

**Monitoring and Protection System for Automatic Load Sharing Power
Transformer (Case Study: Tatek Transformer Factory)**



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DECLARATION

I hereby declare that this Master Thesis entitled “Monitoring and Protection System for Automatic Load Sharing Power Transformer (case Study: Tatek Transformer Factory)” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION

I, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “Monitoring and Protection System For Automatic Load Sharing Power Transformer (case Study: Tatek Transformer Factory)” prepared under our guidance by Tsegay Shiferaw Emerie submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Control Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL SHEET

We, the advisors of the thesis entitled “Monitoring and Protection System For Automatic Load Sharing Power Transformer (case Study: Tatek Transformer Factory)” and developed by **Tsegay Shiferaw Emerie**, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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LIST OF ABBREVIATION

A	Ampers
ANFIS	Adaptive Neuro-Fuzzy Inference System
C	Thermal capacity
DGA	Dissolving gas analysis
IEC	The International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
FIS	Fuzzy Inference System
FLC	Fuzzy logic controller
GUI	Graphical user interface
IL	Load Current
KVA	Kilo Volt ampere
KWH	Kilo watt hour
MF	Membership Function
P	Real power
PS	Power System
TF1	Transformer one
TF2	Transformer two

LIST OF ACRONYMS

A	Idealist Factor
Cmin	Minimum Capacitor
Iref sc	Solar Irradiation (W/m^2)
I	Nominal irradiation (W/m^2)
Im	Solar-generated current or photocurrent (A)
Isc	Short-circuit current taken from the datasheet of the reference module (A)
Isat	Measured Current
VCB	Vacuum Circuit Breaker
VOP	Vacuum oil Processo
WAMPAS	Wide Area Monitoring Protection and Control

ABSTRACT

The transformer needs fast protection as well as continuous monitoring since it is an important electrical equipment as well as essential element for power system to perform effectively. It operates for 24 hours of a day and feeds the load. The transformer damage may occur when the load on the transformer is suddenly increased above its rated capacity because of the growing demands of energy. When this situation occurs, the transformer will be overloaded and overheated partial discharge and arc and may damage the insulation of transformer resulting in interruption of supply. The best solution to avoid the overloading is to operate the number of transformers in parallel. In the suggested approach auxiliary transformer will share the load when the load on the main transformer will rise above its rated capacity. The main aim of the work is also to provide an un-interrupted power supply to the energy consumers (priority based). Fuzzy logic is used for parallel operation of transformers. The problem of interruption of supply due to transformer overloading or overheating can be avoided.

Keywords: *Power Transformer, Dissolved gas analysis, fuzzy inference system, Tatek Transformer factory,*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Protection against fault in power system (PS) is very essential and vital for reliable performance. A power system is said to be faulty when an undesirable condition occurs in that power system, where the undesirable condition might be short circuits, over current, overvoltage etc. The transformer is a static device, which converts energy at one voltage level to another voltage level. The thesis is all about protecting the transformer under overload condition. Due to overload on the transformer, the efficiency drops and the secondary winding gets over heated and may burnt. So, by reducing the load on the transformer, the transformer is protected(Kamat et al., 2018). To minimize these problems, the structures of a distribution network of the factory may have to be modified. This will be done by arranging another transformer through a fuzzy logic controller. The microcontroller compares the load on the first transformer with a reference value. When the load exceeds the reference value, the second transformer will share the extra load. Therefore, the two transformers work efficiently under overload condition and the damage is prevented. The power transformer is one of the most significant equipment in the electric power system, and transformer protection is an essential part of the general system protection approach. Transformers are used in a wide variety of applications. From small distribution transformers serving one or more user to very large units that are integral parts of the bulk power system. Overloading protection means detecting problems with the transformer and isolating it from the load. A fuzzy logic controller is an intelligent tool that serves as an overloading protection for distribution transformers. It has logical rules which protect distribution transformers against overloading conditions (Lakdawala et al., 2017)

Overloading protection for the distribution transformer can be reduced by around 20% of electric power interruption. Protection and overloading protection in a particular is one of the measurement strategies to improve the power system's reliability status. In Tatek Transformer Factory, many Distribution transformers are worn out frequently in different parts of the factory due to different reasons. The major causes of this malfunction of the distribution transformer were overloading conditions which can be

easily prevented through overloading protection. Moreover with the increasing population and their unavoidable demands, the demand of electric power is high increase. With the increase in demand of power, the existing systems may become overload (Infokum, 2022). The overloading at the consumer load appears at the transformer terminals which can affect its efficiency and protection systems. One of the reported damage or tripping of the distribution transformers is due to terminal overload. To escape the damaging of transformer due to overloading from consumer end, it involves the control against over current tripping of power transformers. Where the technology of the day has given the opportunity to use the latest trends and controllers, processors are one of the day requirements to apply in the remote protection of the transformer.

Problem identification due to faults in power transformers during operation by using dissolved gas analysis such as key gas, IEC ratio, Duval triangle techniques, and fuzzy logic approaches (Palke & Korde, 2020). The Power Transformer is static device and one of the most important equipment in the electrical system are used for the step up or step down of electrical energy for transmission and distribution purpose. Power Transformer are the integral component of almost every transmission and distribution system. Power transformer might be subjected to several electrical and mechanical faults during operation. The continuity of service with high level of reliability is an important characteristic of a transmission system that requires continuous monitoring of system and its components. There are several gases separated from the transformer oil in case of incipient fault. These gases are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon dioxide (CO_2) and carbon monoxide (CO). In each type of fault, certain gases emerge at a higher rate, and the type of fault can be determined by looking at which gases emerge from it. In general, H_2 and CH_4 gases are formed in partial discharge fault, C_2H_4 and C_2H_6 gases occur in thermal faults and H_2 and C_2H_2 gases occur in arc fault. The type and severity of the fault is determined by evaluating these gases with the oil dissolved gas analysis (DGA) method. There are many methods such as IEC ratio codes based on DGA, Rogers and Dornenburg. in this global economic crisis for managing the ageing population of power transformer there is a need of reliable health monitoring system and effective diagnostics of fault. Transformer criticalities are identified and integrated for evaluation of health monitoring

of power transformer. In this thesis transformer's different diagnostic test parameters such as DGA, temperature control, dissipation factors and oil electrical and physical condition are identified. These tests parameters are integrated with the help of fuzzy logic modelling.(Chantola et al., 2018) For monitoring and protection system for automatic load sharing of the power transformer, in Tatek transformer factory measurement of parameters is important because these parameters gives the information about the deterioration of transformer insulation. Long service life of a transformer requires proper condition monitoring of transformer for effective maintenance.

The purpose of power system protection is to detect faults or abnormal operating condition and to initiate corrective action. Relays must be able to evaluate wide variety of parameters to establish that corrective action is required. Obviously, a relay cannot prevent the fault. Its primary purpose is to detect the fault and take the necessary action to minimize the damage to the equipment or to the system. The most common parameters which reflect the presence of a fault are the voltages and the current at the terminals of the protected apparatus or at the appropriate zone boundaries (Ravikumar et al., 2021)

Therefore, the aim of this study was to protect the distribution transformers in Tatek Transformer Factory, alternatively some researchers were conducted in order to eradicate the drawbacks of the traditional protective techniques this led to many improvements in transformer protection in terms of lower installation and maintenance costs. Furthermore, for the past several years' fuses, circuit breakers and electromagnetic relays were used for the protection of power systems. The traditional protective fuse and electrometrical relays present several drawbacks. Therefore a proposed solution is chosen to develop a fuzzy logic controller-based transformer overload protection system because the fuzzy logic controller provides greater flexibility, more adjustable characteristics, high accuracy, reduced size, and lower cost along with many ancillary functions such as control logic, event recording, fault location data, remote setting, self-monitoring and checking, (Blackburn et al., 2018). Electricity is an extremely handy and useful form of energy. It plays an ever-growing role in our modern industrialized society. So the demand for electrical energy is ever increasing. The electrical power systems are highly non-linear, extremely huge, and complex networks. Such electric

power systems are unified for economic benefits, increased reliability and operational advantages. However, some of the generated electrical energy is lost in transmission and distribution lines due to a widely dispersed power sources and loads. The consumer service interruptions in Transformer factory are mostly due to failure in the distribution network. Distribution systems have suffered mainly from the following: voltage and current imbalance, poor voltage regulation, peak power or energy losses, conductor heating or equipment, etc. The phase voltage and current unbalances are major factors leading to extra losses, equipment overloading. In this thesis “Monitoring and Protection System for Automatic Load Sharing of Transformers” is using two transformers, one is a main transformer (TF1) and the next is a backup transformer (TF2). Here the load is directly connected to the secondary of the main transformer as well as the backup transformer; the two transformers are connected through the controller.

1.2. Statement of the Problem

Modern power system requires accurate, reliable technique for detection of faults, real time data monitoring and fast response speed. The reliable operation of the power system depends upon the effective functioning of the power transformer. In Tatek transformer factory the electricity demand is increasing abruptly and also the whole system is moving towards the electricity on the other hand, due to overload, the transformer at the substation/distribution gets overheated and interruption of supply occurs at the consumer end, and overloading leads to permanent damage of transformer which is much expensive to install new every time. The existing system presently is done manually by technician this result in damage of transformer. This is a heavy loss to any grid or industries, here are even chances for the equipment to get damaged and power interruption. There is a need for an optimal solution or technique for this problem. To avoid this problem, we use the substitute of paralleling of transformer which results in continuity of supply to the consumer, and safety of transformer from damage due to overload. The main duty of this investigation is how unbalance due to uneven distribution of single-phase loads at the secondary side of the distribution network can be minimized using automatic load sharing fuzzy logic based system has real time data monitoring, detection of abnormal condition, low maintenance cost and more flexibility in Tatek Transformer factory.

1.3. The Objective of the Study

1.3.1 General Objective

The general objective of this study is to design a Monitoring and Protection System for the Automatic Load Sharing Power Transformer control mechanism based on the parallel combinations of load-sharing transformers for the Tatek Transformer factory application.

1.3.2 Specific Objectives

Load sharing provides sufficient protection to distribution transformer under overloaded conditions. Due to overload on transformer, the efficiency drops and windings get overheated and may burn. By sharing a load current on transformer for each phase the transformer was protected. Therefore, the The specific objectives of this study was to protect transformers from overloaded conditions by sharing the load.

1.4. Scope of the Study

The scope of this thesis is the development of a fuzzy logic controller on the monitoring and protection system for automatic load sharing of power transformers during overload and under-load protections for the Tatek transformer factory under peak load to protect the transformer during overload conditions. Introducing this method have the advantage to maintain a stable level of short circuit current .reduce the voltage drop and imbalances the current and it reverses power protection etc. so the thesis deal with theoretical and mathematical method and simulation. It is implemented on MATLAB software tool.

1.5. Limitations of the Study

The thesis deal with load sharing of the transformer to ensure the safety of the power transformer thereby protecting the distribution system when there exists a state of overload the thesis does not encompass other transformer failed reasons like lighting short circuit of windings birds tree and others. The thesis also does not try to show the

implementation in substation since it is complicated and would take a lot of analysis. Also, the optimization of the membership and scaling factors using the evolutionary algorithm is not done.

1.6. The Motivation of the Study

Electric energy demand in the Tatek transformer factory is over increasing every year. So the previously installed distribution transformer in the distribution network of the factory was not capable of carrying this over increased load. While I visited to Tatek Transformer factory many malfunctioning or burnt distribution transformers were seen that are stored in the store of the office. Most of these malfunctions happened due to overload and overcurrent. To combat this problem many options there like protective relay protection, and break insulation. Of these I come up with the most cost-effective and efficient thesis entitled monitoring and protection system for automatic load sharing of distribution transformer techniques using fuzzy logic controller schemes in the Tatek transformer factory is chosen.

1.7. Significant of the Study

This thesis will contribute a technique for distribution utilities at the low voltage distribution network that will bring the following point: A case study of monitoring and protection system for automatic load sharing of power transformer in Tatek Transformer factory distribution network, Structural survey on load sharing and benefit of automatic load sharing, Increase quality and reliability of supply service to the consumers, Unbalance will be considerably minimized thereby ensuring that voltage drop and power losses are reduced, This will increase the life span of the utility installations. Maximization of the capabilities of the existing distribution station in terms of the infrastructures and equipment. Resource full distribution of power flow.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

This chapter will discuss the study about the significant effect of overload in the Tatek transformer factory distribution system network and some cite on this area. At present the load control systems were operated manually. This may cause increasing short-circuit currents that increase necessary breaker capacity, the risk of circulating currents running from one transformer to another transformer, circulating currents that diminish load capability, and increased losses. The formerly used techniques are tried to overcome in this thesis by using an automatic load-sharing mechanism. The main aim of this thesis is to save the transformer from failing or permanent damage, when in an overload and under load state.

The transformer is a device that works most significantly in electric power framework on various occasions, the load on the transformer varies outside the ordinary working limits, which leads to overburdening and reduces the transformer's life span. The issues of overvoltage and overload are common in transformers. As a result of such abnormalities, the intrusion of supply occurs, and the efficiency of the system drops. The main purpose of this thesis is to secure the transformer from permanent damage in an overburden condition.

2.1. Power Transformer

A transformer is the most important electrical machine used to transfer electrical energy from one circuit to another without changing its frequency. It is used either to step up or step down the voltage to minimize transmission losses in the electrical circuits. It works on the principle of electromagnetic induction (Reddy, 2020). They are used in the generating station and substation at each end of transmission line. The transformers used at the generating stations end of the transmission line are for stepping up the voltage and transformers used at the substation end of the transmission line are for stepping down the voltage. A transformer is composed of several unique components, each of which contributes to the overall performance of the transformer in a different way. The main components are the core, windings, insulating materials, transformer oil, tap changer,

conservator, breather, cooling tubes, Buchholz Relay, and explosion vent.

2.1.1. Components of Power Transformer

A transformer facilitates the delivery of power electric energy at minimum power loss. The basic parts of a transformer are the core, the primary winding, and the secondary winding. Apart from these, there are various other components such as insulation, transformer oil, cooling arrangements, protection relays, enclosure, etc. Present in larger transformers. The components of a power transformer are mentioned below



Figure 2.1 Parts of power transformer

Source: <https://www.allumiax.com>

2.2. Use of Power Transformer

A power transformer is a static device used for transforming power from one circuit to another without varying the frequency. This is a very simple definition of a transformer. Because there is no moving or rotating component, a transformer is introduced as a static device. Power transformers perform based on an AC supply. A transformer operates on the rules of mutual induction. Power transformers are used to:

- Step up the level of generated voltage to the high voltage level for transmission purposes.
- Fed-up the transmission system via high voltage (with low current) which

reduces the line losses.

- Step up or step down the level of voltage in the generating and substation according to the requirements.

Transformers can be classified in several methods, based on their purpose, application, production, etc. Consider that these classifications occasionally overlap e.g. a transformer can be both a three-phase form and a step-up form at the same time. The types of transformers include the following:

- a) **Step-up transformers transform the low-voltage (LV) and high-current input** from the primary section of the transformer to the high-voltage (HV) and low-current value on the secondary section of the device.

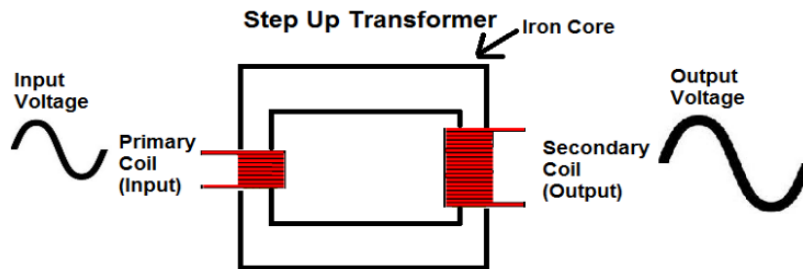


Figure 2.2. Step up Transformer (Reference: learningaboutelectronics.com)

- b) **Step-down types transform the high voltage (HV) and low current values** from the primary section of the device to the low voltage (LV) and high current output on the secondary section of the type.

