelihood (pf), won't persevere constant recognitions to operational variations [37][38]

Deviations of the reliability indices $\Delta\Lambda(i)=[\ \Delta\Lambda_{MTTF}(i)\ \ \Delta\Lambda_{PF}]$ which comprise MTTF ($\Delta\Lambda_{MTTF}(i)$) and p_f ($\Delta\Lambda_{PF}(i)$) are considered for individual component by means of the fuzzy logic system

$$\Delta\Lambda(i)=f_k(V(i))\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(A)}$$

Where $V(i)$ signifies the set of operative deviations of respective module, and f_k characterizes the plotting occupation of the anticipated fuzzy logic arrangement [1] from input to output.

Having calculated $\Delta\Lambda(i)$, genuine dependability files of workings [1] are modernized permitting to functioning deviations by

$$MTTF(i) = MTTF(i-1) + \Delta\Lambda_{MTTF}(i) \quad \ldots\ldots\ldots\ldots(B)$$

$$p_f(i) = p_{f(i-1)} + \Delta\Lambda_{PF(i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(C)$$

where MTTF (i-1) and $p_{f(i-1)}$ are the unique reliability catalogues, MTTF (i) and p_f (i) are the rationalized indices gained subsequently optimization.

Various leveled fuzzy framework has the adaptability [1] for pleasing new unplanned operative varieties for the other hardware by just including a fresh out of the box new arrangement of participations at the abnormal state [1].

Inputs inside of the low level gather the quantity of the arranged operational varieties happening in every part [1]. Fuzzy tenets at this equal then overhaul the joint influences of the arranged operative varieties on trustworthy records on every different part. The abnormal state manages the spontaneous operational varieties on every part in a very much alike way [1].

Numerous parallel logical system units inside the high level [1]area unit betrothed by individual discrimination one unexpected functioning dissimilarity as a result of the input for evaluating its many influence on the component's dependability [1]. The low equal in calculation links the deliberate and accidental operative dissimilarities on each part for estimating their overall impacts on the [1] $\Delta\Lambda$ (i) on its dependability indices

Membership function is represented for each as follows

1. level membership function signify Unplanned Operational Variations
2. High level membership function signify Planned Operational Variations

For the maintenance determination, the Mean Time to Failure (MTTF) of a transformer is measured by taking planned and unplanned operational variations as inputs

Low level involvement for entirely transformer considers

1. Age Difference
2. Load Factor Variation (%)
3. Operating Temperature Variation

Complex involvement purposes for all transformer considers

1. Difference of Insulation Degradation Level (%)
2. Ambient Temperature Dissimilarity(^{0}c)

We suggest a graded fuzzy organization together of good management algorithms exist in at every offshore station [1]. Our projected fuzzy arrangement features a versatile construction for straightforward integration with different management procedures, and portions common aims with them like most energy delivery and minimum operational prices [1]. Our projected fuzzy system has conjointly a variable structure that involves low-level fuzzy memberships that signify planned functioning dissimilarities happening in every substation; and high-level fuzzy relationships that map the unplanned effective variations as perturbations in parameters process every numerous membership finish of the low-level system [1].

Our graded fuzzy system relatives every remote station to its associated power grid, for interchangeably executing and enhancing conservation plans of the offshore [1] station in line with operational variations throughout operation

2.3 Organization of Fuzzy Logic Arrangement for Each Transformer

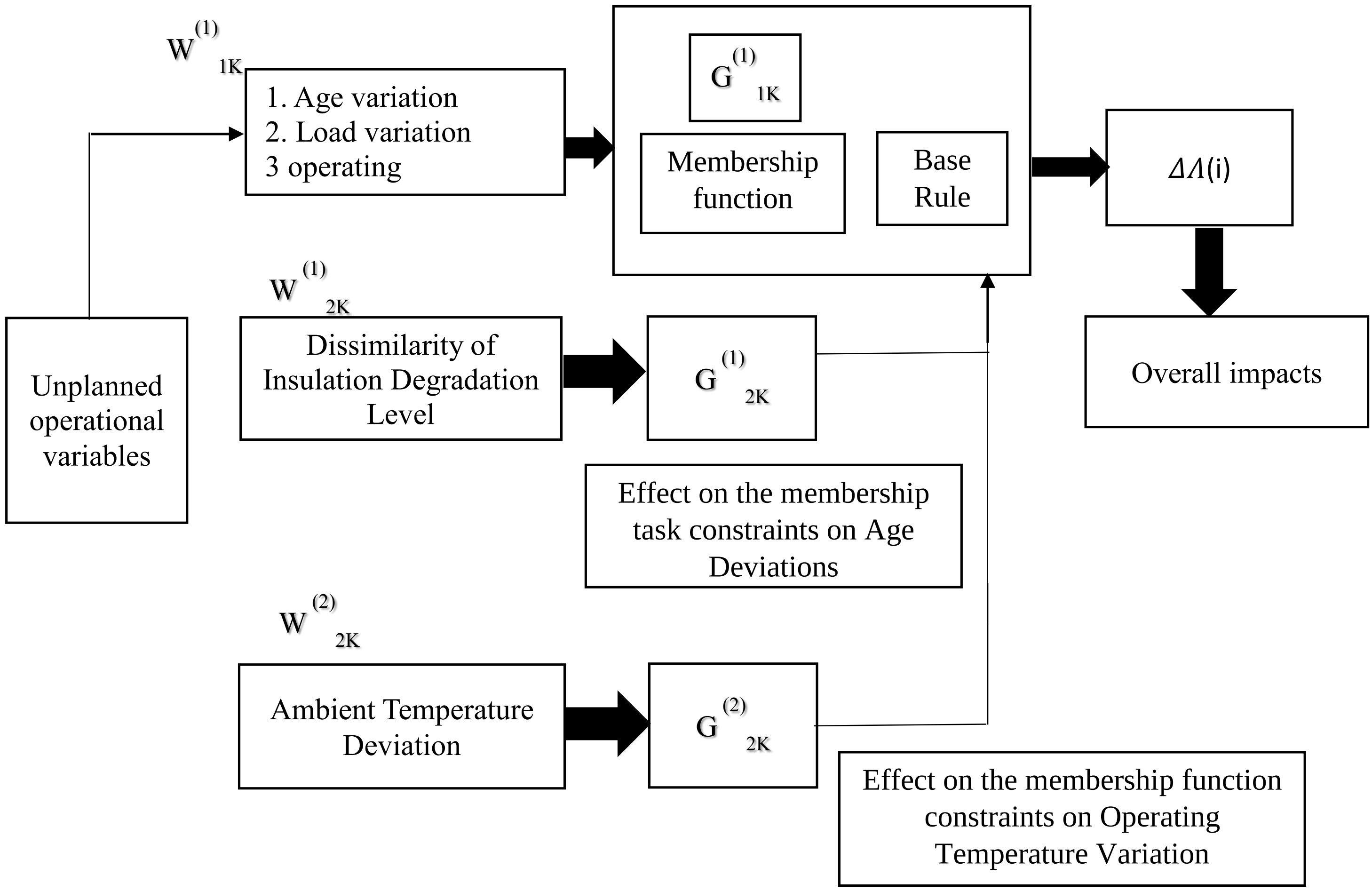


Figure 7 Arrangement of ordered fuzzy logic arrangement for maintenance.

The anticipated numerical logic framework embodies a computationally temperate two-level structure for each part. The progressive fuzzy framework amid this paper is authorized by exploitation sort 1 illation number juggling rather than sort [4]2 surmising math. Accordingly, there's no complexity between the normal progressive fuzzy framework and sort 2 fuzzy association. Related with category 1 fuzzy[6] framework, the expected progressive fuzzy framework has the flexibleness for [1]obliging original spontaneous effective dissimilarities for alternate device by only including an extra arrangement of participations at the abnormal state.

Low level membership for individual transformer are planned[1] based on

(a) Age Dissimilarity
(b) Load Factor Dissimilarity
(c) Functioning Temperature Dissimilarity

High level membership for individual transformer [1]are planned based on

(a) Insulation deprivation level
(b) Ambient temperature

2.4 Execution of fuzzy logic in Matlab by considering unplanned operational variations

In the maintenance of substation, inputs measured are age dissimilarity, load factor deviation, operating temperature variation, [21][22]and the output measured is MTTF (Mean Time to Failure) Five output language levels [MW, SW, NC, SB, MB] signify the adjustment of MTTF of individual transformer as in "Most Worse," "Slight Worse," "No change," "Slight Better," and "Most Better."[23]

The fuzzy logic is developed as

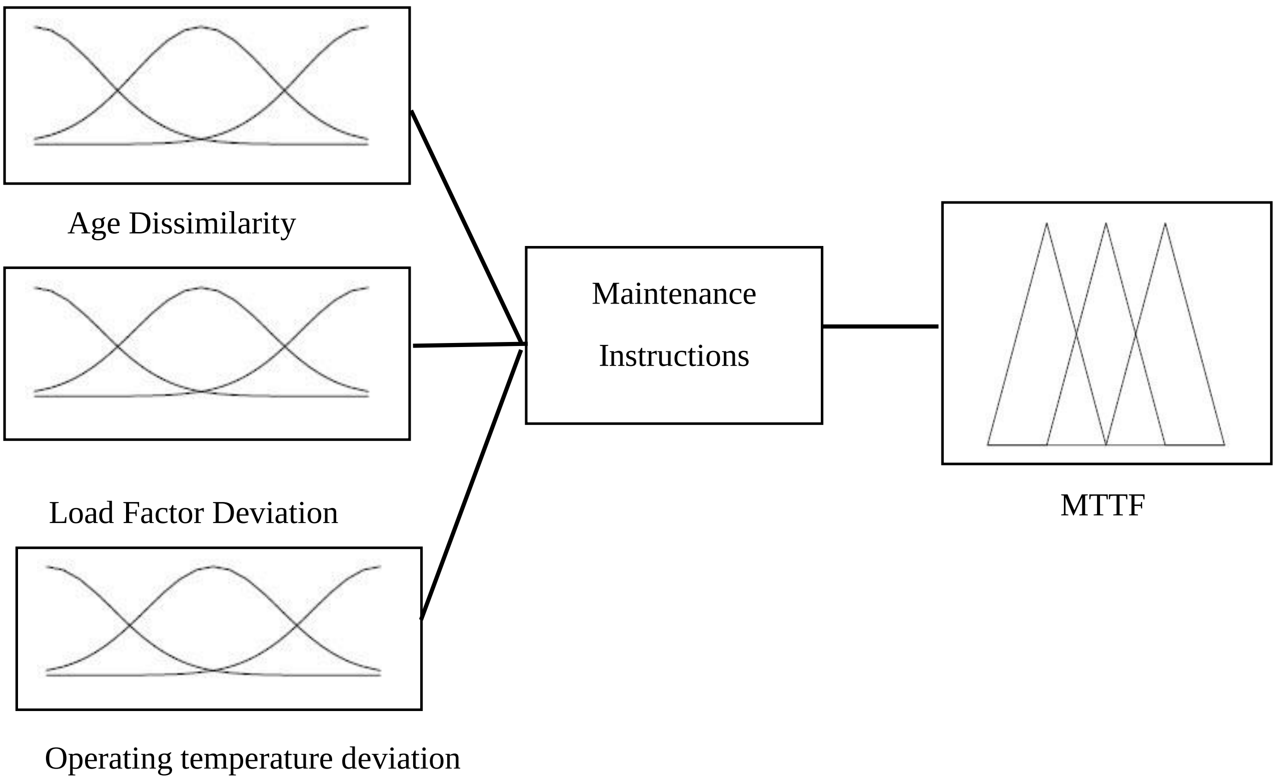


Figure 8 Fuzzy logic block diagram for unplanned operational dissimilarities

Low level membership occupations for transformer by considering unplanned operational variation

Input:

(a) Input: Age dissimilarity (yr).

(b)Input: load factor deviation (%).

(c)Input: operating temperature deviation (°C).

2.5 Inputs and outputs by considering unplanned variations

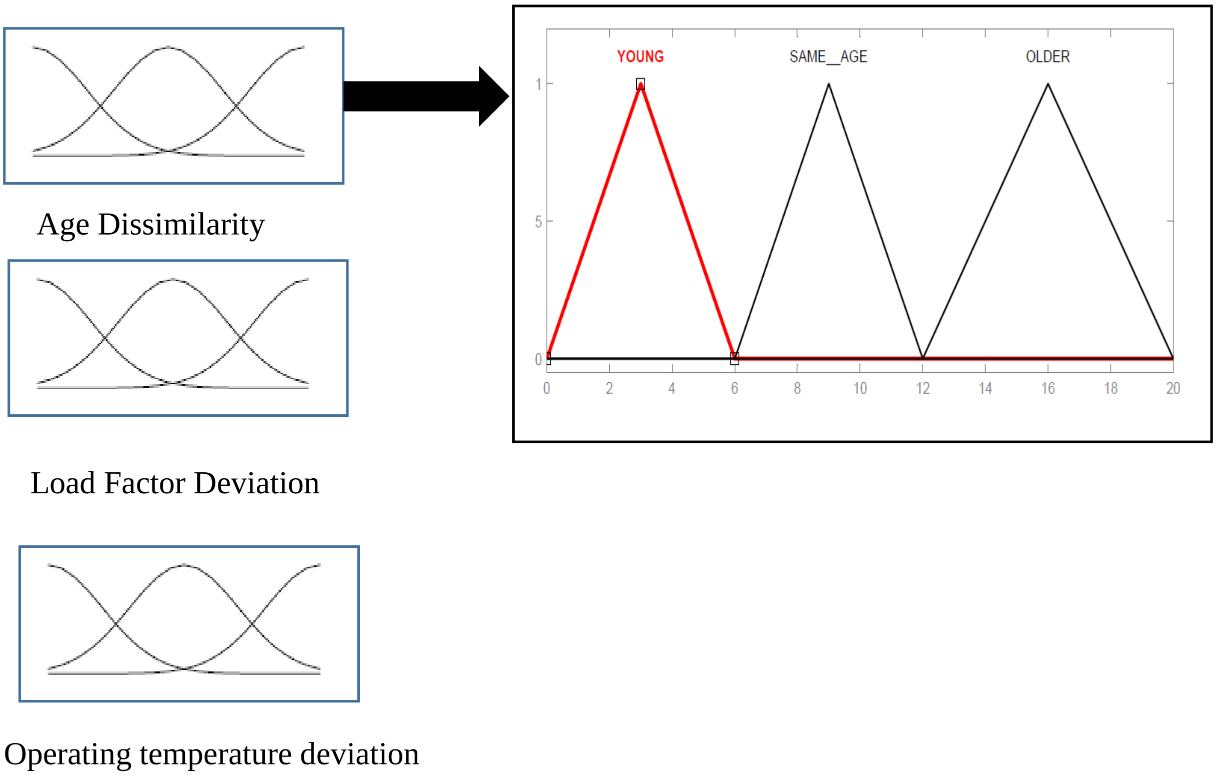


Figure 9 Input of unplanned variations by considering three inputs

Membership function used for giving the input to fuzzy input is a Triangular membership function for all three inputs. The membership function used in the output function is Trapezoidal and Gaussian membership function.

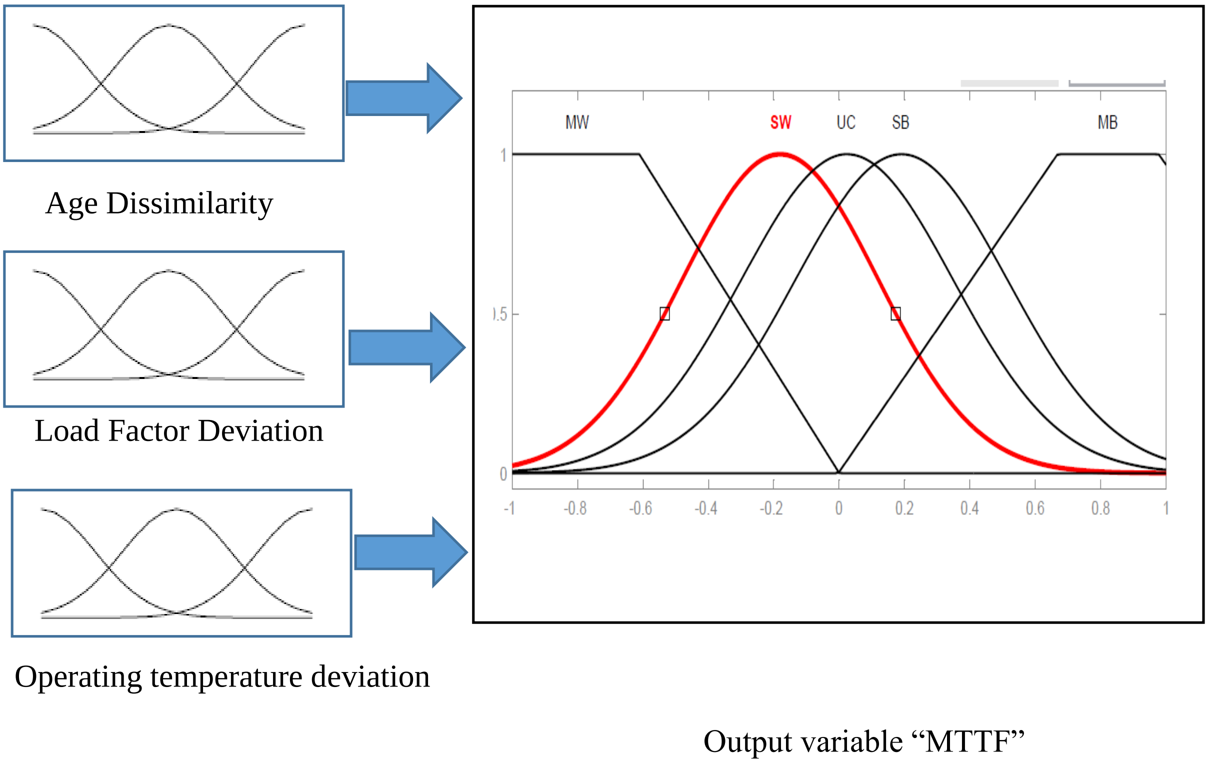


Figure 10 Input of unplanned variations by considering three inputs

By exploitation mamdani fuzzy model, we will estimate the MTTF of an electrical device. Rules area unit generated by considering the triangular membership perform of every input. Those membership area unit given as

1. Age dissimilarity – [Young, Same, Old]
2. Load factor deviation - [Light, Same, Heavy]
3. Operating temperature deviation-[Low, Same, High]

After the implementation of input and output in the fuzzy logic, certain set of rules are composed by using mamdani fuzzy rules in the rules editor.in the output ,the membership used is Gaussian membership function.

2.6 Maintenance of substation by considering planned and unplanned variations

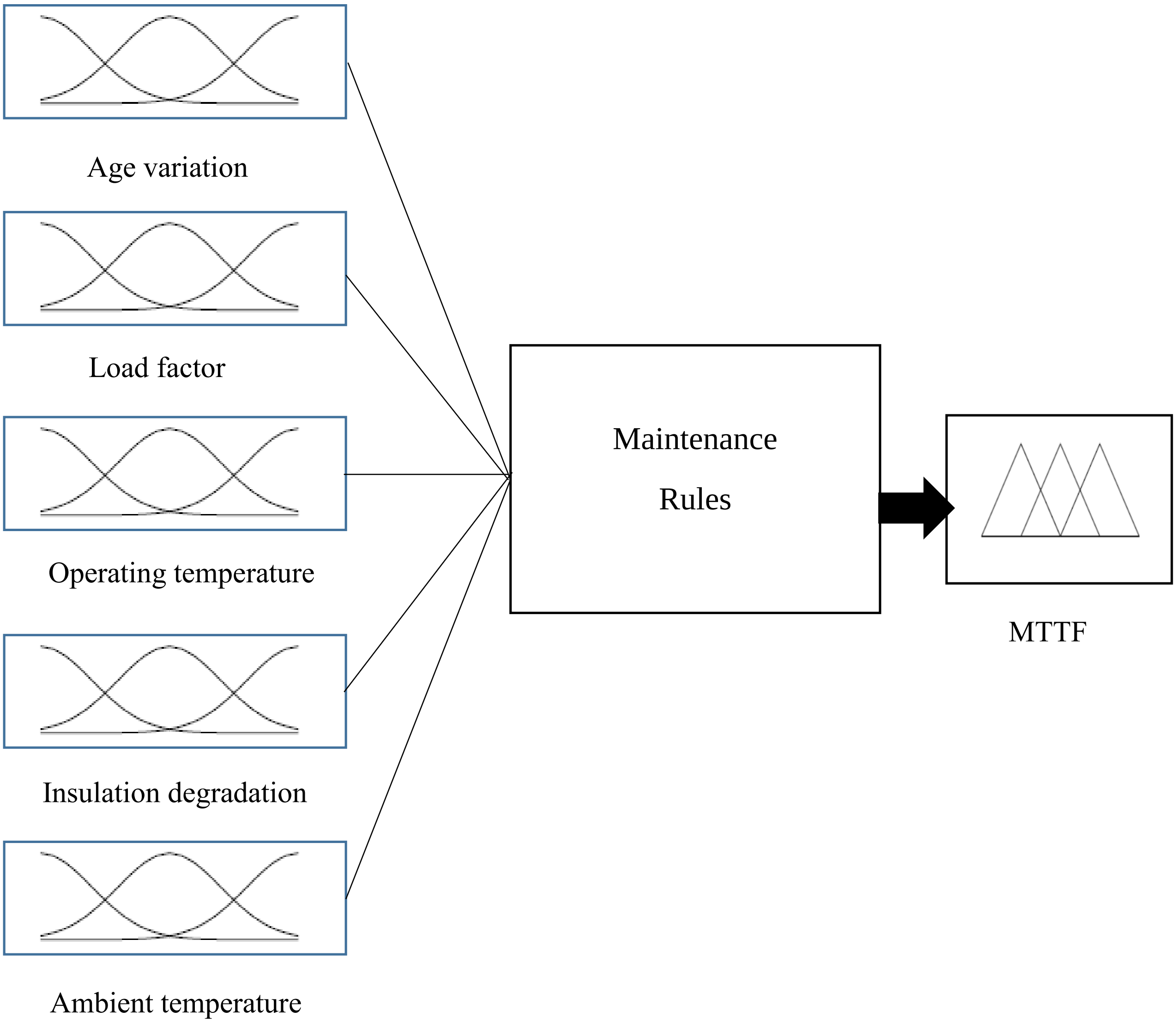


Figure 11 Fuzzy logic for implementing maintenance schedule by considering all variations

There are five different inputs considered here. [15]In this implementation of fuzzy logic both planned and unplanned operational variations are taken into consideration. They are[40]

1. Age variation
2. Load factor variation
3. Operating temperature variation
4. Insulation degradation level
5. Ambient temperature