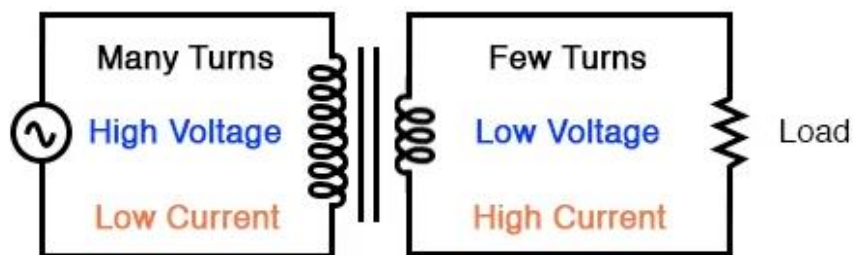


Figure 2.3. Step-down Transformer (Reference: allaboutcircuits.com)

- c) **Three-Phase Transformer and Single-Phase Transformer:** A three-phase transformer is typically employed in a three-phase power network as it is more

efficient than single-phase types. But when size imports, it is recommended to employ a bank of three single-phase vs. a three-phase transformer, as it is simpler to transmit than one single three-phase set.

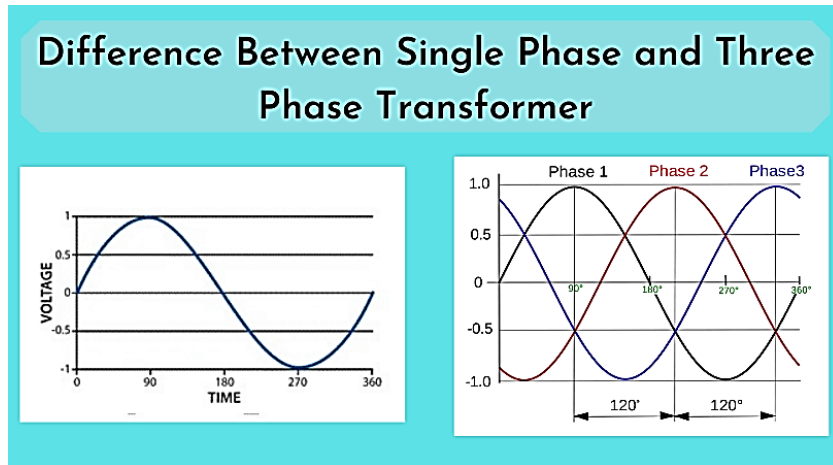


Figure 2.4. Single-phase transformer vs. three-phase transformer (laxmiassociates.in)

- a) **Oil Cooled and Dry Type Transformer:** This type is related to the transformer cooling configuration used within the transformer. In oil-cooled types, the cooling method is transformer oil. While in the dry types, air cooling is applied instead.

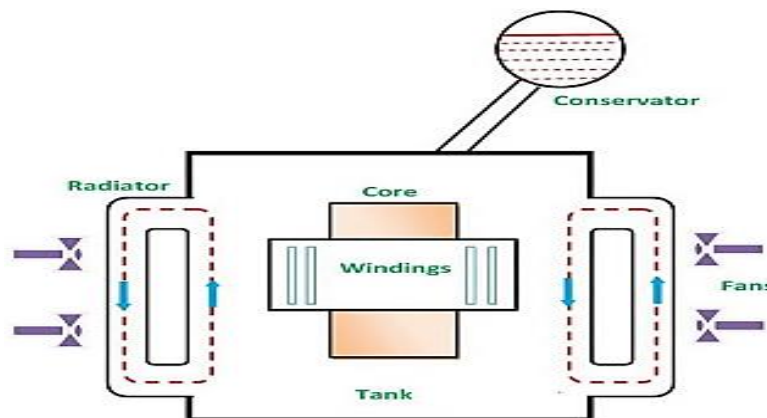


Figure 2.5 cooling a transformer (Reference: electricallive.com)

Also, Power transformers can be divided into three types according to the ranges. They are large power transformers, medium power transformers, and small power transformers.

The range of large power transformers can be from 100MVA and beyond

The range of medium power transformers can be from -100MVA

The range of low-power transformers can be from 500-7500kVA

Source:<https://www.elprocus.com/>

These transformers transmit the voltage. It keeps a low voltage, a high current circuit at one section of the transformer, and on the other side of the transformer, it keeps a high-voltage low current circuit. A power transformer works based on the principle of Faraday's induction law. It explains the power network into areas where every gear attached to the system is designed per the rates set by the power transformer.

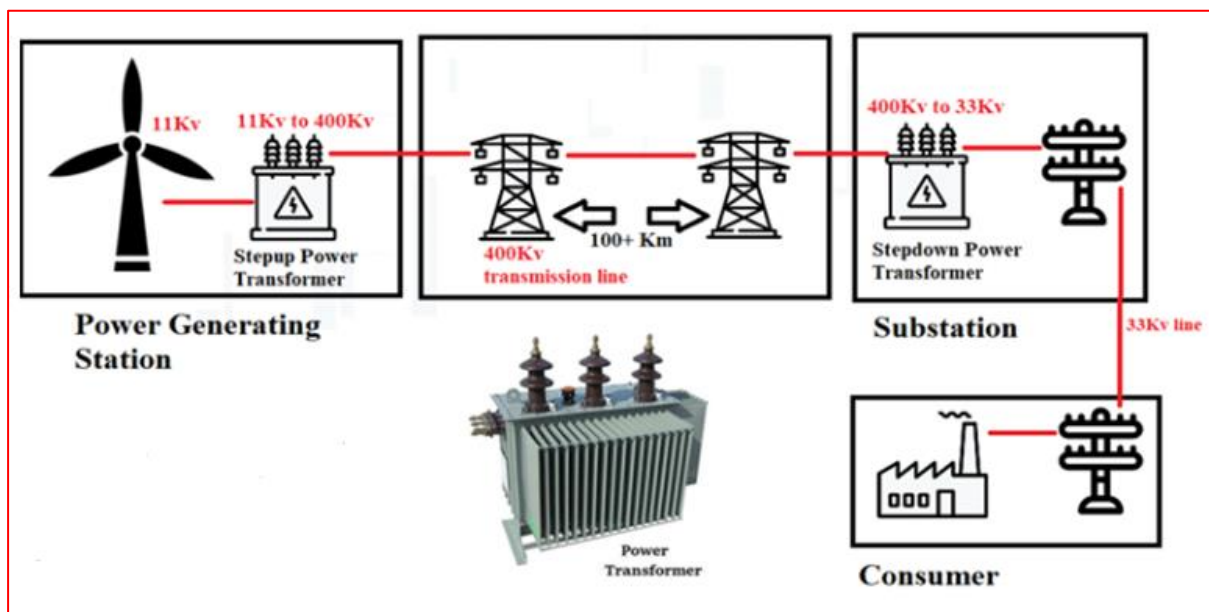


Figure 2.6. Generation and transmission stage diagram of power transformer

Source:<https://circuitdigest.com>

The power transformer is used in the generation and transmission stages. It can be a single phase or three phases. A power transformer is used for stepping up or down higher-rated voltages in both these stages. That we know. Only there are some additional design changes in it for working at higher voltages. This transformer is provided with tapping on the primary winding side. Power lines are subjected to many variations according to demands and to work with that, tapping is provided on the primary side. By setting the proper tap, we can maintain proper voltage at the secondary side winding. You can change the taps even when the power supply is on. It is put in

operation during peak load. This means it is connected in parallel with a normal transformer and when there is high peak demand during morning or evening hours, then the power transformer is used. During non-peak hours, the normal transformer comes into the picture, and the power transformer is shut off. The main thing here is that power is transmitted without changing the frequency. Two winding transformers are generally used where the ratio of high voltage and low voltage is greater than 2. It is cost-effective to use an **auto transformer** where the ratio between high voltage and low voltage is less than 2.

2.3. What is Distribution Transformer

A transformer mounted on the utility pole near the consumer load points which step-down the high voltage to the safest rated voltage according to the utilization needs is known as a distribution transformer. Distribution transformers are generally rated for 11kV, 6.6 kV, 3.3 kV, 440V, 230V, 120V, and 110V (Noshahr et al., 2019).

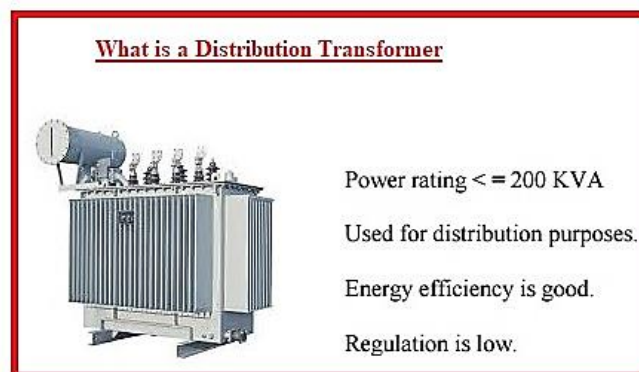


Figure 2.7. Distribution transformer

Source:(<https://www.theengineeringknowledge.com>)

The main purpose of a distribution transformer is to step down the high level of distributed voltage to a low level of voltage according to the needs of consumers (both commercial and residential). That provides the final voltage transformation in the electrical power distribution system stepping down the voltage used in the distribution lines to the level used by the customer. Since these transformers are energized 24 hours a day, their proper working is very important and so strong protection is required.

2.3.1. Use of Distribution Transformer

Distribution transformers are used (Kamat et al., 2018):

Step down the level of high voltage to the low voltage according to the system (e.g. 230V, 400V, 120V, 240V, etc.).

Distribute the electric power to the consumer units.

Provide both single-phase and three-phase power to the consumers according to their needs.

2.3.2. Types of Distribution Transformer

Based on the application or requirement, these transformers are categorized into different types like single phase, three phases, underground, pad-mounted, and pole-mounted transformers (Ajenikoko et al., 2020).

2.3.2.1. Single phase transformers

These transformers are specially used for networks wherever a three-phase supply is not required. Usually, these are used for repairing overhead distribution loads in residential. These are also applicable in industrial lighting, light commercial loads & power applications.

2.3.2.2. Three phase transformers

This kind of transformer is used to hold electrical energy from the main distribution circuit to a minor distribution circuit. This type of transformer transmits the current to a secondary distribution circuit and also reduces the voltage of the primary distribution circuit. These transformers reduce the voltage supply for the primary circuit based on the consumer requirement.

2.3.2.3. Pad Mounted transformer

This form of distribution transformer consists of a locked steel cupboard that is configured on a concrete pad. This type is set in locations where they do not have

enough place for a fenced enclosure. This device can be employed with electric energy distribution lines at an overhead electrical path for dropping the primary voltage to provide for the customers. A single type of this pad-mounted transformer can serve several homes/a large building. The power level of this type differs from 75 kVA to 5000 kVA and contains fixed fuses and switches.

2.4. Key Difference between Distribution and Power Transformer

Power transformers are used in the transmission network of higher voltages whereas Distribution Transformers are used in the distribution network of lower voltages (Mokryani, 2022). The power transformers are available in various ratings of 400 kV, 200 kV, 110 kV, 66 kV, 33 kV in the market and the distribution transformer are available in 11 kV, 6.6 kV, 3.3 kV, 440 V, 230 Volts, Power transformers are used in power generating stations and transmission substations, and the distribution transformer is installed at the distribution stations from where the power is distributed for the industrial and domestic purposes, The size of the power transformer is large as compared to the distribution transformers, In Power Transformer, the iron and copper losses take place throughout the day but in distribution transformer, the iron loss takes place 24 hours i.e., throughout the day, and the copper losses depend on the load cycle(Kamat et al., 2018)

2.5. Automatic Load Sharing of Transformer

Automatic Load sharing means generally equally sharing the load in the power system. In the power system load sharing of the transformer is achieved with different techniques. It means in distributed power system if two transformers are connected, one transformer shares the load in normal condition. If load demand is increasing and one transformer is connected but not able to fulfil demand then another transformer is directly connected with the main transformer in parallel and shares the load. In the power system, it is called load sharing of the transformer. The main transformer is called a power transformer and another transformer that is connected to the main transformer is called a slave transformer in the power system (Kalyani et al., 2018).

2.5.1. Parallel Operation of Transformers

Two transformers are said to be connected in parallel if the primary windings are connected to supply bus bars and secondary windings are connected to load bus bars. Fig. (2-4) shows two transformers A and B in parallel. For supplying a load in more than the rating of an existing transformer, two or more transformers may be connected in parallel with the existing (main) transformer. The transformers are connected in parallel when the load on one of the transformers is more than its capacity. Due to the parallel operation of the transformer reliability of the power system is increased and damage to the various equipment (Shi et al., 2017)

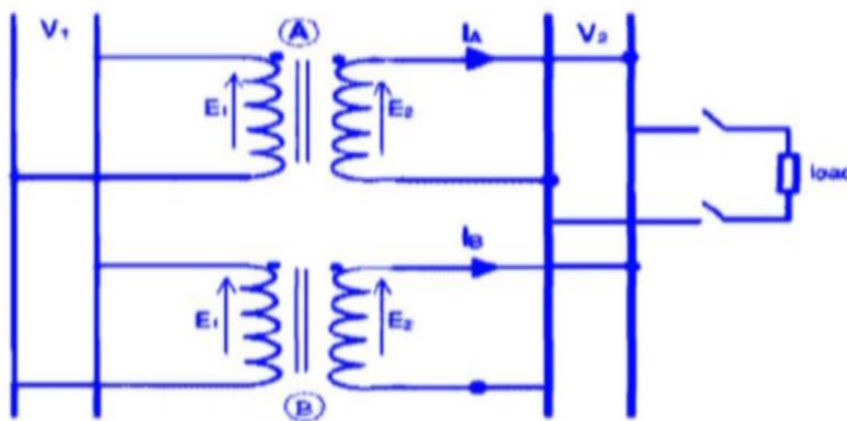


Figure 2.8 Parallel operation of Transformer

Source:<https://electrical-engineering-portal.com>

Substations like transformers are reduced. To archive parallel operation of transformers some conditions are to be satisfied compulsory. The above figure shows the two transformers are connected parallel. There are a total of two buses in the system one is a supply bus and another one is a load bus. At the load bus, the load is connected. E_1 is the primary side voltage and E_2 is the secondary side voltage. If a condition occurs and the load is suddenly increased, then the second transformer is in parallel with the main transformer to supply the load demand.

2.5.2. Need of Parallel operation for load sharing

Firstly, if one transformer fails, the continuity of supply can be maintained through other transformers, Secondly, when the load on the substation becomes more than the capacity of the existing transformers, another transformer can be added in parallel, Thirdly, any

transformer can be taken out of the circuit for repair/routine maintenance without interrupting supply to the Consumers.(Fernando et al., 2018) Purposes of using parallel connection:

- To maximize electrical power system efficiency.
- To maximize electrical power system availability.
- To maximize power system reliability.
- To maximize electrical power system flexibility.

2.5.3. Conditions for Parallel Operation of Transformer

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance.

- Same voltage & Turns Ratio (both primary and secondary Voltage Rating is same).
- Same Percentage Impedance and X/R ratio.
- Identical Position of Tap Changer.
- Same KVA ratings.
- Same Phase angle shift (vector group is same).
- Same Frequency rating.
- Same Polarity.
- Same Phase sequence

2.6. Transformer failure and causes

There are various types of faults in the transformer faults may occur in different parts and components of the transformer due to mechanical, electrical, or thermal stress caused due to different conditions. Some of the most commonly occurring failures of the transformer and their causes are listed below (Eyuboglu et al., 2020). There are various types of faults in the transformer namely;

2.6.1. Auxiliary Equipment Faults

These are types of faults as a result of failure in the transformer. Winding. Such kinds of faults came into being due to winding and core insulation, gas cushion, and drop-in

transformer oil.

2.6.2. Winding and Connection Faults

These types of faults are serious in nature because they cause immediate damage to the transformer. It usually occurs due to faults between turns, damage to insulation due to overload.

2.6.3. External Short Circuits And Overload Faults

Insulation of the windings is mostly affected by the loads applied to the transformer. External short and overload faults usually give raise the temperature of the windings and cooling system. Such kinds of faults and be checked by monitoring the winding and oil temperature.

2.6.4. Partial Discharge (PD)

PD occurs in the gas phase of voids or gas bubbles. It is usually easily detectable by DGA, however, because it is produced over very long periods of time and within large volumes of paper insulation. It often generates large amounts of hydrogen.

2.7. Conventional Transformer Protection Schemes

Different transformer protection schemes are employed based on the size of the transformer and its rating. Transformers are one of the most critical and expensive components of any distribution system. It is an enclosed static device usually drenched in oil, and hence faults occurring to it. But the effect of a rare fault can be very dangerous for the transformer, and the long lead time for repair and replacement of transformers makes things even worse. Hence power transformers protection becomes very crucial.