2.7 Input and output for both planned and unplanned variations

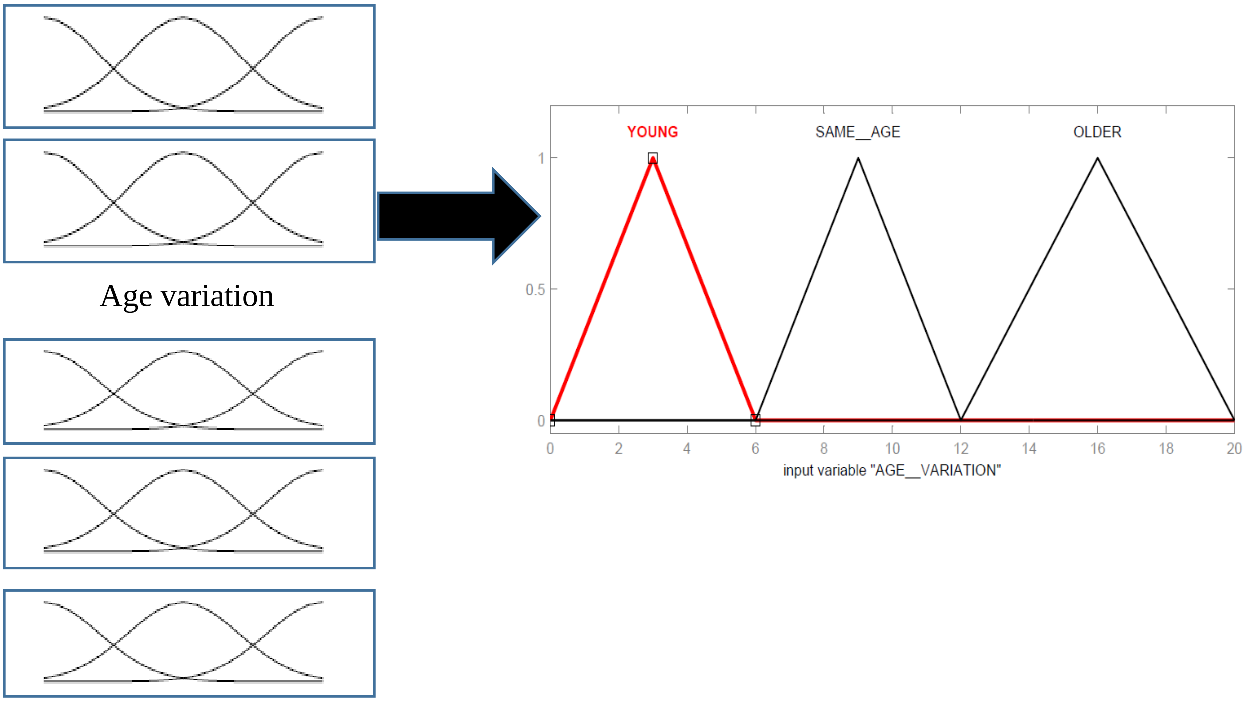


Figure 12 Input for maintenance schedule by considering both type of variations

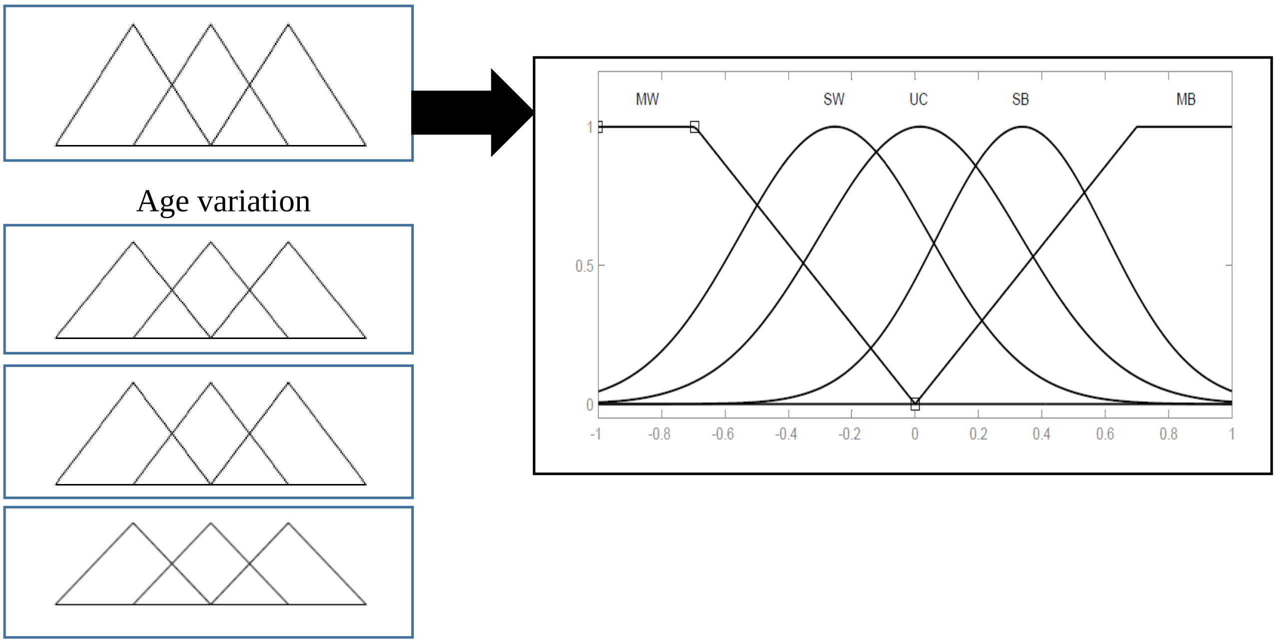
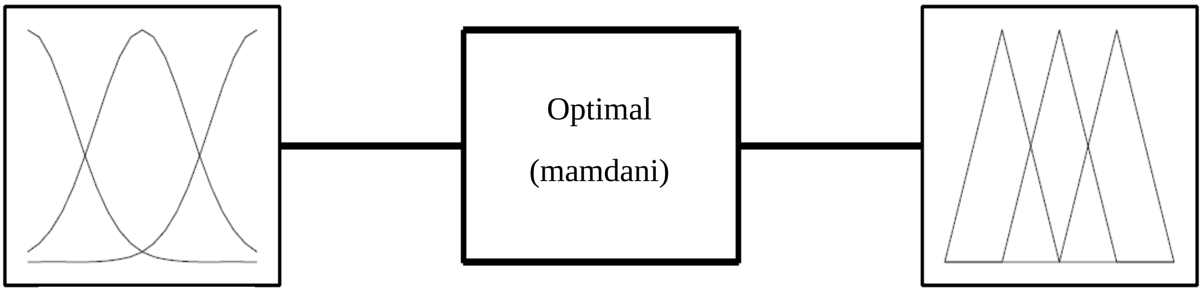


Figure 13 Output for maintenance schedule by considering both type of variations

2.8 Fuzzy logic diagram for finding optimal solution

In this membership function, the optimal and suboptimal solutions are considered by taking energy not served (ENS) and failure[42] cost and thus the reliability gain can be achieved.

The main aim is to achieve higher reliability with same operational cost [6]

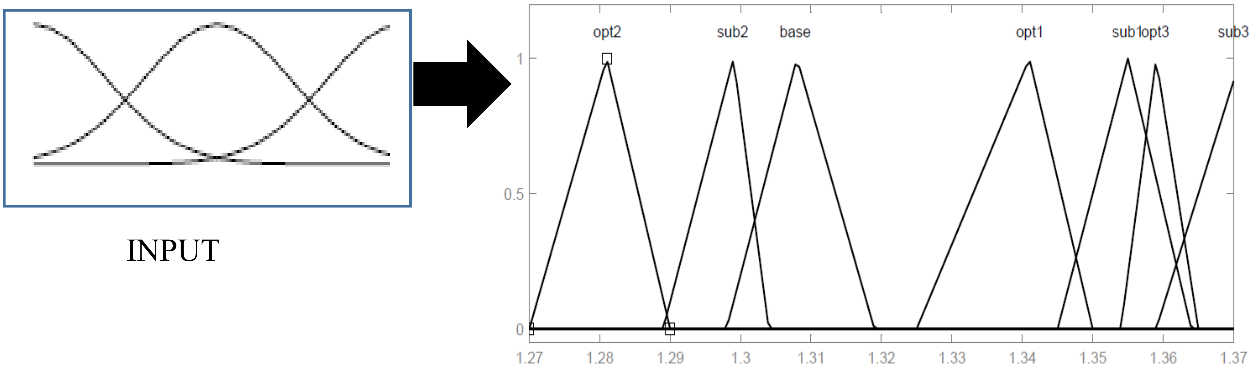


ENS

Failure cost

Figure 8 Fuzzy model for finding optimal solution

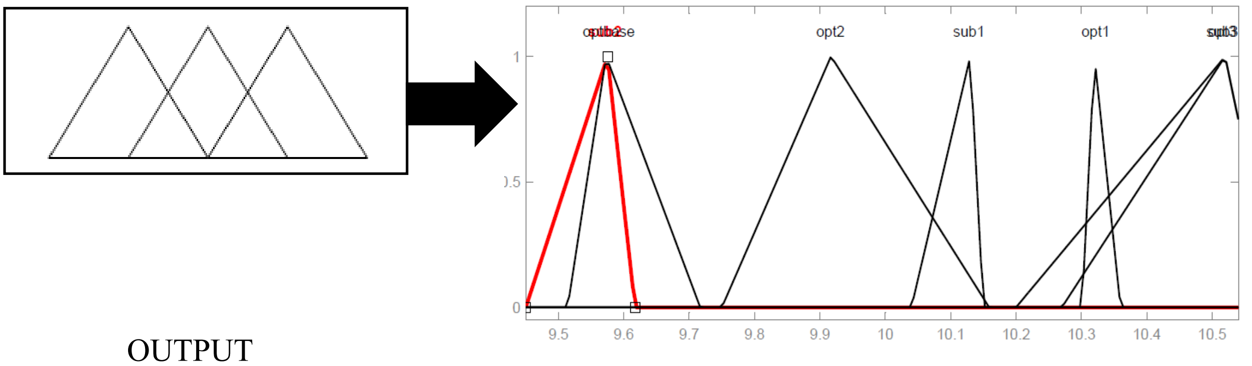
2.9 Input and output for finding optimal and suboptimal solution



INPUT

Input variable-Energy Not Served (ENS)

Optimal and suboptimal values are useful in acquiring reliability gains and maintenance costs.



OUTPUT

Output variable-Failure Cost

Figure 9 Output and input membership functions to find optimal solution.

2.10 Introduction Mean time between failures (MTBF)

Mean time between failures (MTBF) is that the prognosticated period between inborn disappointments of a framework all through operation. MTBF are regularly ascertained in light of the fact that the normal worth (normal) time between disappointments of a framework. The MTBF is regularly a piece of a model that expect the unsuccessful framework is in a flash repaired (interim to repair, or MTTR), as a region of a[43][44] recharging system. this can be in refinement to the unit of time to failures (MTTF), that failure measures normal time to disappointments with the displaying suspicion that the unsuccessful framework isn't repaired (vast repair time).

The meaning of MTBF relies on upon the meaning of what's thought about a framework disappointment. For confounded, fixable frameworks, disappointments range unit considered to be those out of style conditions that place the framework out of administration and into a state for repair. Disappointments that happen that may be left or kept up in Associate in Nursing unrepaired condition, and don't put the framework out of administration, don't appear to be considered disappointments underneath this definition.[46][47]Furthermore, units that territory unit brought down for routine consideration or inside control don't appear to be considered among the meaning of disappointment Mean time between disappointments (MTBF) portrays the normal time between two disappointments for a repairable framework[48], while interim to disappointment (MTTF) indicates the normal time to disappointment for a non-repairable framework.

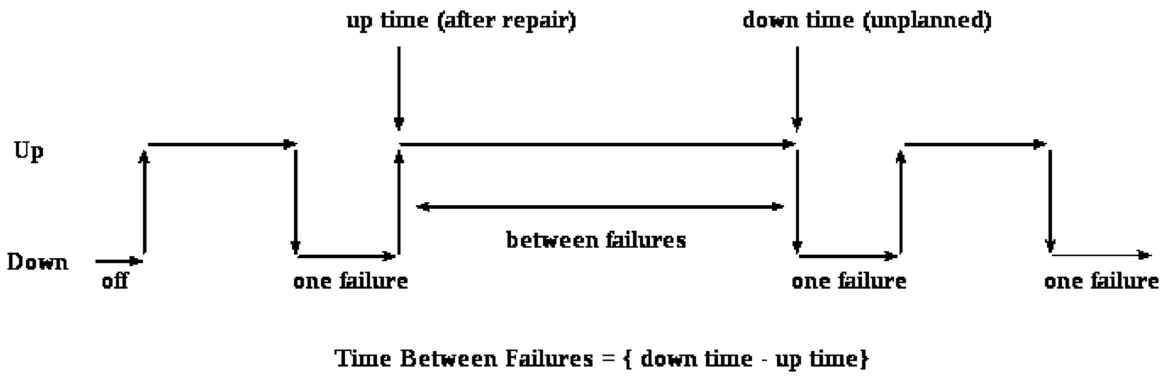


Figure 10 Time between failures

For every perception, the "down time" is the immediate time it went down,[49] which is after (i.e. more noteworthy than) the minute it went up, the "up time". The distinction ("down time" short "up time") is the measure of time it was working between these two occasions.

$$\text{Mean time between failures} = \text{MTBF} = \frac{\sum (\text{start of downtime} - \text{start of uptime})}{\text{number of failures}}.$$

2.11 Difference between MTBF & MTTF

MTBF is the most popular reliability term of the product manufactured by any company. It provides measure of amount of failures per million hours of the product. This is very important in critical applications such as telephone networks, data communication [50] network where due to failure entire system will be down and services to the consumers will be hampered. Usually price centric end users never consider MTBF before purchasing any [14] product. MTBF is used for both repairable and non-repairable items.

MTBF = 1/(FT1+FT2+FT3+••••• +FTn)

Wherever FT is the failure of the each module of the scheme. To calculate the Overall MTBF, failure rate of all the individual components used to make the system is taken into calculation. Operating and storage temperature need to be considered for calculation.

Example: There are total 9 strategies being verified for about 500 hours. During the test 3 disappointments have happened. Let us analyse MTBF of this batch of goods.

MTBF=9 x 500 hours/3 failures

MTBF= 4500 hours/failure

Meantime to-failure (MTTF) is fundamental bit of dependability for non-repairable things: The aggregate number of life units of a thing isolated by the aggregate number of [14] disappointments inside of that populace, amid a specific estimation interim under expressed conditions.

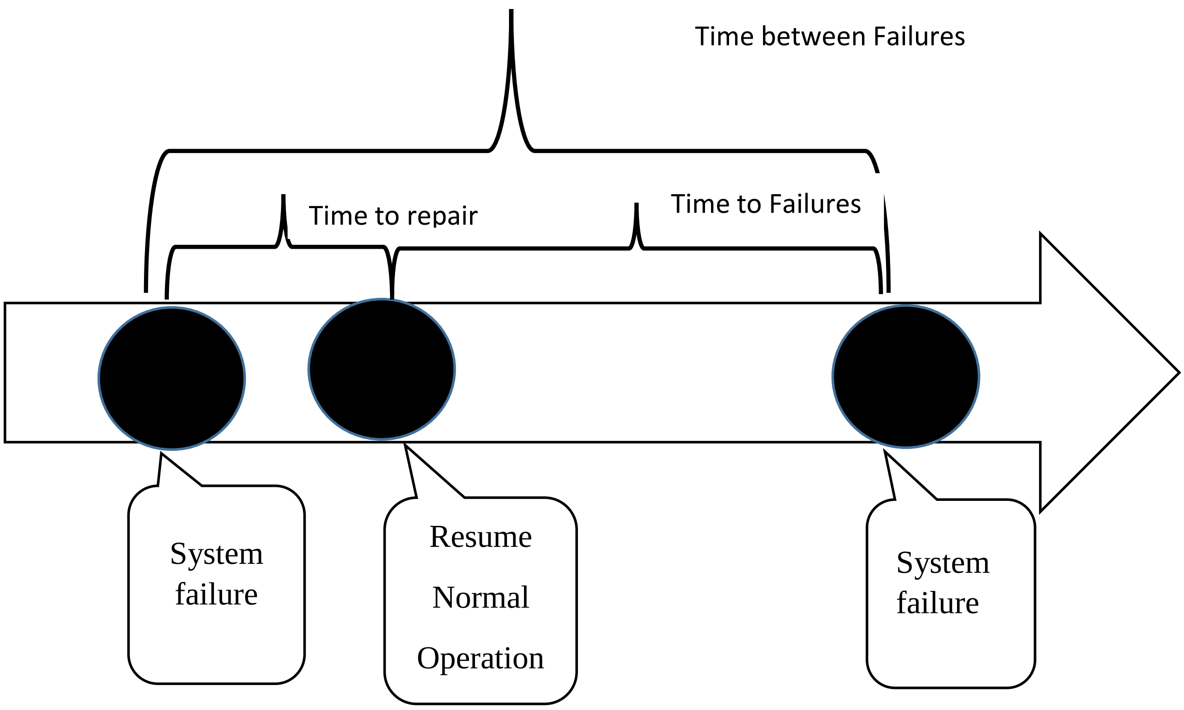


Figure 11 Difference between MTBF and MTTF

Components which are maufactured by considering MTBF are sensors .where as the components which are manufactured by considering mttf are generators ,tranformers.

2.12 Implementatin of MTBF by fuzzy logic

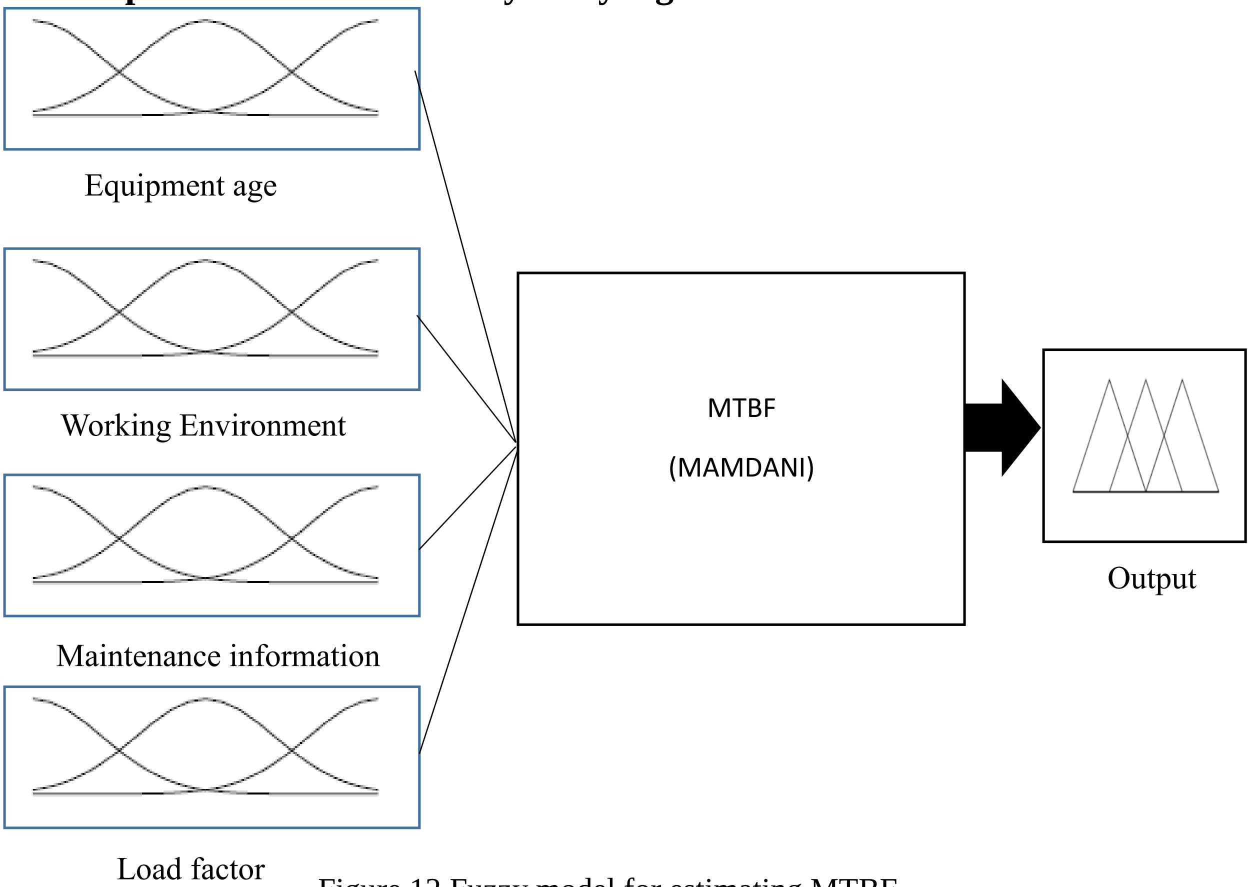


Figure 12 Fuzzy model for estimating MTBF

Essentially, maturing the element will diminish the MTBF; unfavourable work space origins the diminishing of the MTBF; the increment in the heap likewise diminishes the MTBF. The contributions are consolidated over "if then" standards specified by type1-fuzzy specialists utilizing fluffy deduction framework to develop yield of the progressions of the MTBF. For sample, if the

(a) Participation of age resembles to “older”,

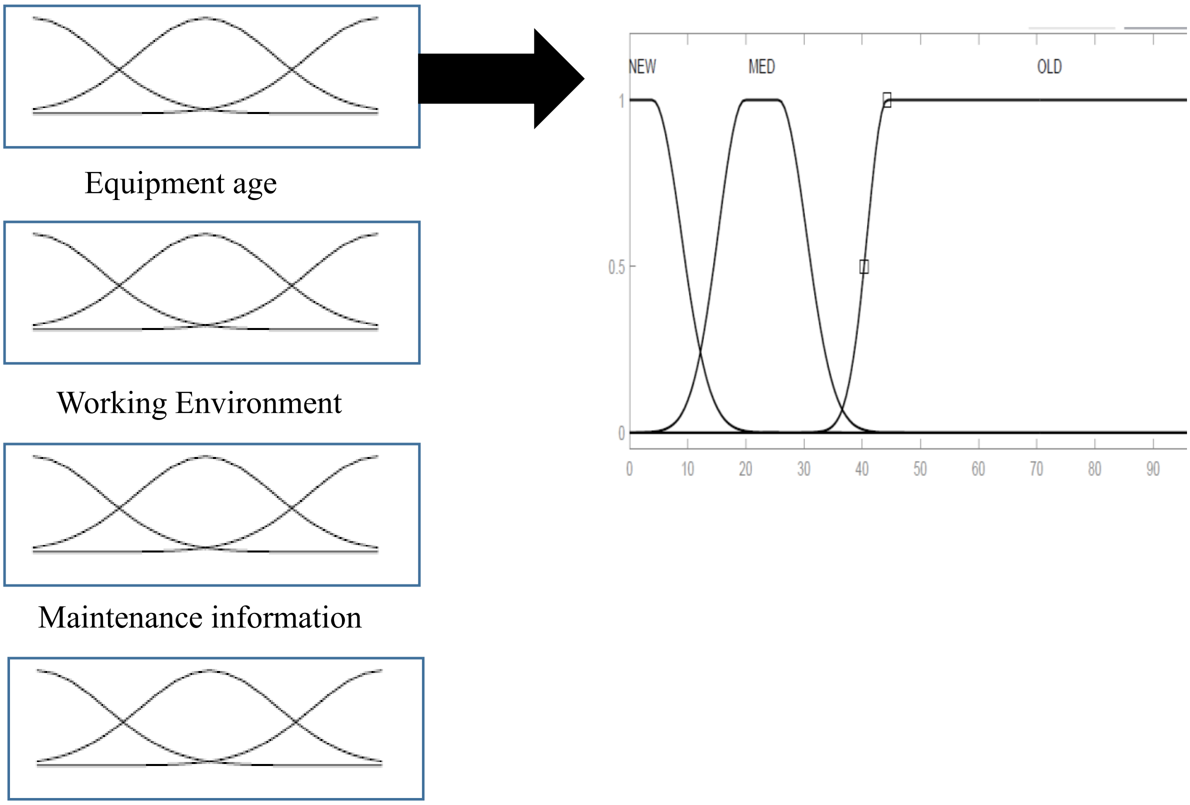
(b) Occupied location to “poor”,

(c) Load factor to “higher” and

(d) The time of earlier conservation to “long”,

Then the output is the “low” of the MTBF.

2.13 Input and output for estiamting the caluculation of MTBF



Load factor

There are four different types of inputs given for the estimation of mtbf containing Equipment age, Working Environment, Maintenance information, Load factor.