Faults occurring on a transformer are mainly divided into two types, which are, **external faults and internal faults**, to avoid any danger to the transformer, an external fault is cleared by a complex relay system within the shortest possible time.

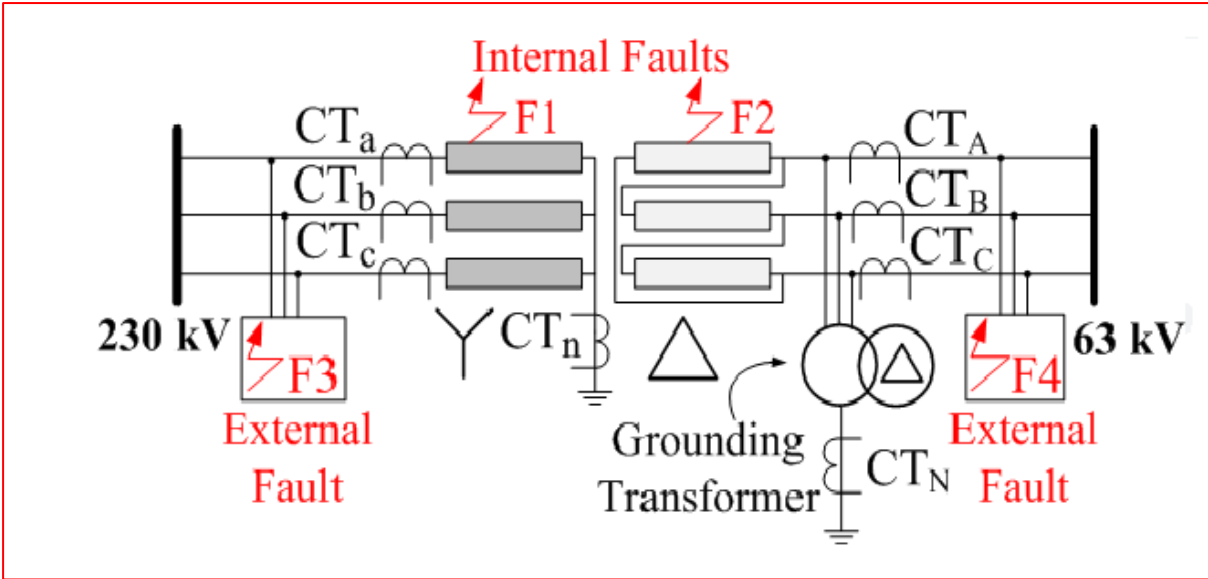


Figure 2.9 Internal and external fault algorithm

Source: <https://www.epowerplus.com/blog/External-and-Internal-Faults-in-Transformer>

The internal faults are mainly based on sensors and measurement systems. It is better to talk about those processes. Before there, it is important to understand that there are many types of transformers and in this thesis, will discussing mainly about power transformer that is used in distribution systems. Basic protection features like over excitation protection and temperature-based protection can recognize conditions that eventually lead to a failure condition, but complete transformer protection provided by relays and current transformers are appropriate for transformers in critical applications. Some common protection schemes for transformers are described below.

2.7.1. Buchholz Relay

Buchholz relay is a gas-actuated relay. Under normal operating conditions, the Buchholz relay is completely filled with oil. When a fault occurs and gas bubbles are formed in the transformer tank. The gas starts accumulating in the relay chamber. Buchholz relays help in detecting minor as well as major faults in the transformer. For minor faults, it gives an alarm,

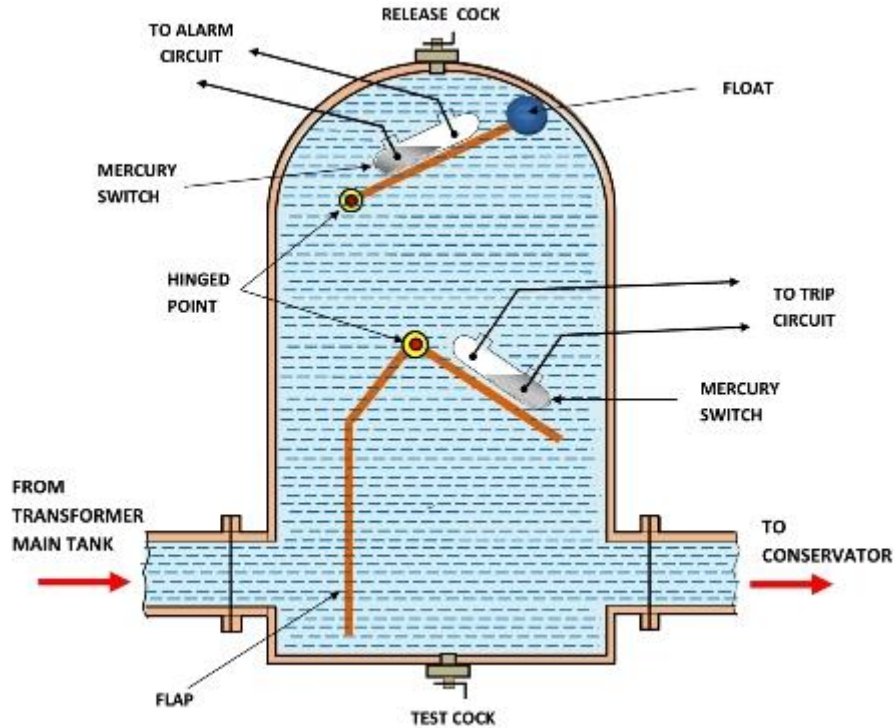


Figure 2.10 Working principle of Buchholz relay

Source: <https://www.electricaleasy.com/>

And for major fault events, it trips the circuit. Disadvantages of Buchholz Relay

- The Buchholz relay can only be implemented in transformers and other electrical equipment having absorbed oil.
- This sort of relay is applicable to an oil absorbed transformer.
- This relay can detect only when the oil level is below.
- This relay does not guard the connecting cables. So separate security is required for the cables.
- It has the high response time.
- The least operating time of the Buchholz relay is 0.1 seconds

2.7.2. Differential relay Protection

The differential protection scheme is used to protect the transformer against phase-to-phase faults and phase-to-ground faults. It is also known as circulating current protection. The operation of differential protection is based on the comparison of

currents flowing in the primary and secondary windings of the transformer. Principle of Differential Protection scheme is one simple conceptual technique. The differential relay actually compares between primary current and secondary current of power transformer, if any unbalance found in between primary and secondary currents the relay will actuate and inter trip both the primary and secondary circuit breaker of the transformer.

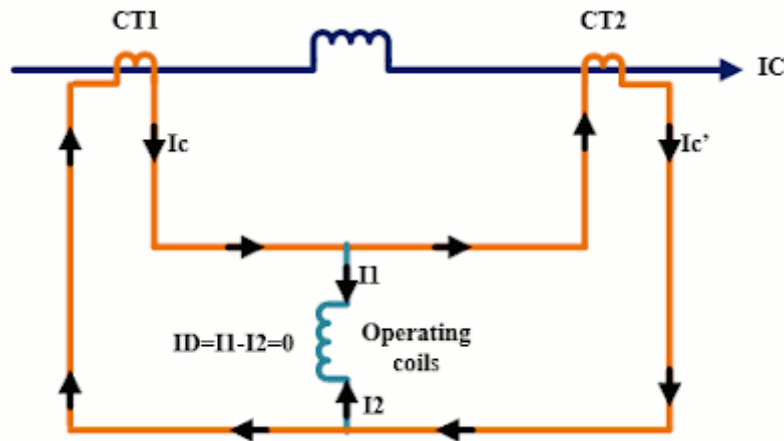


Figure 2.11 Differential relay protection

Source: <https://www.elprocus.com/differential-relay/>

Disadvantage of differential relay

- Unmatched characteristics of CTs.
- Ratio change as a result of tapping.
- Magnetizing inrush current.

2.8. Review of related literature

A lot of research work has been carried out on fault detection and Protection on power transformers which are mainly centred on how to use monitoring condition and protection systems in order to develop a more efficient and precise faults detection system in power system networks. Incorporate artificial intelligent approaches which process the information from alarms and protection relays in power distribution and transmission systems. Several research works are reported on the automatic load sharing of the transformer by using different algorithms and optimizations respectively. In this

section, related works are reviewed based on performance measuring criteria such as tracking time, integral absolute error, efficiency, output power under variable irradiation, and constant temperature conditions. There are different techniques used for transformer load sharing. Let's see one by one.

(Kalyani et al., 2018) proposed a microcontroller-based system. Power supply to the Loads from a single transformer under normal conditions and a standby transformer is connected in parallel through a circuit breaker. A current transformer measures the load current continuously and sends it to the microcontroller by converting it to a corresponding digital value to compare with the reference value set by the user. Whenever the load current more than a reference value, the controller gives an output signal to the relay which energizes the relay coil. The relay coil thus sends a tripping signal to the circuit breaker. Then standby transformer is directly connected to the main transformer. Thus the load is shared by the transformers equally. The current transformer continuously measures the load current and compares it with the reference value. Whenever the load current goes below the reference value one transformer is shut down. If the load value increases further beyond the capacity of two transformers, the load will be cut off from the main supply based on the priority level set by the user. This is done to provide an uninterrupted power supply to higher-priority loads. The load parameters are continuously displayed on the LCD. Due to this, they can show the peak load time duration.

(Lakdawala, 2017)Transformer load sharing with power factor improvement technique, in overload condition there is stress created on the winding of transformer. Due to this the temperature of transformer is get increase and these indicate overloading. In this scheme the protection of the over loading, over temperature of transformer is archived by the perfect load sharing and also scheme involves the power factor improvement technique. In most cases the load side power factor is lagging. Here automatic load sharing module also consist the automatic power factor correction circuit. Loads are inductive in nature so the power factor is lagging in nature. So to improve power factor nearer to the 1.0 capacitor or inductors banks are used

(Tirpude et al., 2017) Automatic Transformer Load Sharing System Using GSM Modem These two transformers are connected with the relay which is controlled by the

embedded controller. Through the microcontroller, we are controlling this sharing of power with the help of relay. The relays will trips to another transformer upon exceeding the limit of load. The ADC is an analog to digital converter which converts the values of analog current value to the digital value. This information is passed to the controller and then the controller checks the instruction and forwards it to the GSM modem. The modem immediately sends that particular SMS to the mobiles for which it is assigned and this will be displayed as load status on the LCD display. This relay is driven with a transistor. Contrast control pre-set is given for LCD contrast control. 7805 three terminal voltage regulator is used for voltage regulation. Bridge type full wave rectifier is used to rectify the ac output of secondary of 230/12V step down transformer. The mains power supply phase is stepped down by transformer to deliver 12V, 500 mA, which is rectified by diode and filtered by capacitor to produce the operating voltage for the operational amplifier.

Several researches had been carried out on line protection using well-defined computational mathematical methods that were not intelligent enough but in recent years intelligent-based methods are being used in fault detection among which is the fuzzy logic system. In the power system, transformers may be loaded beyond their nameplate ratings due to a fault or some emergency conditions. This type of overloading can cause either short-term failures or long-term failures. An increase in hot spot temperature would also lead to the accelerated aging of the transformers resulting in transformer overload. So to keep the body temperature of the transformer within its nameplate rating, the transformer must be loaded efficiently in a controlled manner. This system aims at load sharing of transformers and priority-based load shedding.

In general, the performances of Monitoring and protection system for automatic load sharing power Transformers Loads are supplied from a single transformer under normal conditions and a standby transformer is connected in parallel through a circuit breaker. Whenever the load current exceeds the reference value, the controller sends a high signal to the controller. This sends a tripping signal to the circuit breaker of the standby transformer. Thus the load is shared by the transformers equally as the transformers are identical. The current transformer still measures the load current and compares it with the reference value. Whenever the load current falls below the reference value one

transformer is shut down and this is done in an alternative manner to avoid thermal overloading. If the load value increases further beyond the capacity of two transformers, the load will be cut off from the main supply based on the priority level set by user. This is done to provide an uninterrupted power supply to higher-priority loads.

CHAPTER THREE

METHODOLOGY

3.1. Introduction

Every country depends upon electricity for its development. Normally, the load control systems were operated manually. The formerly used techniques are tried to overcome in this thesis by using an automatic load-sharing mechanism. The main aim of this thesis is to save the transformer from failing or permanent damage, when in an overload state. This chapter provides the methodology used for the mathematical modeling of monitoring and protection systems for automatic load sharing of power transformer systems. The transformer is a device that works most significantly in the electric power framework. On various occasions, the load on the transformer varies outside the ordinary working limits which leads to overburden and reduces the transformer's life span. The main purpose of this thesis is to secure the transformer from permanent damage in an overburden condition.

That is possible to develop a system in which the main transformer supports the second one. The system consists of two transformers, sharing a circuit breaker fuzzy logic control, system as its fundamental part. The components and details modelling in MATLAB software are demonstrated.

3.1.1. Case Study Analysis

The highest work is field data collection, which comprises data on the number of distribution transformers' site observations to evaluate their specification of ratings. This part provides a case study of two power transformers' load sharing in a distribution system with the Tatek transformer factory. The following assumption parameters for each transformer are considered.

3.1.2. Equal Impedances-Equal voltage Ratios- Different kVA

Although it's not common practice for new installations, sometimes two Transformers with different kVAs and the same percent impedances are connected to one common bus. In this situation, the current division causes each transformer to carry its rated load.

There will be no circulating currents because the voltages (turn ratios) are the same. The capacity of T1L= 315kVA and capacity of T2L= 315kVA, Each transformer with 5.75% impedance and each has the same turn ratios, The total load connected to a common is 480kVA. Since current has a direct relationship with kVA, substituting kVA for current into equations and above. It can be seen in the calculations that even though there are different kVA ratings on transformers connected to one common load, that current division causes each transformer to only be loaded to its kVA rating. The key here is that the percent impedances are the same.

3.2. Method

The adopted methodology, as illustrated in Figure 3.1 is employed to attain the specific objectives of this study. First, the related works are reviewed and the problem is identified, then the necessary power transformer data are collected and analyzed. The analysis includes different methods for generating mathematical equations to determine the unknown parameters of the system. A fuzzy logic switching controller is included in this research thesis. The proposed system is designed using two transformers and implemented in MATLAB/Simulink. Their results and analysis have been discussed in detail and conclusions are drawn.

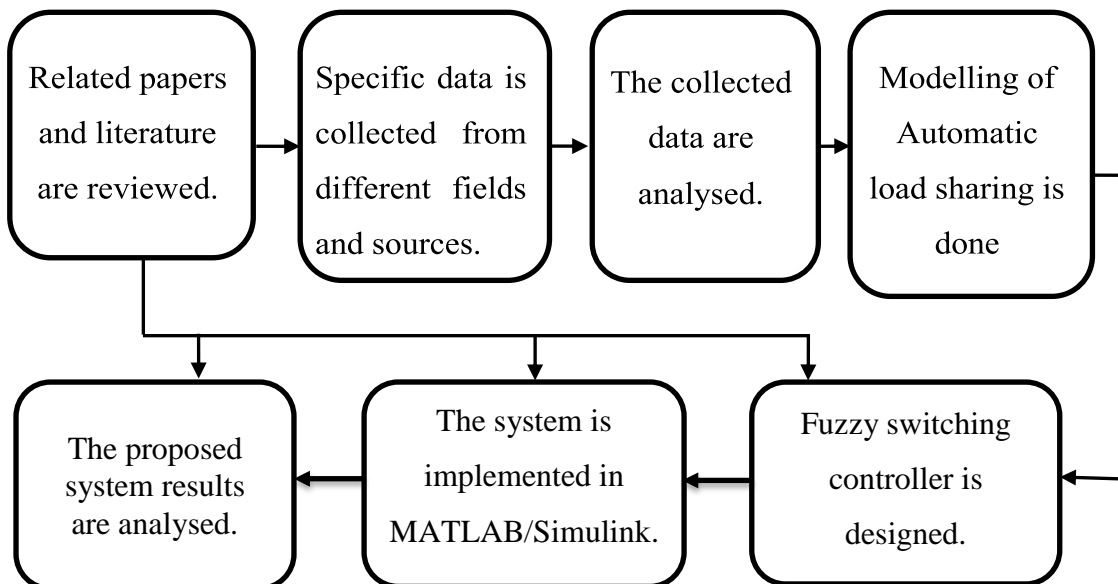


Figure 3.1 Activities related to the proposed method in block diagram.