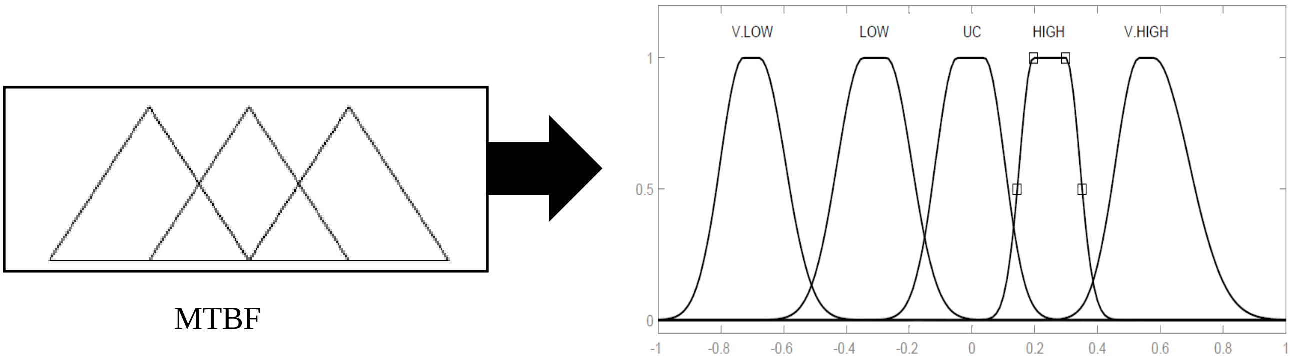
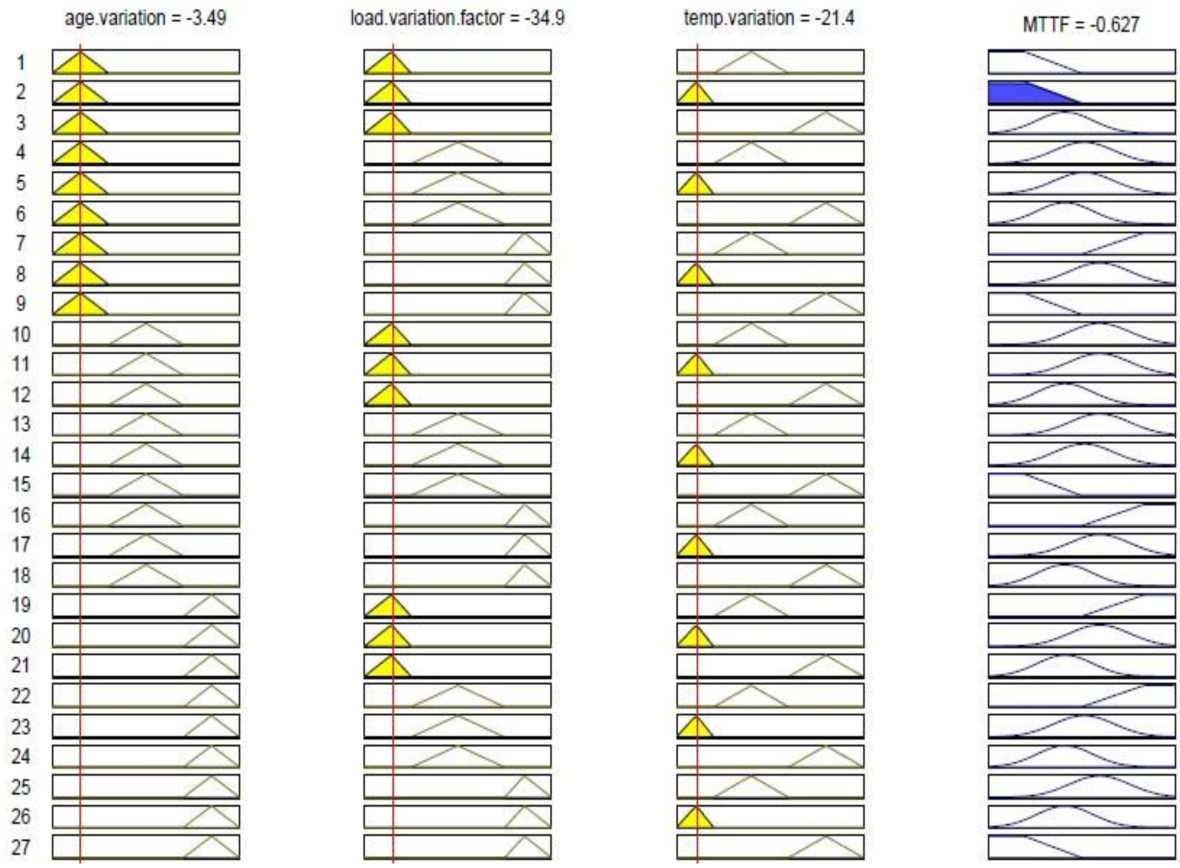


Figure 13 Fuzzy input and output for estimating MTBF

2.14 Results Obtained when unplanned variations are considered



By the above obtained rules, we can estimate a particular condition of a transformer .Depending upon the value of obtained MTTF, the condition of transformer of transformer can be estimated. For example, if the output obtained is in "MW" case. Then we can say that the transformer is going to a failed condition .so we can change the transformer or we can repair the transformer. If the output obtained is "MB", then we can estimate such that transformer is working in good condition.[18][19].

So, by calculating the above MTTF, we can find the failure state of a transformer. Such that we can replace it or repair it.

Usual operational variations for transformer to consider base case optimization such are age dissimilarity ,load factor, average operational condition are assumed as per paper [1] [4] for the implementation of fuzzy logic.

Determination of the Base Case with upkeep arranges [1] earlier balanced utilizing the progressions as demonstrated with expected common operational circumstances we additionally acknowledge a straight maturing procedure and the similar stage aimed at all segments after the establishment of the support period [1]. Further arranged functioning situations (working temperature) are gathered steady all through the support period [1]. No unexpected functioning circumstances are measured. In added term, the spontaneous working varieties should be zero [1].

Low-level fuzzy association utilities: old [1], capacity, and working temperature rises will deteriorate consistency. Five output verbal points [MW, SW, NC, SB, MB] signify the conversion of Failure of each equipment as in "Most Worse," "Slight Worse," "No change," "Slight Better," and "Most Better" [1] Each prearranged working dissimilarity and the variation of MTTF, are linked through the "IF-THEN" guidelines in the low-level fuzzy judgement arrangement. Aimed at instance, if contributions are

The age dissimilarity is "good" and

(a) The load influence dissimilarity is "heavy",

(b) The working temperature dissimilarity is "low", the output is

(c) The modification of MTTF will be "MB". (Most Better)

2.15 Results and surface diagram for finding optimal solution

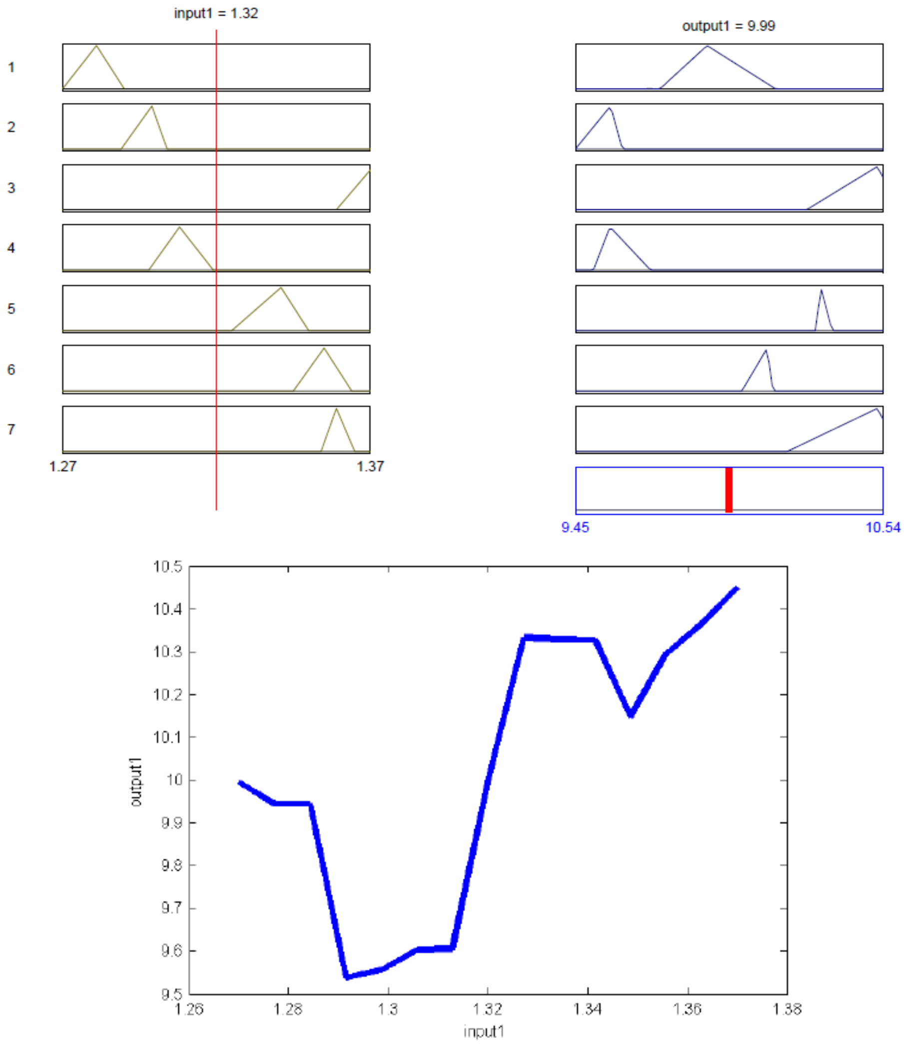
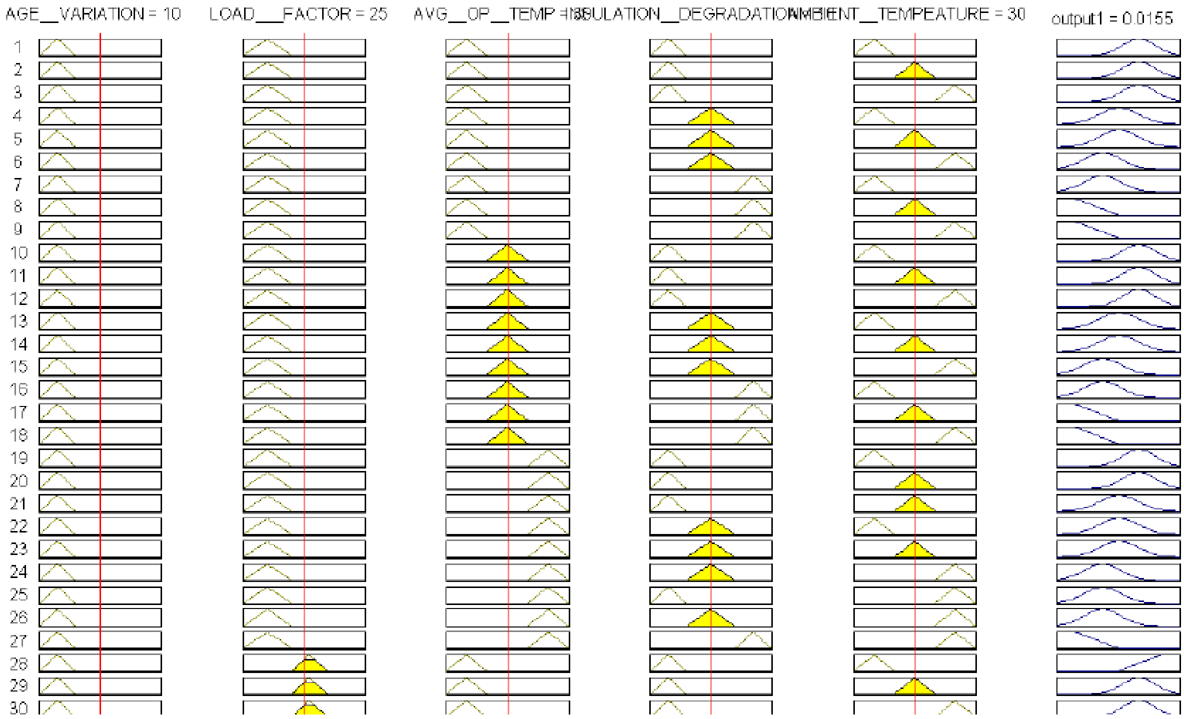
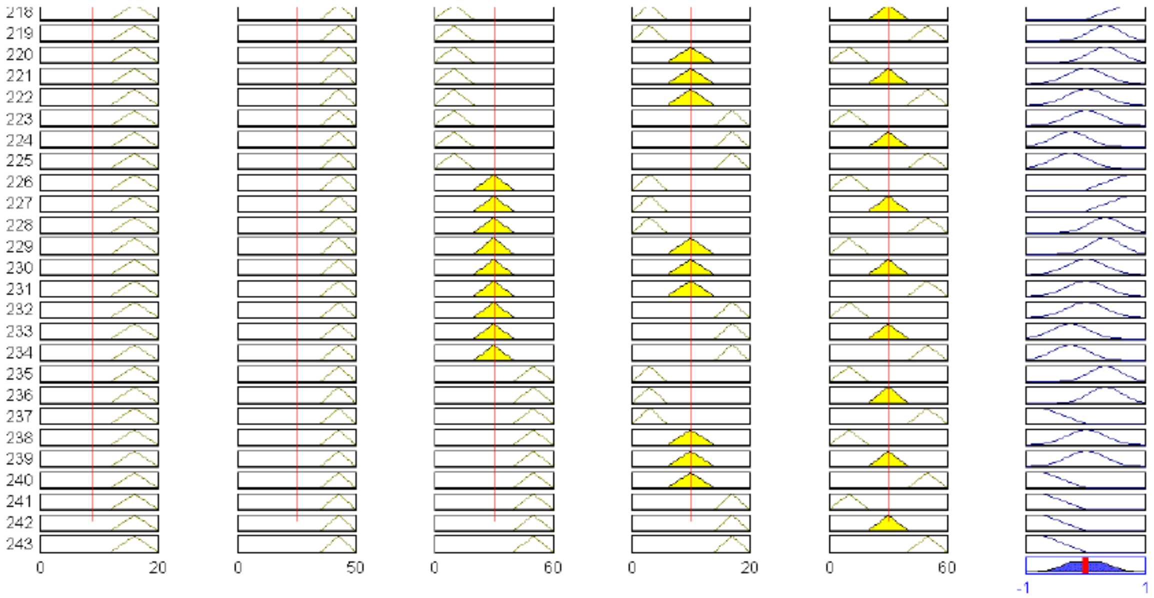