In this thesis, three major components are used to control the load current. The first is the sensing unit, which is used to sense the current of the load. The second is a fuzzy logic controller, which will read the digital signal and perform some calculation, and finally gives the control signal to the sharing breaker circuit. The last is the control unit; in this sharing circuit breaker is the main role, and its function is to change the position concerning the control signal. When designing low-voltage power systems to supply large load currents, paralleled lower-current modules are often preferred over a single, large power converter for several reasons. Automatic transformer load-sharing issues and remedies are relevant topics and a lot of advanced research is being carried out in this area. These issues are mainly due to increased usage of power system utility and unbalanced loads that occur in the power system.

This thesis is mainly used to protect the transformer from getting worn out due to electrical disturbances. The electrical parameters like current and voltage of the transformer are fed as base values, using a controller and the output signal is provided to operate a sharing breaker circuit comparing the base value with the operation electrical parameters. "Monitoring and protection system for automatic load sharing of power Transformer" uses the distance protection function which is used as backup protection for faults within the transformer. This solution provides efficient protection and control in facts installations. The distance protection function can also be used as backup protection for faults in the connected lines. The parameters related to line distance protection are mostly set as primary ohms, which significantly reduces the need to recalculate the current and voltage values. Due to variations in the load, a single transformer may not be handling the power flow. To cope with this problem a parallel operation of transformers is incorporated. This operation is handled by switching circuit breakers using a fuzzy logic controller. Hence transformer-1 and transformer-2 are operated based on the load requirement. Figure 3.2 explains the proposed block diagram of the load-sharing transformer system with fuzzy logic switching drive controller.

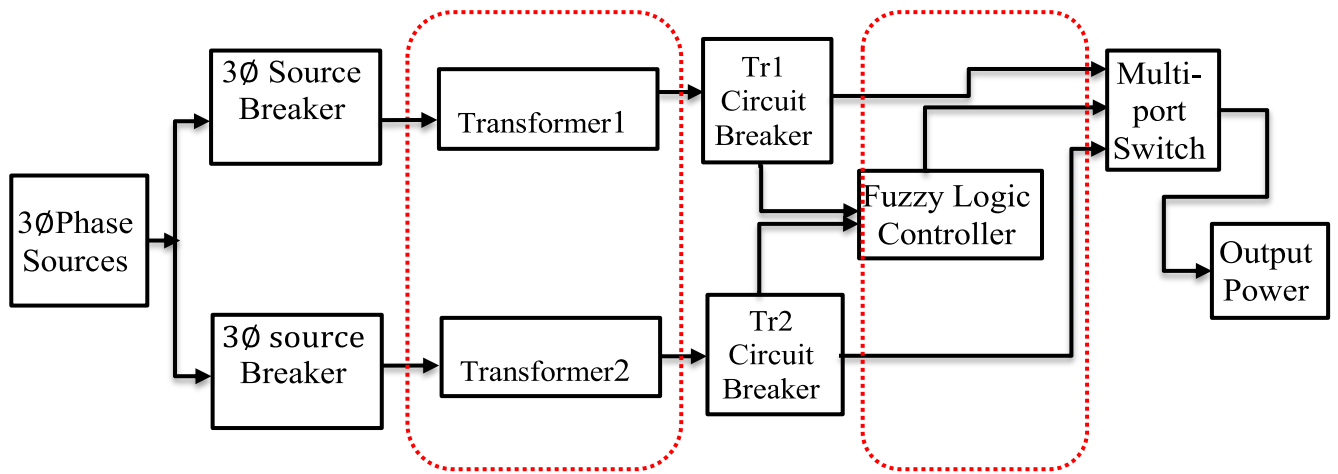


Figure 3.2. Block diagram of the proposed system

When the load is between the operating ranges of Transformer-1, the Transformer-1 circuit breaker will be ON. Also, when the load is between the operating ranges of Transformer-2, the Transformer-2 circuit breaker will be ON. Moreover, when the load power will be beyond the range of each transformer, both the T-1 and T-2 circuit breaker will be in an ON state. The analysis of the controller is done based on considering the capability of the transformers. Finally, the proposed system is developed by using MATLAB/Simulink and the result is discussed and the conclusion is drawn.

3.3. Mathematical Modelling for Determining KVA Ratings

A Failure Modes and Effects Analysis were conducted at Tatek Transformer Factory from December 19 to January 3, 2022. For load assessment Measurement data were collected using interviews and direct measurement of the consequences of failures in terms of electric power interruption, damage of the components, or further damage of subsequent sub-systems. Two weeks were given for data collectors and supervisors for 3 days on methods of extracting the information through interviewing, and direct measurement.

There is a mathematical equation for determining the KVA rating of transformer-1 and transformer-2. From the collected data following parameters are calculated.

For load assessment area of A:

Real power P=

$$(50*81+315+400+500+1250+750*233.36+700*21+800*42.5)W=230,265W=230.265KW.$$

From this load current can be calculated.

$$I_L = \frac{\text{Real Power}}{\sqrt{3} \times V_s \times pf} \quad (3.1)$$

$$\frac{230.265}{1.73 \times 380 \times 0.8} KW = 437.8A$$

Then to find the KVA rating of the Transformer-1

$$KVA_A = \frac{\text{Real Power}}{pf} \quad (3.2)$$

$$\frac{230.265}{0.8} KW = 287.8KVA$$

From this, the transformer rating is selected above this value because the transformer rating has to be greater than the actual load. This is done for safety purposes and expansion, in case more loads were added at a later date. Therefore, the transformer rating is approximately 315KVA.

For load assessment area of B:

In a similar way, rated power was the sum of the entire total load that was delivered to the consumer.

Real power P

$$= (400+315*594.5+750+1250*5+800+458.5*250+425*80+) =40000W= 23.96KW$$

From this load and current can be calculated

$$I_L = \frac{\text{Real Power}}{\sqrt{3} \times V_s \times pf} \quad (3.3)$$

$$\frac{23.9625KW}{1.73 \times 380 \times 0.8} KW = 23.96 \frac{23.96}{526} = 455.46A$$

Then to find the KVA rating of the Transformer-2

$$KVAB = \frac{Real\ power}{PF} \quad (3.4.)$$

$$\frac{242.245}{0.8} KW = 303KVA$$

From this, the transformer rating was selected above this value because the transformer rating was greater than the actual load. This was done for safety purposes and expansion, in case more loads were added at a later date. Therefore, the transformer rating was approximately 315KVA.

3.4. Mathematical Modelling of Two Load Sharing of Transformers

Two transformers of equal voltage ratios are selected for working in parallel. This can avoid a circulating current between the transformers (Yamamoto, 2019)

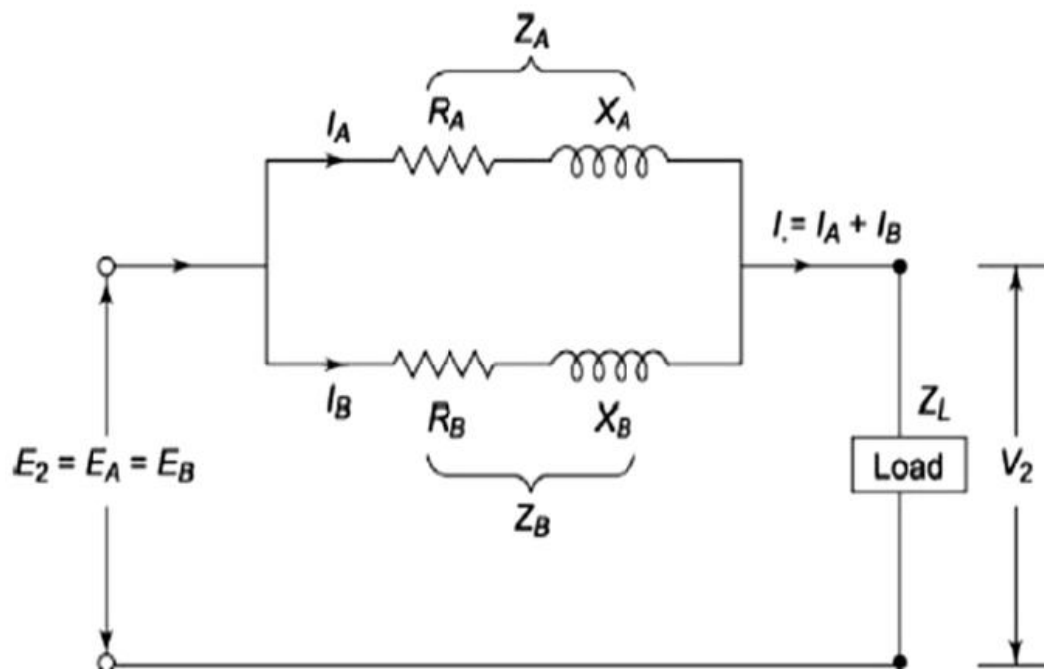


Figure 3.3. Equivalent circuit of parallel transformers

From Figure 3.3 Circuit the following parameters are calculated

$$I_A Z_A = I_B Z_B = I_L Z_L \text{ V (say)} \quad (3.5)$$

$$Z_A = R_A + X_A \quad (3.6)$$

$$Z_B = R_B + X_B \quad (3.7)$$

Here:

$$I_L = I_A + I_B \quad (3.8)$$

And Z_{equ} is the equivalent impedance of the two transformers given by $Z_A Z_B$

$$Z_{equ} = \frac{Z_A Z_B}{Z_A + Z_B} \quad (3.9)$$

From Equations (3.4), (3.5), and (3.6)

$$I_A = \frac{V}{Z_A} = \frac{I_L Z_L}{Z_A} = I_L \frac{Z_B}{Z_A + Z_B} \quad (3.10)$$

$$I_B = \frac{V}{Z_B} = \frac{I_L Z_L}{Z_B} = I_L \frac{Z_A}{Z_A + Z_B} \quad (3.11)$$

From the above, it has been seen that the transformer with higher impedance supplies lesser load current and vice versa. If transformers of dissimilar ratings were paralleled the transformer with a larger rating shall have a smaller impedance as it has to produce the same drop as the other transformer, on a larger current. Thus, the ohmic values of the impedances must be in the inverse ratio of the ratings of the transformers.

$$\text{Therefore} \quad I_A Z_A = I_B Z_B = \frac{I_A}{I_B} = \frac{Z_B}{Z_A} \quad (3.12)$$

3.4.1. Secondary Winding

In this study the transformer used has 120 turns of coil in the primary; therefore, the

secondary winding turn is calculated as shown below:

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} \quad (3.13)$$

$$\frac{120}{N_2} = \frac{11000v}{430v}$$

$$N_2 = 5 \text{ turns}$$

From the above calculation that understand the transformer has a turn ratio of 120:5=11000:43

3.4.2. Primary current calculation

The transformer used is a step-down transformer (11000VAC:430VAC). It is known that a transformer with fewer turns in the secondary than in the primary would step down the voltage but would step up the current. The below calculation will verify

$$\frac{N_1}{N_2} = \frac{I_2}{I_1} \quad (3.14)$$

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} \quad (3.15)$$

$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{1100}{43} = \frac{168.03}{I_1} = I_1 = 6.57A$$

The above calculation shows that the step-down transformer has stepped up the primary current from 6.57 to 168.03A at the secondary.

3.4.3. Analysis of voltage protection circuit

Overvoltage protection is a power supply feature that shuts down the supply or clamps the output when the voltage exceeds a preset level. Most power supplies use an over-voltage protection circuit to prevent damage to the electronic components. The impact of an over-voltage condition varies from one circuit to the other and ranges from damaging

the components to degrading the components and causing circuit malfunctions or firing.

The over-voltage and under-voltage protection circuit is capable of measuring and monitoring voltage from 410 to 440VAC. Whenever the primary voltage of the transformer is adjusted, the secondary voltage also changes, and based on the fuzzy logic controller the input voltage can be monitored, display and the transformer can be protected from any over-voltage fault.

3.4.4. Transformer secondary winding turns calculation

The 11000VAC primary and 430VAC secondary transformer used has 120 turns of coil in the primary; therefore, the secondary winding turn is calculated as shown below:

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{120}{N_2} = \frac{11000v}{430v} \quad (3.16)$$

$$N_2 = \frac{11000}{340} = 4.69 \approx 5 \text{turns}$$

This shows that the transformer has a turn ratio of 120:5=1100:43

3.4.5. Transformer primary current calculation

The transformer used is a step-down transformer (11000VAC:430VAC). It is known that a transformer with fewer turns in the secondary than in the primary would step down the voltage but would step up the current. The below calculation will verify that;

$$\frac{N_1}{N_2} = \frac{I_2}{I_1} \quad (3.17)$$

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} \quad (3.18)$$

$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{1100}{43} = \frac{84.02}{I_1} = I_1 = 3.28A$$

The above calculation shows that the step-down transformer has stepped up the primary current from 3.28A to 67.21A at the secondary. Verification of the sine wave characteristics displayed on the oscilloscope. Calculating voltage peak to peak yield

$$V_{pp} = V_{\max} - V_{\min} \quad (3.19)$$

$$V_{pp} = (304.2 - (-303.8))v = 608v$$

Calculating Vrms results in

$$V_{rms} = \frac{V_p}{\sqrt{2}} = \frac{608v}{\sqrt{2}} = 430v \quad (3.20)$$

$$V_p = \frac{V_{pp}}{2} \quad (3.21)$$

$$T = \frac{1}{F} = \frac{1}{50Hz} = 20ms, F=50Hz \quad (3.22)$$

3.5. Modelling of fuzzy logic-based protective relay

The Fuzzy logic interface is used to make decisions. Relaying is a subdivision of power system protection engineering that is interested in determining abnormal operating conditions and obtaining corrective events for power system protection. Since human interference in the power system is not possible when a fault occurs, a fast response has the most important role in protective relay systems. Thus it is more precise than conventional relaying techniques, To protect transformers from overload conditions(Chaitanya et al., 2018). The Fuzzy logic inference system (FIS) was an intelligent tool to manage the loading condition. The proposed fuzzy logic-based input and output was defined as:

T_{1L} represents a load of transformer one.

T_{2L} represents the load of transformer two

Change in output Power

3.6. Circuit Breaker Size Calculation for Three-Phase Supply

To find the breaker size for the three-phase supply voltage, we must know the exact kind of load as there are many factors affecting the load current. In other words, the same rule won't apply to the different types of loads i.e., light, motor, inductive or capacitive load as the motor takes initially a very high current during the starting process as well as power factor involvement(Kaur & Singh, 2016). Let's find the correct size of the circuit breaker for three-phase circuits as follow.

For transformer one the maximum load power is 100kW for 430v, the size of the circuit breaker can be determined by;

$$P = \sqrt{3}VI \quad (3.23)$$

$$\text{Current, } I = \frac{P}{V\sqrt{3}} \quad (3.24)$$

$$\text{Current, } I = \frac{100,000W}{430v \times \sqrt{3}} = 134.43A$$

For safety usually, the recommended size of the circuit breaker is 1.25 multiplied with the current determined from the three-phase load power and voltage.

The recommended current will be, $I = 1.25 \times 134.43A = 168.04A$. The next closest standard of the circuit breaker is 200A.

For transformer two the maximum load power is 50kW for 430v, the size of the circuit breaker can be determined by;

Applying Equation (3.22);

$$\text{Current, } I = \frac{50,000W}{430v \times \sqrt{3}} = 67.21A$$

For safety, the recommended current will be, $I = 1.25 \times 67.21A = 84.01A$. The next closest standard of the circuit breaker is 100A

CHAPTER FOUR

CONTROLLER DESIGN

From the previous chapter, automatic load sharing refers provides sufficient protection to the distribution transformer under overloaded conditions. This thesis used the fuzzy logic technique to determine the condition monitoring and protection of the transformer. This chapter will discuss the basics of fuzzy logic, how fuzzy logic is used for automatic load sharing, and steps to monitor and control load sharing. In this work fuzzy logic is applied to Roger's IEC-599; as it is the most popular method, which dissolved gases in the insulating oil are analyses through gas chromatography and ratios ($R1=CH_4/H_2$, $R2=C_2H_2/C_2H_4$, $R3 =C_2H_2/CH_4$,) are calculated for the purpose of detecting of two different kinds of incipient faults: electrical and thermal faults, whereby each type of failure can be subdivided into different categories ,So in this work construct an expert system that measures the level of dissolved gases and suggests weather the power transformer is normal or faulty, and if it was faulty what might be responsible for the accumulation of these gases. The system developed show that the obtained results are satisfactory.