Figure 15 Surface viewer diagram of ENS and failure cost

Maintenance of transformer is thus made in combination with fuzzy logic .membership functions are considered based on the different operational variations occurred in the maintenance of transformer. There will different effect on the transformer, depending on different variation caused in the transformer during the generation of power. Each variation is given a different priority at different point of working. Depending upon the importance of the variation, fuzzy rules are created and maintenance is made depending on failure state.

2.16 Results obtained considering both planned and unplanned variations





The universe of dissertation of both effort and its yield is quantized in overlying fuzzy sets as characterised by their corresponding both level fuzzy involvement meanings.

1) Low-level and high-level fuzzy [16]involvement utilities: old, load, and functioning temperature, insulation degradation level ,ambient temperature increases will worsen reliability Five output language levels characterize the modification of failure time of each transformer as in “Most Worse,” “Slight Worse,” “No change,” “Slight Better,” and “Most Better.” Each prearranged working dissimilarity [30]and the modification of MTTF, are related by the “IF-THEN” directions in the low-level fuzzy reasoning arrangement if contributions are (a) (the load factor dissimilarity is “heavy”), and (b) (the age dissimilarity is “old”) and (c) (the insulation deprivation level is “heavy”), (d) (the functioning temperature difference is “high”), (e) (the ambient temperature is “heavy”), formerly the yield is (f) (the modification of MTTF for this will be “MW”)].

2) Abnormal state fuzzy enrolment occupations: unplanned operational dissimilarities assigned for the abnormal state are active and time-fluctuating on a day by day or level an hourly premise. The arrangement of spontaneous active dissimilarities chose in this effort is for every transformer its protection hardship then surrounding temperature disparity, besides for every electrical switch its surrenders, for example, those occurrence in outing curls.

Corruption in transformer assurance can be seen with broke down gas investigation with transformer-oil models to be gathered more than once. The universe of talk of protection hardship is quantized into [good, no change, bad] though dissimilarities of encompassing temperature are quantized into [low, no change, and high]. The trip curl absconds in circuit breakers can be seen by present mark, which be arranged quantized in [good, no change, bad].

Specification of the Base Case: Expect a direct maturing procedure and the same age for all segments from the earliest starting point of the upkeep period. Additional arranged functioning circumstances are expected steady all through the support time. No unexpected functioning circumstances are viewed as, the spontaneous operational varieties are thought to be zero.

- case 1: Worse-than-anticipated aging and deteriorations.
- case 2: Lower-than-anticipated transformer loading.
- case 3: Worst-than-anticipated working environment& ambient temperature.

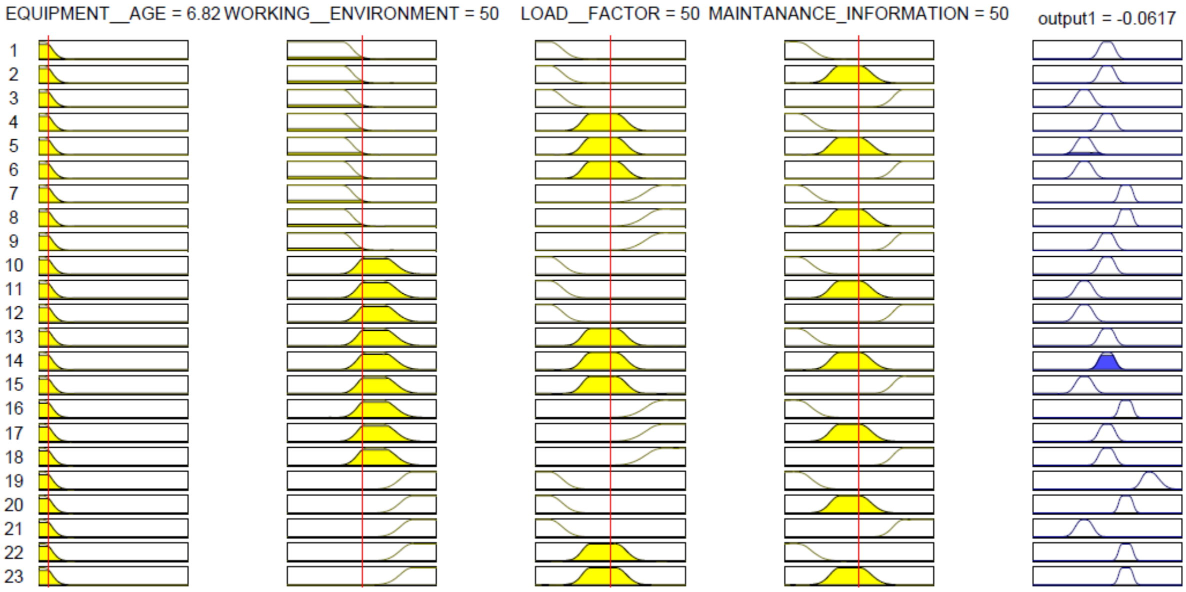
Case 1: Worse-than-expected maturing and decays where every transformer and every electrical switch in are experiencing more awful maturing than the basic case from the earliest starting point of the training time. These components will likewise encounter another arrangement of protection corruption and excursion curl surrenders hence, the base-case support exercises won't have the capacity to meet the obliged dependability prompting higher vitality not-served and disappointment price. Thus, support exercises will essential to be reoptimized as per the exorbitant maturing and disintegrations for giving advanced dependability.

Case 2: : Worse-than-expected maturing and weakening where every transformer and every electrical switch in are experiencing more terrible maturing than the basic case after the earliest starting point of the training time. These components will likewise encounter another arrangement of protection debasement and excursion curl surrenders thusly, the base-case upkeep exercises won't have the capacity to meet the obliged dependability prompting higher vitality not-served and disappointment cost. In this manner, support exercises will need to be reoptimized as per the intemperate maturing and decays for giving higher unwavering quality.

Case 3: Most exceedingly terrible than-foreseen working environment and encompassing temperature where transformer reliabilities are breaking down unnecessarily, which will require reoptimization and scale-up of upkeep exercises. This is comparative however not precisely the same as case 1, where our procedure will manage them in an unexpected way.

The remaining segment will demonstrate how the proposed progressive fluffy rationale framework is successful for re-setting up the ideal support plans for the four above study cases.. Operational cost, energy not served (ENS) and failure costs are assumed according paper [1][51] to find the best optimal condition for a transformer .This assumptions of optimal and suboptimal solutions are considered according to the three cases and base case.

2.17 Rules obtained for the MTBF



Mean time to failure and interim between disappointment is calculated by method for a fuzzy logic.This is accomplished by considering different variational inputs. There will distinctive impact on the transformer, contingent upon diverse variety brought about in the transformer amid the era of power.so diverse low[28] to high need is given to each variety, such that the blend of condition of the considerable [29]number of varieties happened in transformer are analyzed by the method for mamdani fluffy rationale and the yield is gotten, which demonstrates the MTBF condition of a transformer, such that a support is acquainted with the transformer for better living up to expectations. By and large the gadgets that can't be repaired, once there's a pull, then MTBF is ascertained to such sensibly gadgets.

2.18 Summary

Mean time to failure and mean time between failure is caluculated by means of a fuzzy logic.This is achieved by considering differrent variational inputs. There will different effect on the transformer, depending on different variation caused in the transformer during the generation of power.so different low to high priority is given to every variation, such that the combination of state of all the variations occurred in transformer are compared by the means of mamdani fuzzy logic and the output is obtained, which shows the MTBF state of a transformer, such that a maintenance is introduced to the transformer for better working. Generally the devices that can't be repaired, once there's a haul, then MTBF is calculated to such reasonably devices.

CHAPTER 3: FUZZY LOGIC BASED POWER LINE SELECTION OF A CUSTOMER

3.1 selection of power line by using fuzzy logic by a consumer

In a smart grid system, the main advantage is a consumer [13] can use renewable and non-renewable.so, a consumer can able to manage his electrical usages. Suppose if there are substations that give power to a customer, if each substation is providing costs for different interval of time, then the customer can select a substation such that he will be served with low cost price .this process can be done [27][28] in a fuzzy logic way.it is developed as follows by considering three substation of different companies providing different costs at different time[30][20].