4.1. Design of a Fuzzy Information System (FIS)

This section is intended to design a fuzzy logic-controlled for the Tatek Transformer Factory system. The concept of fuzzy logic was first introduced in 1965 by computer scientist Lotfy Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership (Luo et al., 2018). He argued that human thinking is often fuzzy, vague, or imprecise, and, therefore cannot be represented by yes (1) or no (0). Fuzzy logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Its approach to controlling problems mimics how a person would make decisions, much faster. Fuzzy logic incorporates a simple, rule-based if "X and Y then Z" approaches to a solving control problem rather than attempting to model a system mathematically. The FL model is experimentally-based, relying on an operator's experience rather than their technical understanding of the system. Fuzzy Logic is a

form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges in degrees between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Fuzzy controllers are consisting of an input stage, a processing stage, and an output stage. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. There is much software available in the market that is capable of designing such systems, but this thesis used MATLAB fuzzy logic toolbox. Fuzzy controllers apply decision rules (if-then rules) by making use of critical variables to interpolate the output between the crisp boundaries (Eyoh et al., 2018).

In the standard set, an element either belongs to or does not belong to a set $\{0, 1\}$. In contrast, the fuzzy set enables the description of concepts where the boundary is not explicit $[0, 1]$. The elements in Fuzzy set are allotted a degree of membership. A membership function (MF) is a curve that defines how each point in the input space is allotted a degree of membership between 0 and 1. Different membership functions such as triangular, trapezoidal and Gaussian curves are available (Rahman et al., 2018). A chosen fuzzy inference system (FIS) is responsible for drawing conclusions from the knowledge-based fuzzy rule set of if-then linguistic statements. Each linguistic value is characterized by a label and a meaning. Table 4.1. data is taken from (Luo et al., 2018). The above linguistic variables are just a representation of the knowledge. And fuzzy set theory is used to manipulate those variables.

Table 4.1 Meaning of Typical Linguistic Terms in Fuzzy Logic

Linguistic term	Meaning
S	Small
M	Medium
L	Large
NS	Not Share
S	Share
Tp	Trip

2.8.1. Process of fuzzy logic controller

In fuzzy controllers, there are two most commonly used fuzzy inference methods namely, Mamdani and Takagi-Sugeno-Kang (TSK). In most cases the Mamdani fuzzy model is more intuitive and suitable for handling linguistic inputs; its outputs are usually fuzzy sets, and thus, a defuzzification process is often required. In contrast, the TSK inference approach produces crisp outputs directly, as TSK fuzzy rules use polynomials as rule consequences (Chen et al., 2021). The design process is.

- Identify controller Inputs and Outputs as the Fuzzy variables.
- Partition Inputs and Outputs into several Fuzzy Sets and label them according to the problem to be solved.
- Assign or determine a membership function (MF) for each fuzzy set.
- Choose appropriate scaling factors for the input and output variables to normalize to the [0, 1] interval range.
- Fuzzily the inputs
- Develop the fuzzy IF-THEN rules to solve the problem.
- Choose the Inference engine.
- Aggregate the fuzzy outputs of each rule.
- Choose a defuzzification method

A fuzzy logic controller is a type of controller which doesn't require an accurate dynamic model of the system and thus it is less sensitive to model uncertainty. It can handle non- linearity as well. Due to the lack of precise modeling of protection of

transformers modules and uncertainty in the performance of transformers systems due to the varying oil of transformer and temperature, fuzzy tracking is found to be more suitable for monitoring and protection of automatic load sharing of power transformer. This controller can deal with uncertainties like unmodeled physical quantities, non-linearity, and unpredictable changes in the operating point of the protection of transformer system(Controllers & Kang, n.d 2020.). Fuzzy-based switching controller is a functional method that can formulate logical decisions based on fuzzy concepts and transform the fuzzy rules by employing fuzzy implications into the fuzzy linguistic output.

In fuzzy controllers, there are two most commonly used fuzzy inference methods namely, Mamdani and Takagi-Sugeno-Kang (TSK). In most cases, the Sugeno model is more stable than the Mamdani model. It is also more robust than Mamdani in dealing with the minimum number of errors under the state of uncertainties. Most of the experimental analyses done by different researchers show that the Sugeno model is not affected by the noise (errors) as much as the Mamdani model. Another advantage of a Sugeno type is that its consequents can have as many input parameters per rule. This allows more flexibility for developers to design Sugeno-based FIS.

The fuzzy controller has three stages namely fuzzification, rule inference/evaluation, and defuzzification.(Brier & Lia dwi Jayanti, 2020). Fuzzy-based controller is a functional method that can formulate logical decisions based on fuzzy concepts and transform the fuzzy rules by employing fuzzy implications into the fuzzy linguistic output. Input data from the external world is processed by the fuzzy inference engine to produce the data to be used back in the external world. The stages of FLC are given in Figure 4.1 shown below.

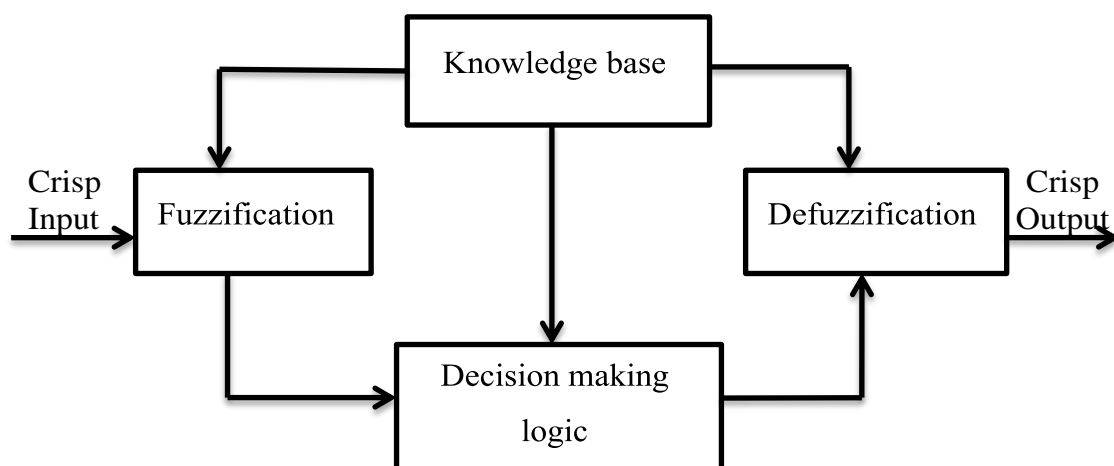


Figure 4.1 Structure of Mamdani-type fuzzy information system

The **fuzzification** step includes taking the crisp input, such as the change in the load current reading, and combining it with the stored membership function to get the fuzzy inputs. The membership function should be assigned for each input in order to transform the crisp inputs into fuzzy inputs. After the membership function is assigned fuzzification takes a real-time input and compares it with the stored membership function information to produce fuzzy input values.

In the rule evaluation, the fuzzy processor uses linguistic rules to determine the action to be taken in response to a given set of input values. The output of the rule evaluation is a fuzzy output for each type of consequent action.

The final step in fuzzy logic processing is **defuzzification** in which the expected value of an output variable is derived by isolating a crisp value in the universe of discourse of the output fuzzy sets. In this process, all of the fuzzy output values effectively modify their respe(Brier & Lia dwi Jayanti, 2020).

Centroid of gravity: $COA =$

$${}^zCOA = \frac{\int_z \mu_A(z)zdz}{\int_z \mu_A(z)dz} \quad (4.1)$$

Where $\mu_A = \pi r^2$ $\mu_A(z)$ is the aggregated output membership function? This is the most widely adopted defuzzification strategy, which is reminiscent of the calculation of expected values of probability distributions ctive output membership function. The flow chart of the fuzzy logic-based switching logic fuzzy controller is given in Figure 4.2 below.

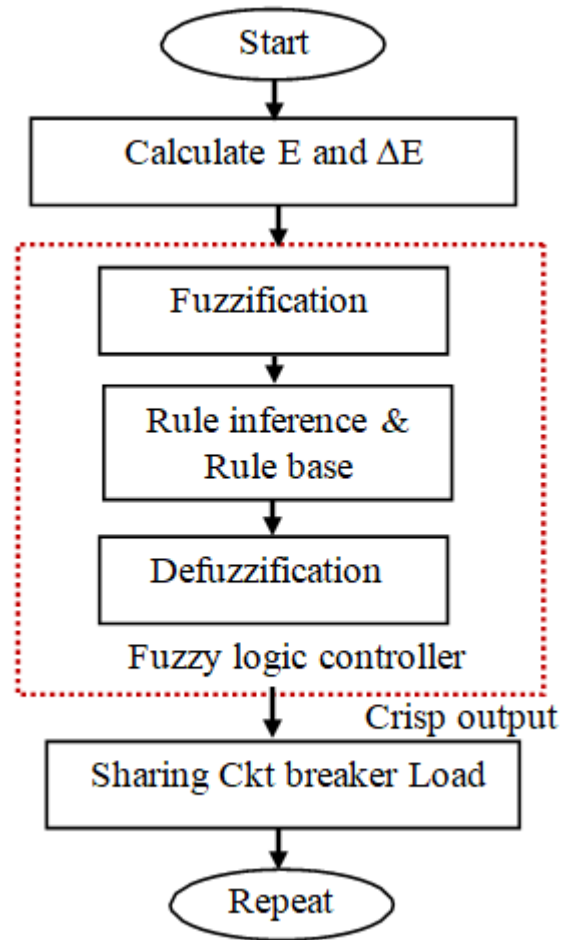


Figure 4.2 Flow chart fuzzy logic-based overload protection system

4.2. FLC System model and the proposed method

The proposed fuzzy logic-based switching logic controller has a subdivision of automatic load-sharing power transformer system protection engineering that is interested in determining abnormal operating conditions and obtaining corrective actions for load-sharing system protection. Since human interference in the power system is not possible when a fault occurs, a fast response has the most important role in protective systems. The Fuzzy Logic Controller is used to control the power generated by a three-phase source, Parallel transformer source, and three-phase load. Depending on the load demand and available power, the controller selects an individual source or combination of sources that will meet the load demand. Triangular membership functions for Justification, Mamdani inference system for rule processing, and centroid for De-fuzzy analysis and process by fuzzy logic are used. A typical fuzzy system

consists of membership functions, a rule base, an inference procedure, and a rule viewer which were explained in the following sections. After giving the membership function for each input-output linguistic value and generating the possible operational rules then the next step is to evaluate the rules of the controller for the input values if the output is appropriate or not.

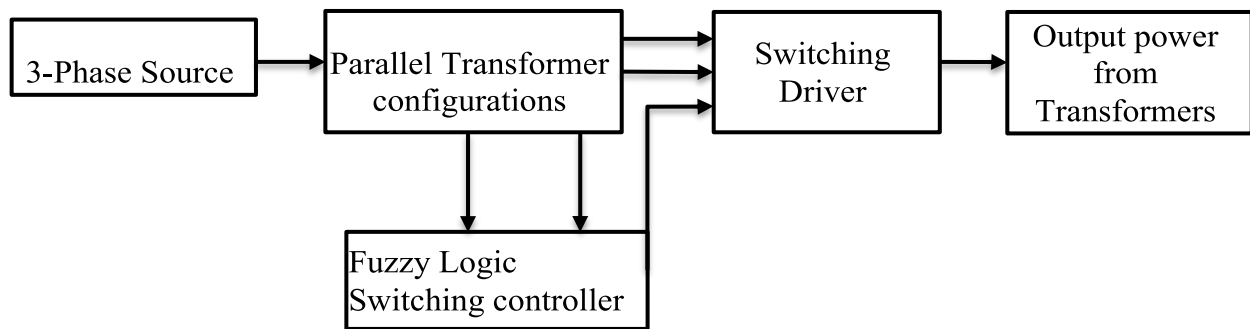


Figure 4.3 Fuzzy logic controller implementation

2.8.2. Fuzzy Inference Mechanism

To conclude a rule base needs a mechanism that can produce an output from a collection of IF-THEN rules. This is done using the computational rule of inference. The Inference Mechanism provides the mechanism for referring to the rule base such that the appropriate rules are fired. Two types of fuzzy inference systems can be implemented on MATLAB Fuzzy Logic Toolbox: Mamdani type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined. The two most commonly used inference procedures in FLC are Mamdani's Max-Min and Max-Algebraic Product (or Max-Dot) composition. The inference or firing with this fuzzy relation is performed via the operations between the fuzzified crisp input and the fuzzy relation representing the meaning of the overall set of rules. As a result of the composition, one obtains the fuzzy set describing the fuzzy value of the overall control output. In this thesis, Mamdani's max-min composition inference method is used. Typing fuzzy on the MATLAB window starts the FIS editor. Now in this system, the input is named T1L and T2L to indicate the input load for each phase, and the output is named Change output to calculate the total change of load for each phase. The first step is to provide input and output in the FIS editor and save the system with an appropriate

name. Here, I have given the name Overload Protection. It is shown in Figure 4.7 below.

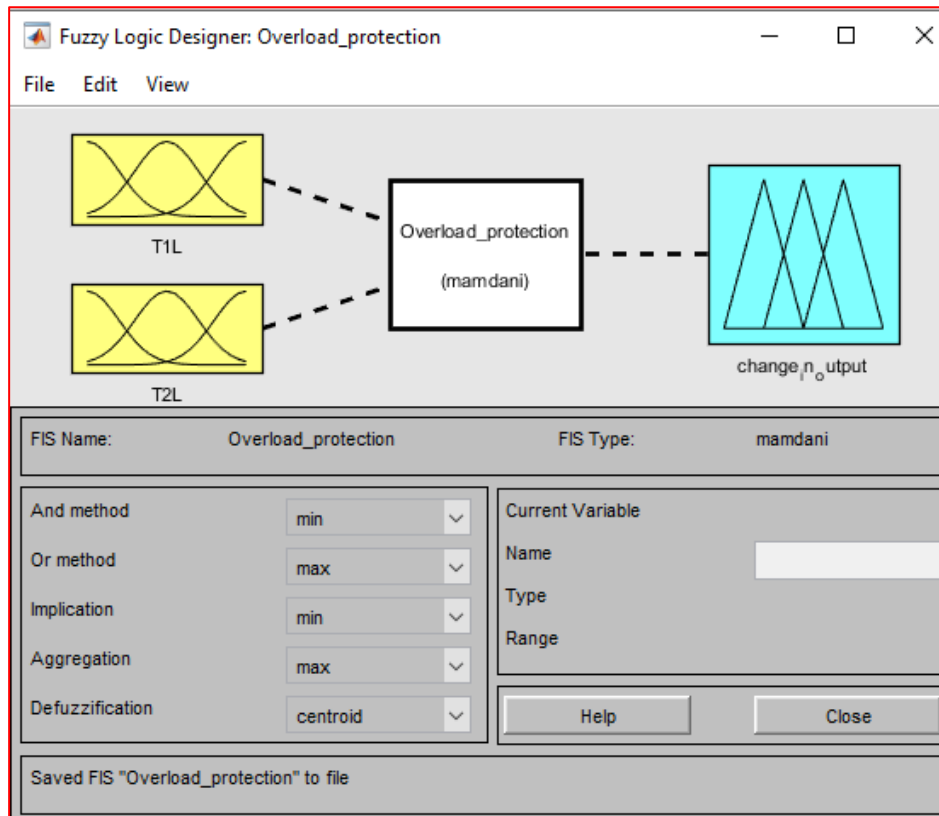


Figure 4.4 Fuzzy logic interface model

The FLC has 2 inputs named T_{1L} and T_{2L} . FLC has one output which is a signal for activating switches such as a Change in output (KW). All inputs have 3 triangular membership functions namely, small, Medium, and large (S, M, and L) as shown.