3.2 Implementation with fuzzy membership function

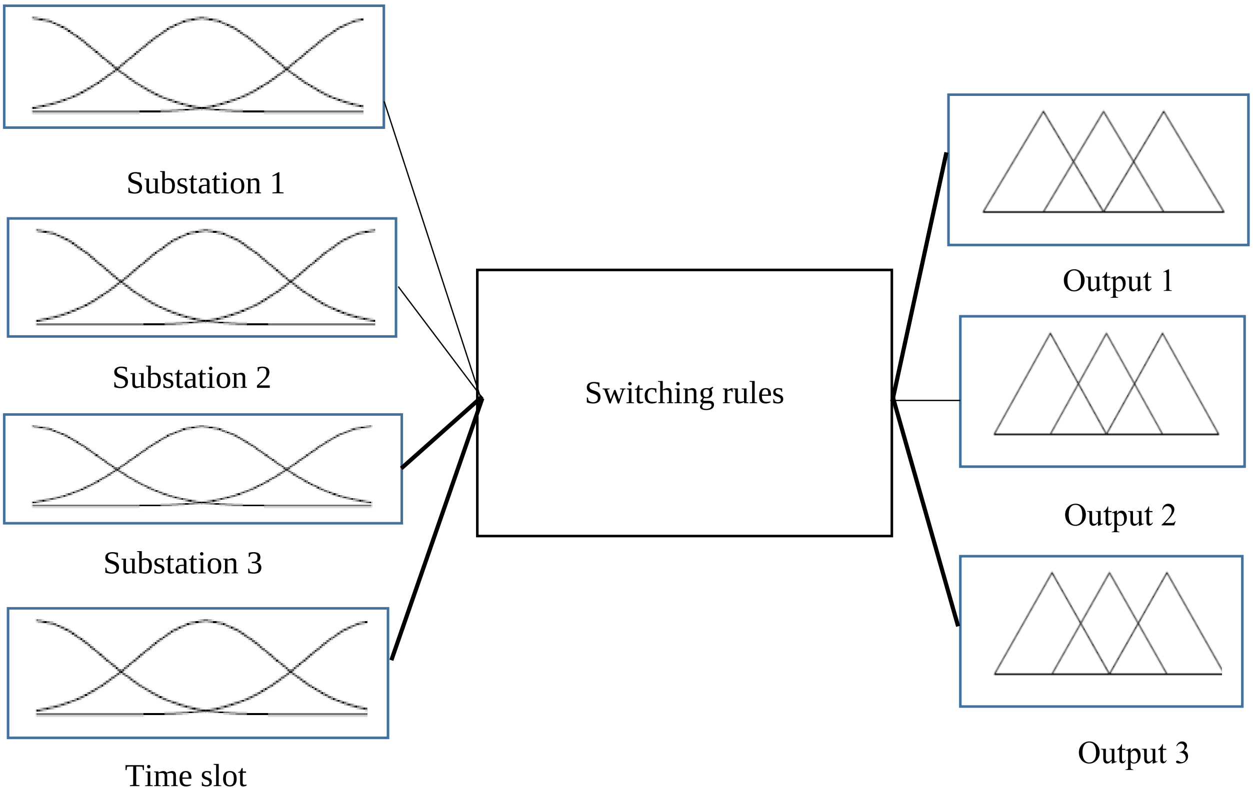


Figure 16 Fuzzy logic block diagram for switching between substations

3.3 Input and output for customer selection fuzzy logic

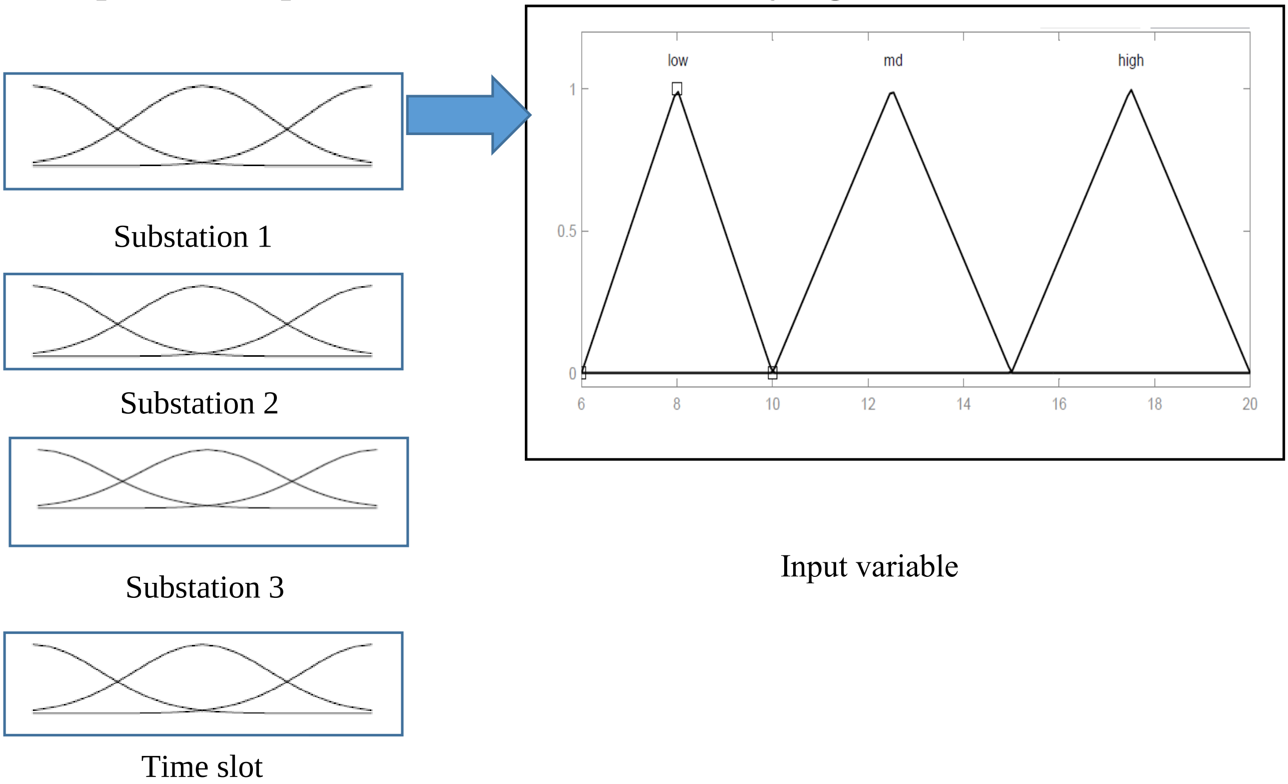


Figure 17 Input for substation switching by considering three inputs

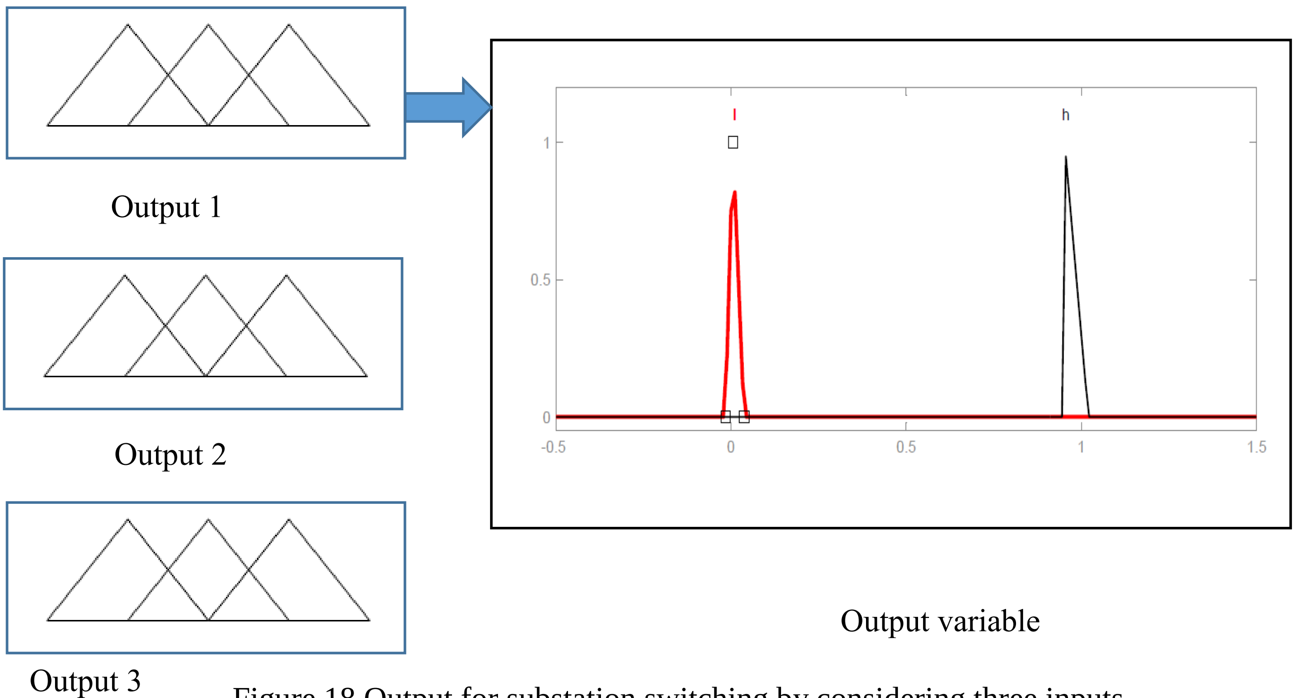
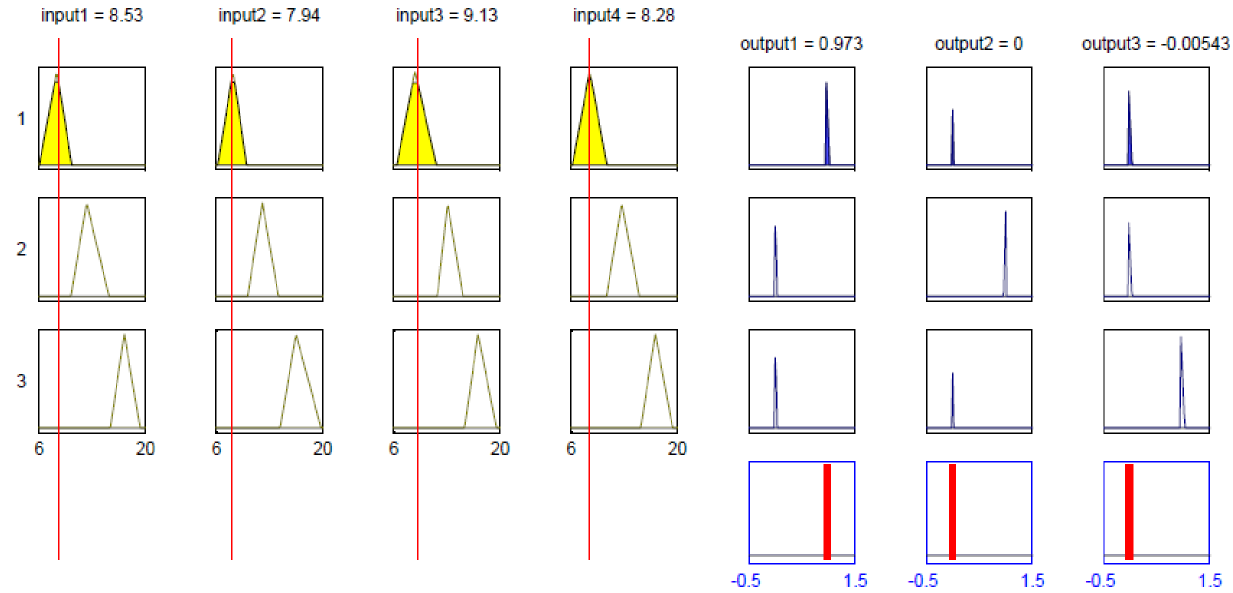


Figure 18 Output for substation switching by considering three inputs

3.4 Rules Obtained In the Output and discussion



3.4 Summary

A customer can switch to the substation that provides low cost of power at a particular interval of time by comparing the cost of each substation supply by using fuzzy logic. By comparing the output of different substations,[25] one of the output from the proposed three outputs is chosen, such that three will be a switching to High or Low in the output. If the output is High then, the customer will switch to that substation,[26] then remaining will be in Low state.so they will not be chosen. They will closed later when they provide low cost.

CHAPTER 4: CONCLUSIONS AND FUTURE WORKS

4.1 Conclusions

This proposes is a standard and adaptable outline for upgrading the alteration of burden point responsibleness resulting from unplanned operational varieties all through operation of a framework streamlined support set up. As an important piece of keen matrix, the anticipated support guide can report any unnecessary crumbling of burden point responsibleness inside every substation, and need the upkeep enhancer to alertly re-build up the substation's ideal upkeep exercises for meeting the obliged responsibleness with most reduced cost all through operation.

Operational varieties emerge often in light of spontaneous or unpredicted climate varieties and condition-corruption of transformers and circuit breakers that are to have essential effects on the upkeep programming of seaward substations. Our stratified scientific rationale is incontestable to be computationally temperate and adaptable for taking care of these impromptu operational varieties in an exceedingly medium measured force framework that should hence have a genuine potential for huge framework applications.

MTBF and MTTF are calculated for a particular transformer or a circuit breaker .then depending on the obtained output ,we can say that there will be an occurrence of failure in the system .Depending on the component used in a particular system we can calculate either MTTF or MTBF. For suppose, if we use equipment like sensor which is not repairable, then MTBF is used .if we use equipment like generator or compressor, then MTTF is calculated because, they are repairable equipment.

4.2 Future works

Development in the maintenance techniques must be done. The three scenarios based on the case study must implemented .The collected data must be used to find the optimal and suboptimal solutions of different scenarios and fuzzy logic is to be generated for the collected data of substation and want to make the system work with better operating cost. Maintenance techniques must be generated such that the power system must be maintained with minimum operational cost. Mean time to failure and mean time between failures must estimate perfectly either for replacing the device or to repair the system .In case of repair, the time interval between to successive failures should be high, such that the equipment works perfectly.