2.8.3. Membership functions of input-output variable

The fuzzy membership function is the graphical way of visualizing the degree of membership of any value in a given fuzzy set. Fuzzy membership function is used to convert the crisp input provided to the fuzzy inference system. The input and output membership functions are designed based on the load conditions and parallel transformer operating conditions. The following load input variables are used for distinguishing each membership function. The membership function defined how the input is mapped to member values. Following are a few important points relating to the membership function

- Membership functions were first introduced in 1965 by Lofti A. Zadeh in his first research paper “fuzzy sets”.
- Membership functions characterize fuzziness (i.e., all the information in fuzzy set), whether the elements in fuzzy sets are discrete or continuous.
- Membership functions can be defined as a technique to solve practical problems by experience rather than knowledge.
- Membership functions are represented by graphical forms.
- Rules for defining fuzziness are fuzzy too.

2.8.3.1. Triangular membership function

Triangular Membership Function (MF) is one of the most encountered MF in practice because of its simplicity and it should be formed using straight lines. The selection of MF shape is problem specific (Azam et al., 2020). These straight-line membership functions have the advantage of simplicity. Triangular shapes represent fuzzy numbers, (Azam et al., 2020). Indeed, if one has no priority on the shape of MFs, triangular shapes are simple to implement and fast for computation.

In this thesis, a triangular-based membership function is applied for both input and output variables because Figure 4.5 represents a triangular membership function for a certain input and output. The selection of MF shape is problem specific. Triangular shapes represent fuzzy numbers, These are the simplest shapes (Azam et al., 2020). Indeed, if one has no priority on the shape of MFs, triangular or trapezoidal shapes are simple to implement and fast for computation.

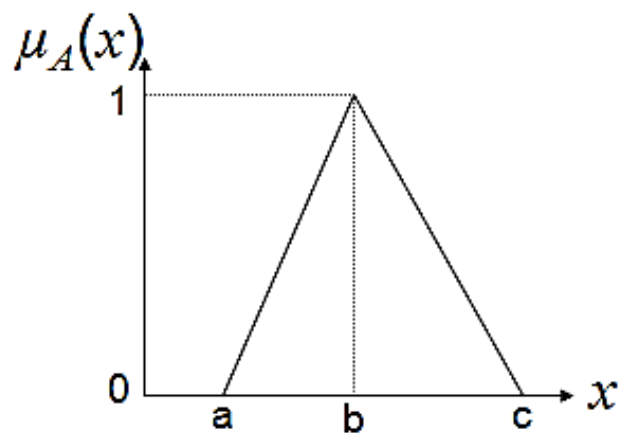


Figure 4.5. Triangular membership function structure

Where, a, b, and c represent the x-coordinate for a capital triangle, x represents the real value (Crisp Value) from the private variable fuzzy universe of discourse. Function outputs range between 0 and 1 and represent the value of the degree of membership of x. b has a value of 1 membership degree, increasing the membership degree of elements located between a and b closer to the element of b, while the elements located between b and c are considerably less degree its membership slowly closer to the element of c. Equation (4.2) explains the evaluation of the given membership function in Figure 4.5

$$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{x-a}{b-a} & \text{if } a \leq x \leq b \\ \frac{c-x}{c-b} & \text{if } b \leq x \leq c \\ 0 & \text{if } x \geq c \end{cases} \quad (4.2.)$$

The final operation of the triangular membership function of any fuzzy model can be determined as follows in Equation (4.2);

$$\text{trimf}(x; a, b, c) = \max(\min(\frac{x-a}{b-a}, \frac{c-x}{c-b}), 0) \quad (4.3.)$$

Now the next step is to define the range of inputs. So to provide fuzzy membership functions, and simply represent input logic; it could be divided ranges in different regions shown in Table 4.2 below.

Table 4.2 Ranges for Input Load Variable

Input and Output load Description	Fuzzy logic Linguistic term	KW Rang
Small	S	0 to 140
Medium	M	70 to 200
Large	L	170 to 315

2.8.4. Fuzzy partition of input variables

FLC-based Monitoring and Protection system for automatic load sharing power transformer technique can be formulated with different options of input/output parameters of the system. The input parameters can be an error (E) and change in error (ΔE or E) with the output of change in power (ΔP). The equations that represent the input and outputs are shown in Equations (4.4) and (4.5) respectively.

$$E(K) = \frac{T1(L)-T1(L-1)}{T2(L)-T2(L-1)} \quad (4.4)$$

$$\Delta E(K) = E(K) - E(K - 1) \quad (4.5)$$

Thus, knowing the exact input ranges are difficult. In order to cope with this difficulty, the inputs should be between 0 and 315 with scaling factors both at the inputs and output. However, finding the scaling factors manually is tedious. In order to determine the optimal values of the scaling factors, an optimization algorithm is required. In this study, the range of the two inputs are considered as between 0 and 315, and three membership function which is small (0 to 140), medium (70 to 200), large (170 to 315), are selected for these inputs. The membership functions are implemented using the fuzzy logic toolbox in MATLAB/Simulink.

Now when any system goes above its defined limits, it is considered overloaded. Here also above 315 loads, the system is considered overloaded. And no system can handle double loads than defined. So once the system goes over 315 loads, the entire system should be cut off to prevent system damage.

T_{1L} represents the membership function load of transformer one (additional file from Figure 4.6). It consists of small , large , and medium.

T_{2L} represents the membership function load of transformer Two (additional file from figure 4.7). It consists of small, large , and medium.

The output power was membership functions of the proposed control system (Additional file from Figure 4.10). The output linguistic values were not shared, share, and trip

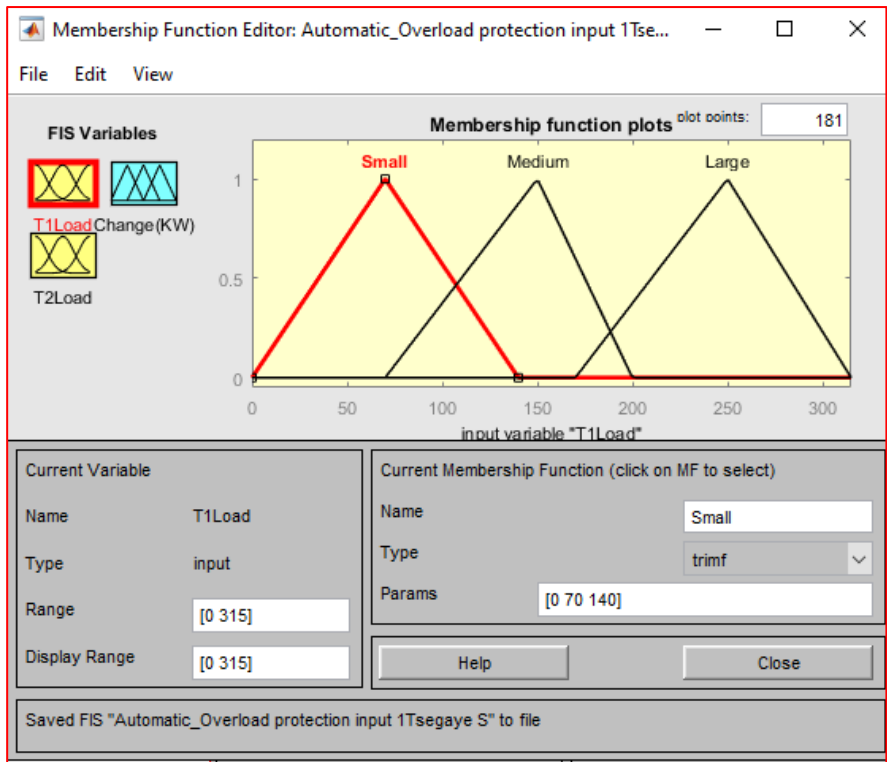


Figure 4.6 Membership functions of transformers load one input variable E

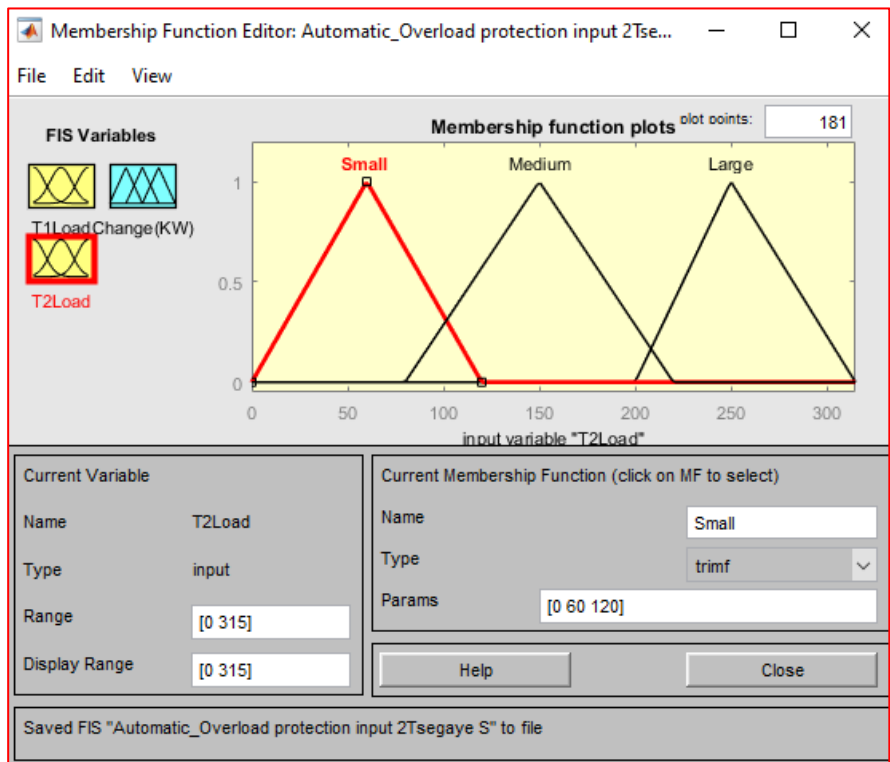


Figure 4.7 Membership functions of transformers load two inputs variable ΔE

The input membership function design for the proposed FLC is shown in the following Figures 4.6 and 4.7. Hence, two inputs which are error and change of error are considered and their results are shown based on their range and degree of membership.

2.8.5. Knowledge-Based / Rule Based

The knowledge base is the core part of the FLC. It defines all relevant parameters and the control rules of the system, and mainly consists of two parts. The first one is the database which provides necessary information for the proper functioning of fuzzification and rule base. It includes the fuzzy sets that represent the meaning of linguistic values of input and output variables and physical domain and their normalized counterparts together with scaling factors. The other one is the rule base which is used to represent in a structured way in the form of if-then rules. These rules are generally defined based on the information obtained from the control system given by the experts.

Its output is a mathematical weight function in terms of these two inputs. In this study, the fuzzy rules of the proposed system have been derived from the system behavior and tests carried out in Simulink. The fuzzy rule base is shown in Table 4.3.

Table 4.3 Rule base of transformer load

<i>E</i>	ΔE		
	Small	Medium	large
Small	Not share	Not share	Share
Medium	Not share	Not share	Share
large	Share	Share	Trip

Nine rules are considered for better accuracy and dynamic response. The different operating conditions are considered in order to improve protection performance in terms of automatic load sharing. The following is a general expression of the fuzzy rule based on the error (*E*), change error (ΔE), and the output power (ΔP).

$$\text{If } E \text{ is Small and } \Delta E \text{ is large then } \Delta P = f(E, \Delta E)$$

where small and large in the antecedent are fuzzy sets and $f(E, \Delta E)$ in the consequent is

a crisp function. In this study, $f(E, \Delta E)$ is expressed by Note share, share and Trip where their values are 200,500 and 630 respectively.

Some of the rules are shown below and the overall rules of the proposed FLC are shown in figure 4.9.

R1: If E is small and ΔE is small then $\Delta P = \text{Note share}$

R2: If E is small and ΔE is medium then $\Delta P = \text{Note share}$

Here is the model of the FIS having two inputs and one output. In the control box, a set of rules have been written. The system was operated per the rules sets. The following Figure 4.9 shows the fuzzy logic rules and operation of the system in different operating conditions.

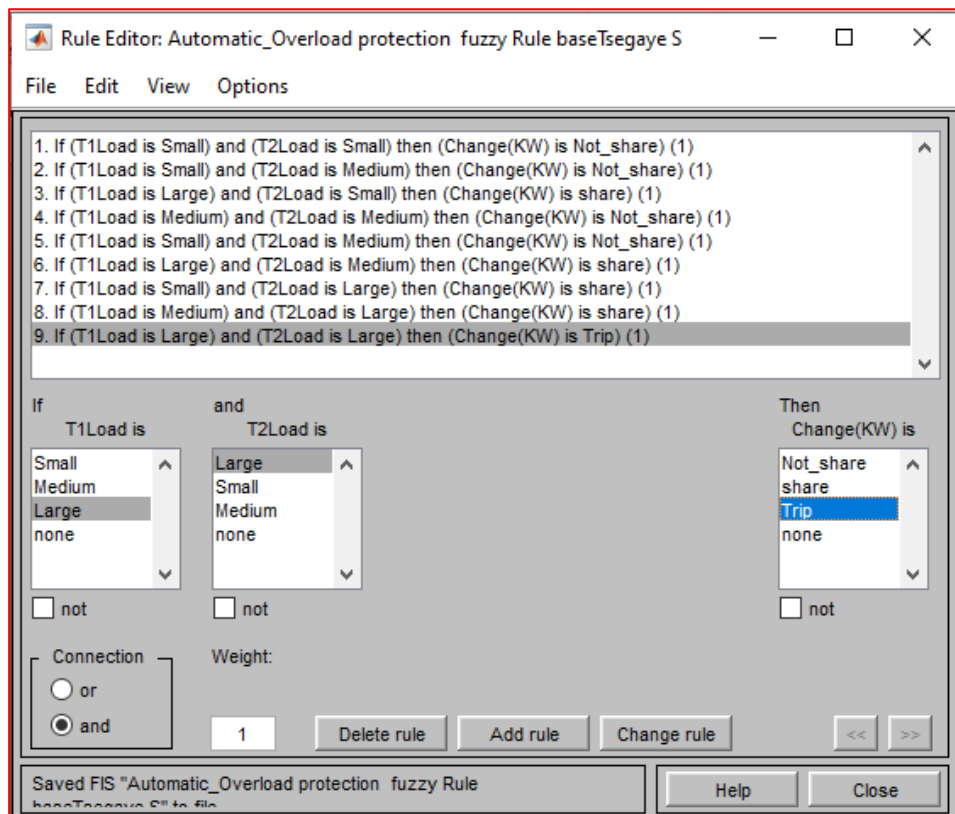


Figure 4.9 The fuzzy logic rules and operation

4.3. Condition Monitoring Technique of Power Transformers

Differential Protection is expected to play a key role in the protection system of power

transformer. Two of the most typical weaknesses of the power transformer differential protection are long delays or even a failure to operate in case of heavy internal faults with current transformer saturation, and unwanted operations for external faults. These disadvantages can be avoided if the position of the fault is quickly and correctly determined. The differential protection relay is used for power transformer differential protection and is capable of protection transformers of any vector group. Condition monitoring for transformers is the process of monitoring a parameter of conditions in transformer (moisture, temperature, pressure etc.), in order to identify a significant change which is indicative of a developing fault. Power transformers are critical and costly assets in the electric power system beginning with the grid, transmission, and down to the plant. They are one of the most important electric apparatus for providing reliable energy flow. This work did focuses on problem identification due to faults in power transformers during operation by using dissolved gas analysis such as key gas, IEC ratio, Duval triangle techniques, and fuzzy logic approaches. Then, the condition of the power transformer is evaluated in terms of the percentage of failure index and internal fault determination. Fuzzy logic with the key gas approach was used to calculate the failure index and identify problems inside the power transformer. The equipment's used in power transmission are very costly and the protection of all equipment's considered primarily. The Power Transformer is the most important equipment in power transmission. If any is considered under faulty condition then the whole system is not reliable and convenient. Benefits of Condition Monitoring for Power Transformer.

- Timely filled measurements
- Confirmation, on the spot, of the presence of the fault gases in the event of alarms.
- On time proactive decision making reducing unplanned outages
- More predictable and reliable maintenance schedules
- Reduced maintenance costs
- The case study results provide a quality control feature, limiting the probability of destructive failures

2.8.6. Proposed fuzzy logic method for DGA

In this thesis Sugeno fuzzy inference system is used for building model for DGA

diagnosis. In Sugeno fuzzy inference system crisp inputs are fuzzified using membership function. Fuzzified inputs are applied to fuzzy rule base. A typical fuzzy rule in a zero-order Sugeno fuzzy model is in the form;

If **X** is **A** and **Y** is **B** then **Z= k** Where A and B are fuzzy sets and k is crisply defined constant. When output of each rule is constant, all output membership functions are singleton spikes. The final output of the system is weighted average of all the rule output which is given as-

$$Output = \frac{\sum_{i=1}^N w_i z_i}{\sum_{i=1}^N w_i} \quad (4.4)$$

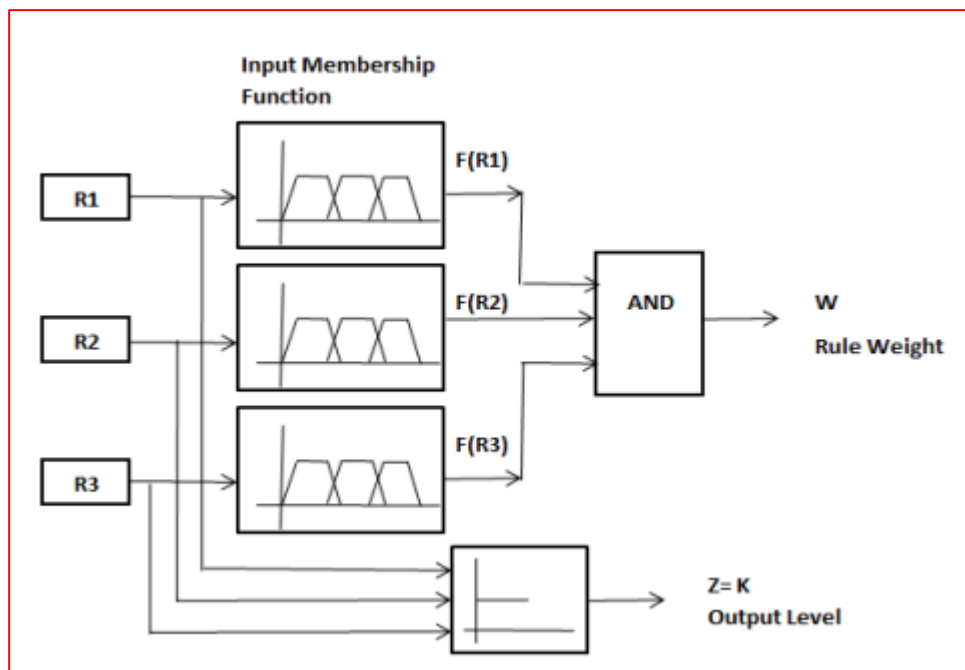


Fig.4.10 Sugeno model of fuzzy inference system

A suitable fuzzy logic system using Sugeno fuzzy logic model is proposed and used to analyse DGA results of power transformers.

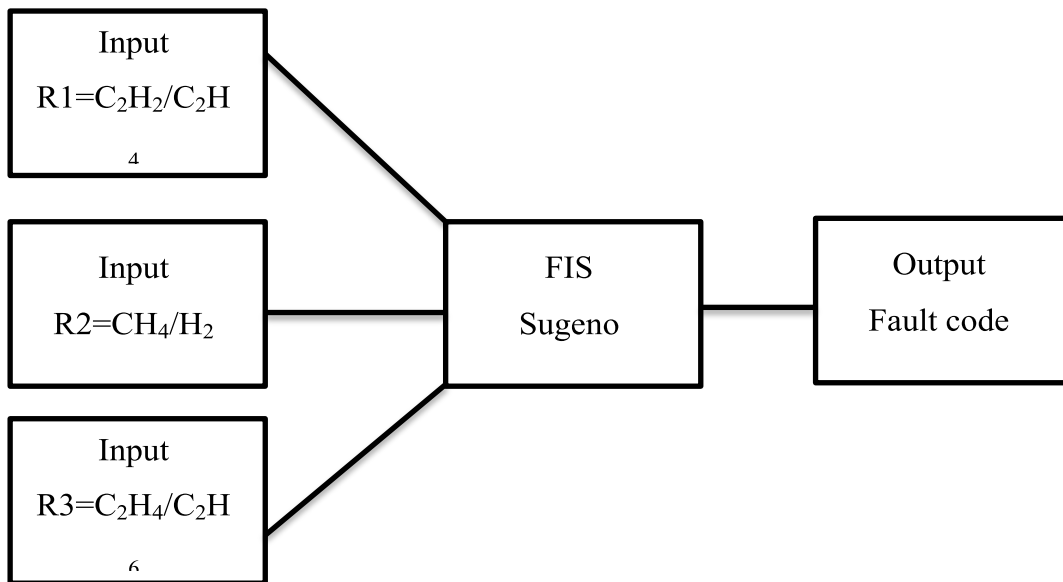


Fig.4.11a Proposed fuzzy inference system

Proposed model of Fuzzy Inference System (FIS) for DGA analysis is shown in Fig.4.11a. Development of fuzzy inference system for DGA interpretation involved following processes.

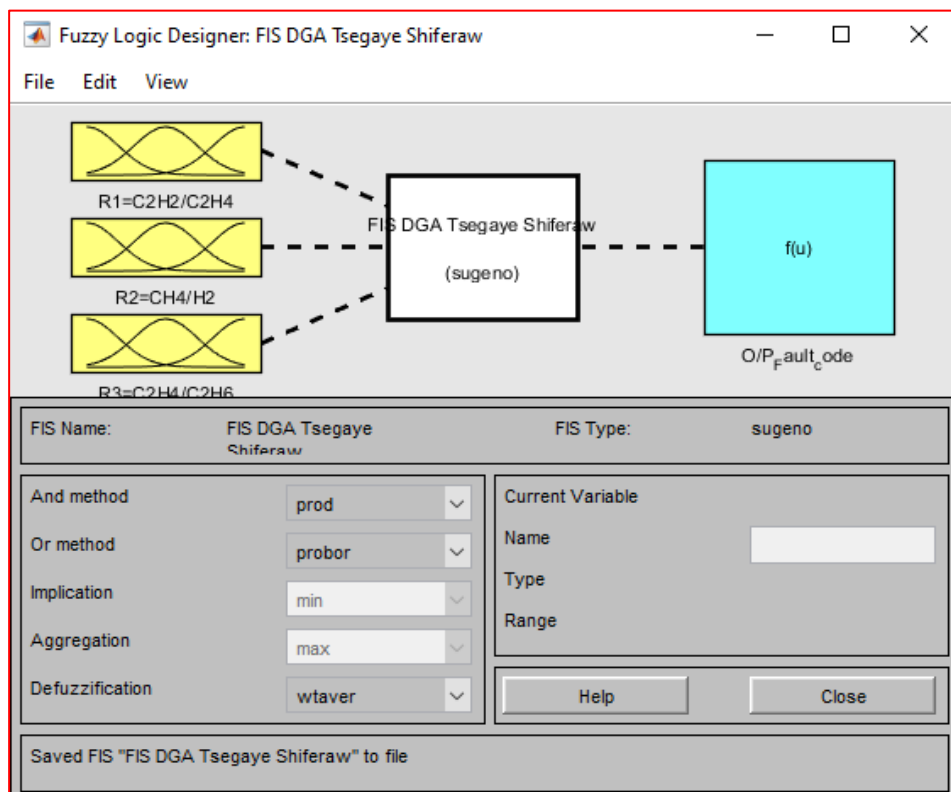


Fig.4.11b Proposed fuzzy inference system

2.8.7. Fuzzification of gas ratios

In fuzzification process gas ratios are crisp inputs, each crisp value of these gas ratios is fuzzified by considering error of $\pm 10\%$ as Low, Medium and High according to membership intervals defined in Table 4.4

Table 4.4. Fuzzy ratios for membership interval

Fuzzy Ratio	R1=C2H2/C2H4	R2=CH4/H2	R3=C2H4/C2H6
Low	$0.09 \leq R1 \leq 0.11$	$0.09 \leq R2 \leq 1.1$	$0.9 \leq Z \leq 1.1$
Medium	$0.09 \leq R1 \leq 3.3$	$0.09 \leq R2 \leq 0.11$	$0.09 \leq Z \leq 3.3$
High	$2.7 \geq R1$	$0.9 \leq R2 \leq 1.1$	$2.7 \leq Z \leq 3.3$

Fuzzy ratios Low, Medium and High are represented by trapezoidal membership functions for each ratio. The membership function applied is Gaussian membership functions for the inputs μ_{Co} and μ_{Vo} such that;

$$\mu(o) = \exp\left[-\frac{1}{2} \left(\frac{o_i - c_i}{a_i}\right)^2\right] \quad (4.5)$$

Where o_i is the i th input variable, c_i is the i th centre of the membership function, a_i is the constant related to the spread of the i th membership function. MATLAB software provides fuzzy logic toolbox for development of Sugeno type fuzzy inference system. By using this tool box proposed fuzzy inference system of DGA interpretation is developed. Figure 8 shows membership function for gas ratio C2H2 / C2H4, likewise trapezoidal membership functions for CH4 / H2 and C2H4/C2H6 gas ratios are defined. This is pictorially shown in MatLab GUI of figure. 4.12, figure 4.13 and figure 4.14

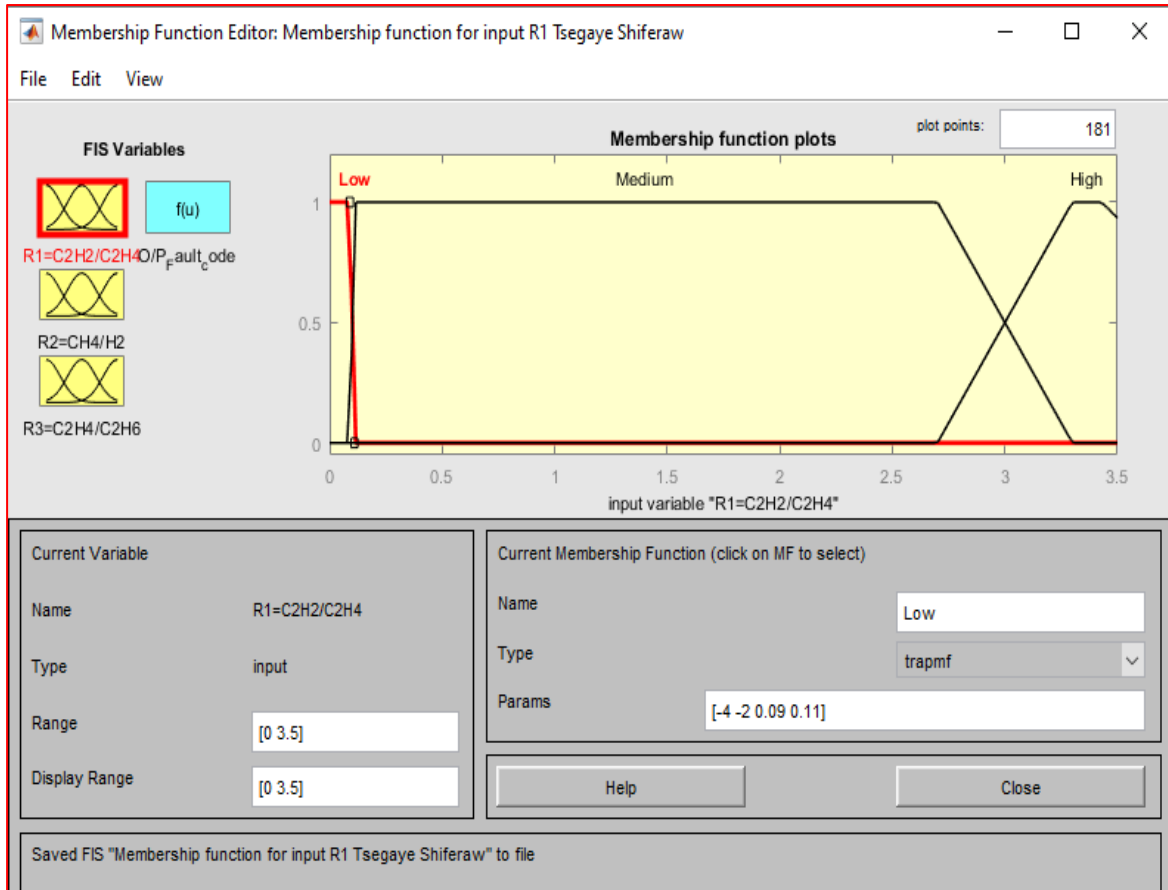


Fig.4.12 Membership function plot for ratio R1= C2H2 / C2H4

$$\mu(o) = \max \left[0.1 + \frac{O_i - C_i}{0.5\sigma_i} \right], \text{ if } O_i \leq C_i \text{ if otherwise} \quad (4.6)$$

$$\mu(o) = \max \left[0.1 + \frac{C_i - O_i}{0.5\sigma_i} \right], \text{ if } O_i \leq C_i \quad (4.7)$$

Low [-4 -2 0.09 0.11]

Medium [0.09 0.11 2.7 3.3]

High [2.7 3.3 3.43 4.49]

Output membership function have a constant value for each fault code as defined in table 4.6. Figure 9 shows membership function for output “fault code”.

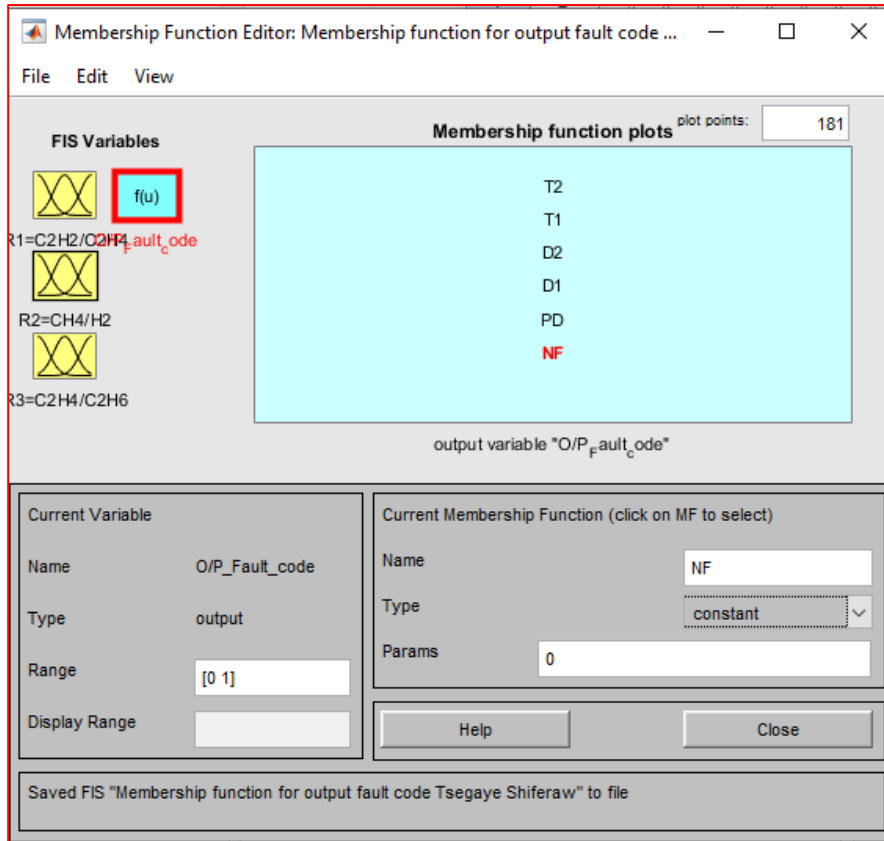


Figure.4.13 Membership function for output “Fault Code”

2.8.8. Fuzzy rule base

A fuzzy rule set having 8 rules defined by linguistic if-then statements is then used to form “judgment” on the fuzzy inputs derived from the three gas ratios. Output of each fuzzy rule is a constant and the solution is arrived by taking weighted average of outputs of fuzzy rules Table 4.5

Table 4.5 Fault Output fault code

Fault type	Fault Code	Fault Type
Overheating of temperature more than 700°C	5	T2
Overheating of temperature 150 °C to 700°C	4	T1
Discharge of high energy density	3	D2
Discharge of low energy density continuous sparking	2	D1
Partial Discharge	1	PD
Normal fault	0	NF

Based on IEC ratio fault detection, following fuzzy rule base is defined

- 1) If C_2H_2 / C_2H_4 is Medium and CH_4 / H_2 is not Medium Then fault is D2
- 2) If C_2H_2 / C_2H_4 is High and CH_4 / H_2 is not Medium Then fault is D2
- 3) If C_2H_2 / C_2H_4 is Medium and CH_4 / H_2 is Medium Then fault is D1

Like this such 8 fuzzy rules are defined.