5. REFERENCES

[1]. C. S. Chang, Zhaoxia Wang, Fan Yang, and W. W.Tan, “Hierarchical Fuzzy Logic System for Implementing Maintenance Schedules of Offshore Power Systems”, *IEE Transactions On Smart Grid*, Vol. 3, No. 1, March 2012

[2]. H. Liao, E. Elsayed, and L. Chan, “Maintenance of Continuously Monitored Degrading Systems,” *Eur. J. Oper. Res.*, 2006, Vol. 175, No. 2, Pp. 821–835

[3]. “SMART GRID Integrating Renewable, Distributed and Efficient Energy", Academic Press; 1 edition , Fereidon P.Sioshansi,,2011, ", page (3-29) and (343-397).

[4]. Yang Fan, “Optimization and Implementation of Maintenance Schedules Of Power Systems”, National University Of Singapore, 2011

[5]. Yang Fan (2011), Adaptive Maintenance Advisor for Offshore Power System Using type-2Fuzzy Logic System, available FTP http://www.eng.nus.edu.sg /EResnews/0906/rd/rd13.html

[6]. “Neuro-Fuzzy And Soft Computing”, Phi Learning Inc, J S R Jang, C T Sun, E Mizutani,1995, Pages (13- 42), (54-59), (73-81)

[7]. Z.Wang, C. S. Chang, F. Yang, andW.W. Tan, “Adaptive type-2 fuzzy maintenance advisor for offshore power systems,”in *Proc. IEEE Int.Conf. Syst.Man, Cybern.*, 2009, pp. 4520–4526.

[8]. Wang Z.-X.; Yang, F.; Tan, W.W and Chang, C. S.; “Intelligent maintenance advisor for marine power system using type-2 fuzzy logic for handling condition updates and operation uncertainties,” 5th international conference on Engine and condition monitoring, (Invited paper), 9-10 Oct. 2008, Singapore.

[9]. L.Zadeh, “Fuzzy sets,” *Inf. Control*, vol. 8, no. 3, pp. 338–353, 1965

[10]. H. Liao, E. Elsayed, and L. Chan, “Maintenance of continuously monitored degrading systems,” Eur. J. Oper. Res., vol. 175, no. 2, pp.821–835, 200

[11]. S. Lu, Y. Tu, and H. Lu, “Predictive condition-based maintenance for continuously deteriorating systems,” Qual. Rel. Eng. Int., vol. 23, no.1, pp. 71–81,2007

[12]. C. Cassady, I. Iyoob, K. Schneider, and E. Pohl, “A generic model of equipment availability under imperfect maintenance,*” IEEE Trans. Rel*., vol. 54, no. 4, pp. 564–571, 2005.

[13]. M. You, L. Lin, M. Guang, and N. Jun, “Cost-effective updated sequential predictive maintenance policy for continuously monitored de- grading systems,” *IEEE Trans. Autom. Sci. Eng.*, vol. 7, no. 2, pp.257–265, 2010.

[14]. Strachan, S.M.; McArthur, S.D.J.; Stephen, B.; McDonald, J.R.; and Campbell,; “Providing decision support for the condition-based maintenance of circuit breakers through data mining of trip coil current signatures,” *IEEE Trans. Power Delivery*, vol.22, no. 1, Jan. 2007, pp. 178-186.

[15]. Lu, Susan; Tu, Yu-Chen; Lu, Huitian; Predictive condition-based maintenance for continuously deteriorating systems, *Quality and Reliability Engineering International*, vol.23, no.1, Feb. 2007, pp. 71-81.

[16]. Mechefske, Chris K; Wang, Zheng; “Using fuzzy linguistics to select optimum maintenance and condition monitoring strategies,” *Mechanical Systems and Signal Processing*□vol. 17, no. 2, March, 2003, pp. 305-316.

[17]. Endrenyi, J.; Aboresheid, S.; Allan, R.N.; Anders, G.J.; Asgarpoor, , R.; Chowdhury, N.; Dialynas, E.N.; Fipper, M.; Fletcher, R.H.; Grigg, C.; McCalley, J.;Meliopoulos, S.;

Mielnik, T.C.; Nitu, P.; Rau, N. Reppen, N.D.; Salvaderi, L.; Schneider, A.; Singh, Ch. ; “The present status of maintenance strategies and the impact of maintenance on reliability,” *IEEE Trans. Power Syst.* vol. 16, Nov. 2001, pp. 638-646

[18]. Mendel, Jerry M.; Uncertain Rule-Based Fuzzy Logic Systems Introductio and New Directions. Upper Saddle River, NJ: Prentice-Hall, 2001.

[19]. Chang, C S; Chen, J. M.; Srinivasan, D.; Wen, F. S.; and Liew, A. C.; “Fuzzy logic approach in power systems fault section identification,” *IEEE Proceedings, Generation, Transmission, and Distribution,* vol.144, no.5, September 1997, pp. 406-414

[20]. Tan, W. W.; Kamal, D. H.; “On-line learning rules for type-2 fuzzy controller,” IEEE International Conference on Fuzzy Systems, 2006, pp. 513-520.

[21]. Zadeh, L. A.; “The concept of a linguistic variable and its application approximate reasoning-1,” Information science, vol.8, 1975, pp.199-249.

[22]. Anders, G.J.; Endrenyi, J.; Ford, G. L.; and Stone, G. C.; “A probabilistic model for evaluating the remaining life of electrical insulation in rotating machines,” IEEE *Trans. Energy Conversion*, vol. 5, Dec. 1990, pp.761-767.Hwang, Cheul; Rhee, F.C.-H., “Uncertain fuzzy clustering: interval type2 fuzzy approach to C-means,” *IEEE Tran. Fuzzy Syst.*, vol. 15, no.1, Feb. 2007, pp .107-120.

[23]. Mendel, Jerry M.; “Interval Type-2 Fuzzy Logic Systems Made Simple,” *IEEE Tran. Fuzzy Syst.*, vol.14, no.6, pp. 808-821, 2006.

[24]. Noor, S. F.; and McDonald, J. R.; “Forced outage rates of generating units based on expert evaluation,” IEEE Trans. Reliab., vol. 45, no. 1, Mar. 1996, p 138–140

[25]. Tanrioven, M.; Wu, Q.H.; Turner, D.R.; Kocatepe, C.; Wang; “A new approach to real-time reliability analysis of transmission system using fuzzy Markov model,” *International Journal of Electrical Energy Systems*, vol. 26, no. 10, Dec. 2004, pp. 821-832.

[26]. Mohanta, Dusmanta Kumar; Sadhu, Pradip Kumar; and Chakrabarti, R.; “Fuzzy Markov Model for Determination of Fuzzy State Probabilities of Generating Units Including the Effect of Maintenance Scheduling,” *IEEE Trans. Power Syst*., vol. 20, no. 4, Nov. 2005, pp. 2117-2124.

[27]. Papoulis, A.; and Unnikrishna Pillai, S.; Probability, Random Variables, and stochastic processes, McGraw-Hill, Dubuque, Iowa, 2002.

[28]. Endrenyi, J.; Anders, G. J.; and L. da Silva, A. M.; "Probabilistic evaluation of effect of maintenance on reliability: An application [to power systems]," *IEEE Trans. Power Syst.*, vol. 13, May 1998, pp. 576-583.

[29]. Satish, L.; Gururaj, B.I.; “Use of hidden Markov models for partial discharge pattern classification,” *IEEE Transactions on Electrical Insulation*, v 28, n 2, April 1993, p 172-82.

[30]. Xu, Yangsheng; Ge, Ming; “Hidden Markov model-based process monitoring system,” Journal of Intelligent Manufacturing, v 15, n 3, June 2004, p 337-350.

[31]. Li, Jia, Najmi, Amir; Gray, Robert M.; “Image classification by a two dimensional hidden Markov model”*IEEE Transactions on Signal Processing*, v 48, n 2, 2000, pp. 517-533.

[32]. Popescu, M.; Gader, P.; Keller, J.M.; “Fuzzy spatial pattern processing using linguistic hidden Markov models,” *IEEE Transactions on Fuzzy Systems*, vol. 14, n1, Feb. 2006, p 81-92.

[33]. IEEE APM Subcommittee, "The IEEE Reliability Test System-1996", *IEEE Trans. Power Syst*., vol. 14, no. 3, Aug. 1999, pp. 1010-1020.

[34]. R. Billinton, P.K. Vohra and Sudhir. Kumar, "Effect of Station Originated Outages in a Composite System Adequate Evaluation of the IEEE Reliability Test System*," IEEE Trans. Power Apparatus and Syst*., v PAS-104, Oct 1985.
[35]. Suresh, P.V.; Chaudhuri, D.; Rao, B.V.A.; "Fuzzy-set approach to select maintenance strategies for multistate equipment," *IEEE Trans. Reliab*., Vol.43, no.3, Sept. 1994, pp. 451 – 456.
[36]. Khanlaria, Amir; Mohammadia, Kaveh; and Sohrabi, Babak; "Prioritizing equipments for preventive maintenance (PM) activities using fuzzy rules," Computers & Industrial Engineering, vol. 54, no. 2, March 2008, pp.169-184.
[37]. Grall, A.; Dieulle, L.; Bérenguer, C.; and Roussignol, M.; "Continuous time predictive-maintenance scheduling for a deteriorating system*," IEEE Trans. Reliab.*, vol. 51, Jun. 2002, pp. 141-150.
[38]. Yang, F.; Kwan, C.M.; and Chang, C.S.; "Multi-objective Evolutionary Optimization of Substation Maintenance using Decision-varying Markov Model," *IEEE Trans. Power Systems,* vol.23, no3, Aug. 2008, pp. 1328-1335.
[39]. Mendel, Jerry M.; Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions. Upper Saddle River, NJ: Prentice-Hall, 2001.
[40]. Chang, C S; Chen, J. M.; Srinivasan, D.; Wen, F. S.; and Liew, A. C.; "Fuzzy logic approach in power systems fault section identification," *IEE Proceedings, Generation, Transmission, and Distribution*, vol.144, no.5, September 1997, pp 406-414.
[41]. Tan, W. W.; Kamal, D. H.; "On-line learning rules for type-2 fuzzy controller,"*IEEE International Conference on Fuzzy Systems*, 2006, pp. 513-520.
[42]. Zadeh, L. A.; "The concept of a linguistic variable and its application to approximate reasoning-1," Information science, vol.8, 1975, pp. 199-249.
[43]. SCARF P.A.: 'On the application of mathematical models in maintenance', Eur. J. Oper. Res., 1997, 99, (3), pp. 493–506
[44]. JIRUTITIJAROEN P., SINGH C.: 'The effect of transformer maintenance parameters on reliability and cost: a probabilistic model', Electr. Power Syst.Res., 2004, 72,(3), pp. 213–224
[45]. ENDRENYI J., ANDERS G.J., DA SILVA A.M.L.: 'Probabilistic evaluation of the effect of maintenance on reliability: an application [to power systems]', *IEEE Trans. Power Syst*.,1998, 13, (2), pp. 576–583
[46]. DA SILVA A.M.L., CASSULA A.M., NASCIMENTO L.C., FREIRE J.C., SACRAMENTO C.E., GUIMARAES A.C.R.: 'Chronological Monte Carlo-based assessment of distribution system reliability'. Ninth Int. Conf.Probabilistic Methods Applied to Power Systems, KTH, Stockholm, Sweden, June 2006,pp. 1–7
[47]. KALINOWSKI B., ANDERS G.J.: 'A new look at component maintenance practices and their effect on customer, station, and system reliability', Int. J. Electr. Power Energy Syst., 2006, 28, (10), pp. 679–695
[48]. MARSEGUERRA M., ZIO E., PODOFILLINI L.: 'Condition-based maintenance optimisation by means of genetic algorithms and Monte Carlo simulation', Reliab. Eng. Syst. Saf., 2002,77, (2), pp. 151–166
[49]. YANG F., KWAN C.M., CHANG C.S.: 'Multi-objective evolutionary optimization of substation maintenance using decision-varying Markov model', IEEE Trans. Power Syst., 2008, 23, (3), pp. 1328–1335

[50]. BILLINTON R., KUMAR S., CHOWDHURY N., ET AL.: 'A reliability test system for educational purposes –basic results', *IEEE Trans. Power Syst.*, 1990, 5, (1), pp. 319–325

[51]. WENYUAN LI., 'Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project', January 24, 2006