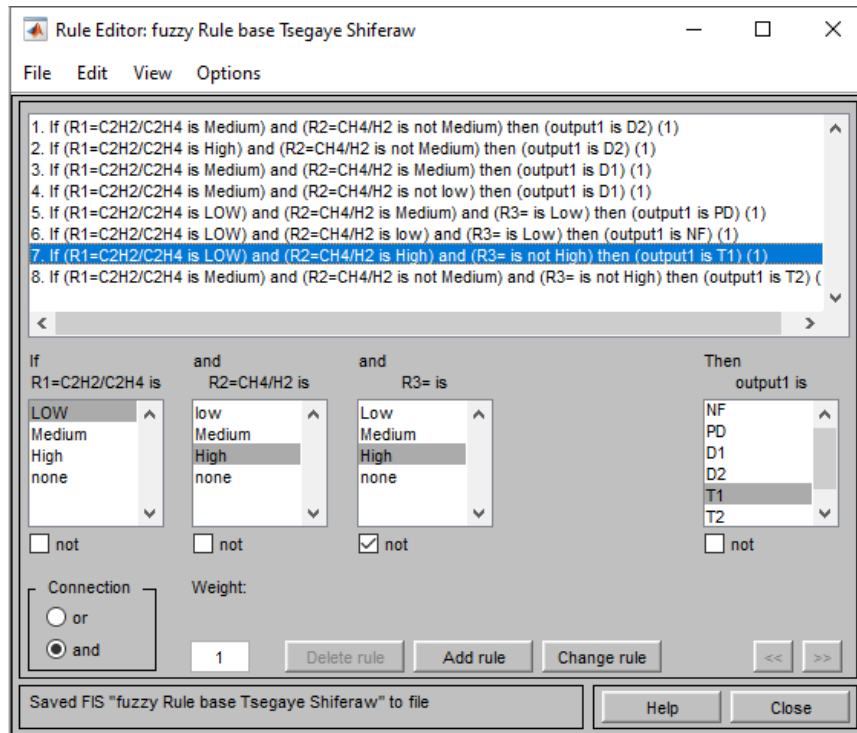


Figure.4.14 fuzzy rule base

2.8.9. IEC standard

According to IEC 60599 the extended Rogers method is used to produce a three digit code for fault determination. The code is determined based on three gas ratio C_2H_2/C_2H_4 , CH_4/H_2 and, C_2H_4/C_2H_6 as given in Table 4.6

Table 4.6 IEC Code determination criteria

Gas Ratio	Value	code
R1=C2H2/C2H4	X<0.1	0
	0.1<X<3	1
	X>3	2
R2=CH4/H2	Y<0.1	1
	0.1<Y<1	0
	Y>1	2
R3=C2H4/C2H6	Z<1	0
	1<Z<3	1
	Z>3	2

4.4. The overall fuzzy logic controller system

Transformer load 1 and transformer load 2 are the input parameters of the controller. The power coming from each component of power sources is assumed to Gaussian random signal generator. The multiport conditional switch will take action according to the rules written in the fuzzy logic controller. Overall, implementations of the fuzzy logic controller and switching driver modeling in MATLAB are shown in Figure 4.22 below

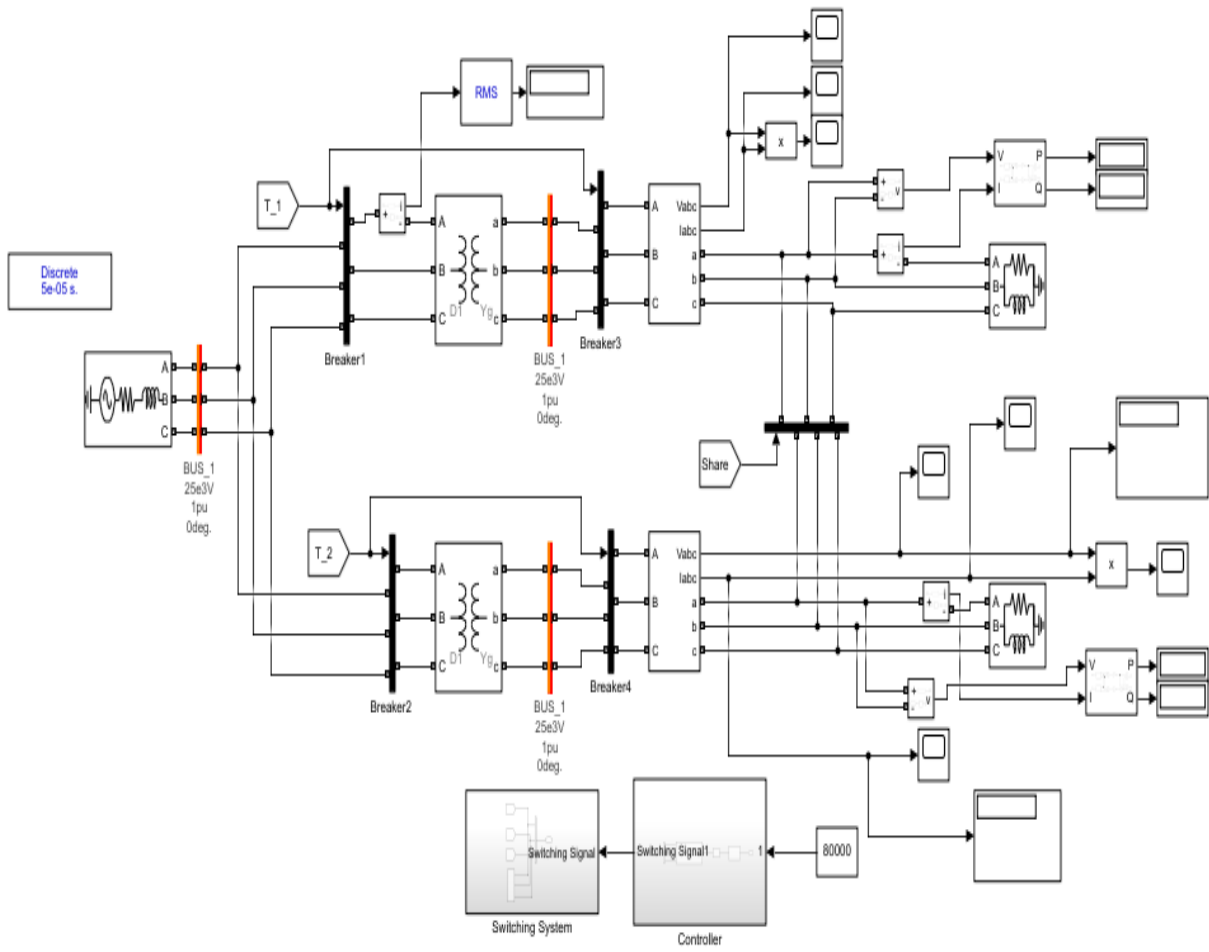


Figure 4.15 Overall protection systems for overloading protection interface

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1. Introduction

In this chapter the results of the design of a fuzzy logic-based (controlled) Monitoring and Protection System for an Automatic Load Sharing Power Transformer system are presented, discussion about the findings will be done at the end the conclusions from the findings and recommendations are made.

5.2. Result and discussin

The results for the monitoring and protection system for automatic load sharing are shown below. We can adjust the input load value by moving the red line shown in the figure 5.1 and can also apply the input value in the box named input.

The controller looks the load on transformer frst and made decisions (not share, share and trip) to protect transformers. Terefore, there was no equipment failure and power interruption due overloading conditions. In order to evaluate the performance of rule based load sharing system, three various types of loads were applied at the output of the distribution transformer. The output changes of the fuzzy logic are related to the input. For example, if the system is medium, changes should be such that the system again becomes perfectly loaded. So the output also should be divided into ranges the same as the input. It is shown in Table 4.3 above. The output switching variable membership function is shown in Figure 4.8. Its membership functions are designed based on the status of the input variable and the switching driver to the transformers. The following switching output variables are used for distinguishing each membership function. The trip is the switching logic during overload condition and both transformers are in OFF condition. T_{2L} is the switching logic during normal operation of T_{2L} and transformer-2 is in ON condition. T_{1L} is the switching logic during normal operation of T_{1L} and transformer-1 is in ON condition. $(T_{1L}+T_{2L})(Share)$ is the condition when the load is greater than each transformer then both transformers will be ON (in share condition). The trip is the condition when the load is greater than the combination of both transformers then both transformers will be OFF.

Table 5.1 Ranges for Output Load Variable

Output load Description	Fuzzy logic Linguistic term	KW Rang
Not Share	NS	0 to 315
Share	S	300 to 615
Trip	T	620 to 670

Case (I): The two transformers were at normal state. When the two transformers were at normal state, during this time the sharing relay was not energized because it feeds its load at normal state.

Case (II): when one of the transformers was overloaded. When one transformer was at normal state and another was overloaded, at this condition the sharing relay was energized to share the load.

Case (III): The two transformers were overloaded for each phase

When two transformers were overloaded, at this condition the relay will trip to protect transformers.

Table 5.2 Comparassion Result of Transformer Switching

Sample result	Voltage ratio	T _{1L} KW	T _{2L} KW	Change KW
1	400/220kv	172	170	184
2	400/220kv	82.4	176	169
3	400/220kv	270	168	470
4	400/220kv	221	176	485

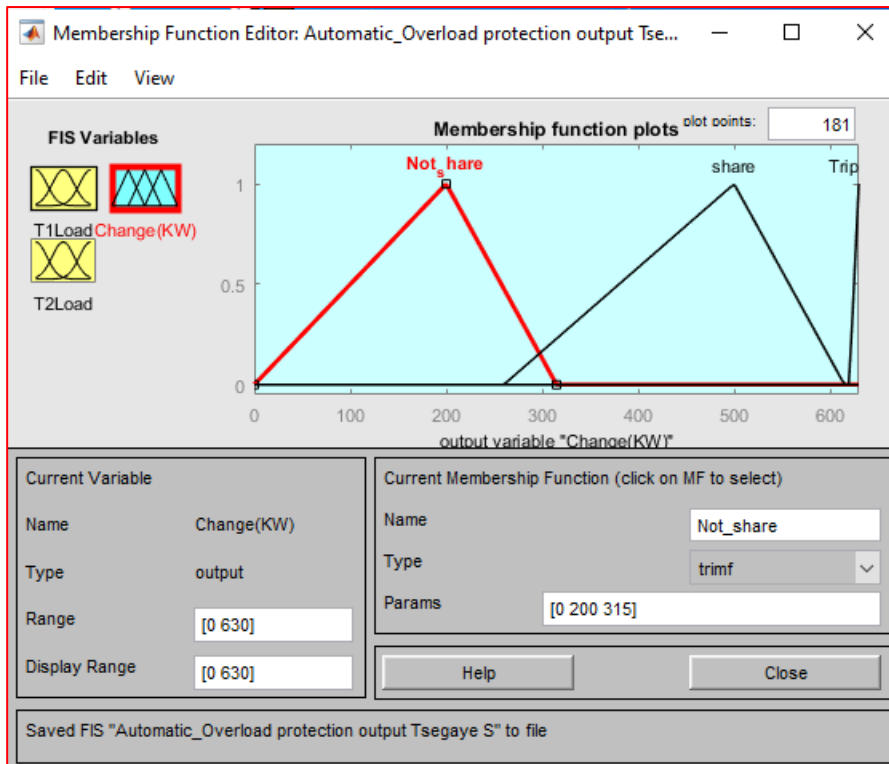


Figure 5.1 Membership functions of change in output power not share

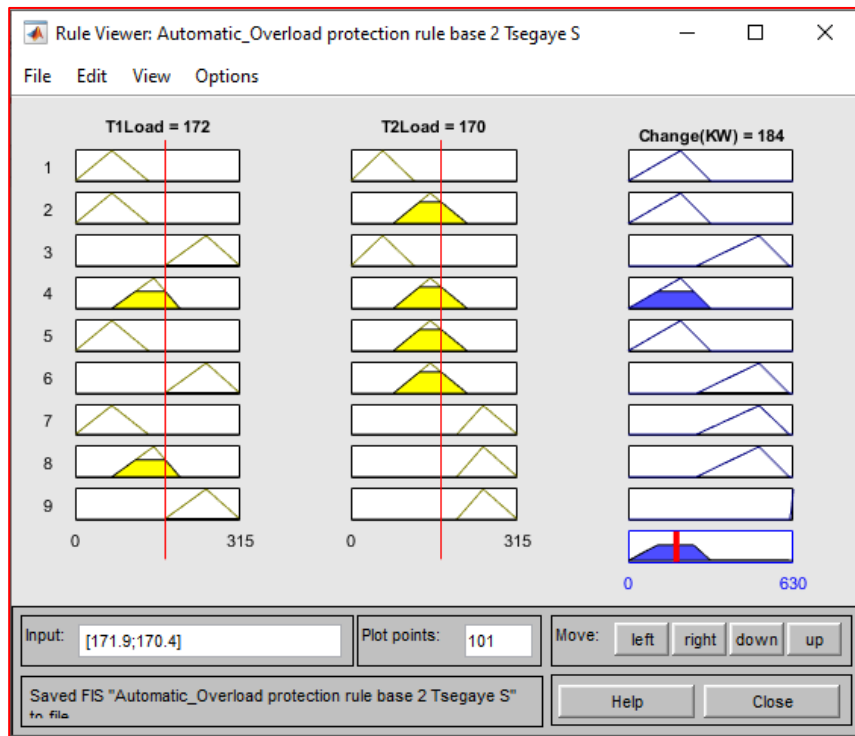


Figure 5.2 Rule evolution of the load at medium

Here in Figure 5.1, the total load is 270 kW. So it means the system is large (L). Now as the total load is 315, the change should be such that the total of the received load and current load is around 315 kW. It means the change must be positive and it has to be added to the actual load value. So, here change indicated from fuzzy logic is 480 kW. So the total system load goes to $270 \text{ kW} + 168 \text{ kW} = 438 \text{ kW}$. Hence, the system is balanced in this case. Now as per the control flow diagram, the control logic checks the system again and finds that it is balanced now. So no further action will be needed until.

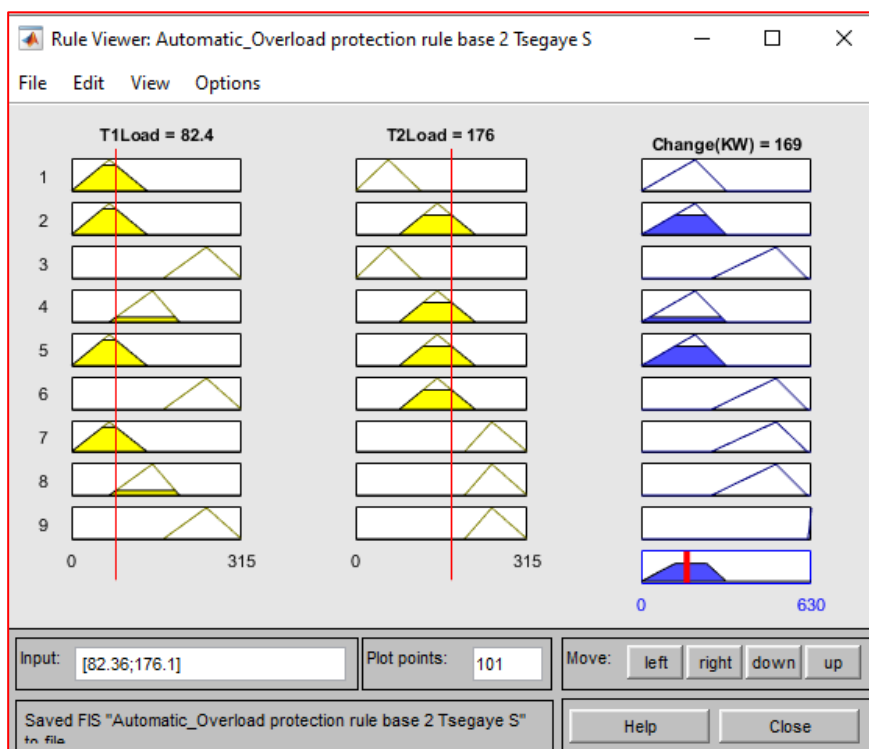


Figure 5.3 Rule evolution of the load at small and large

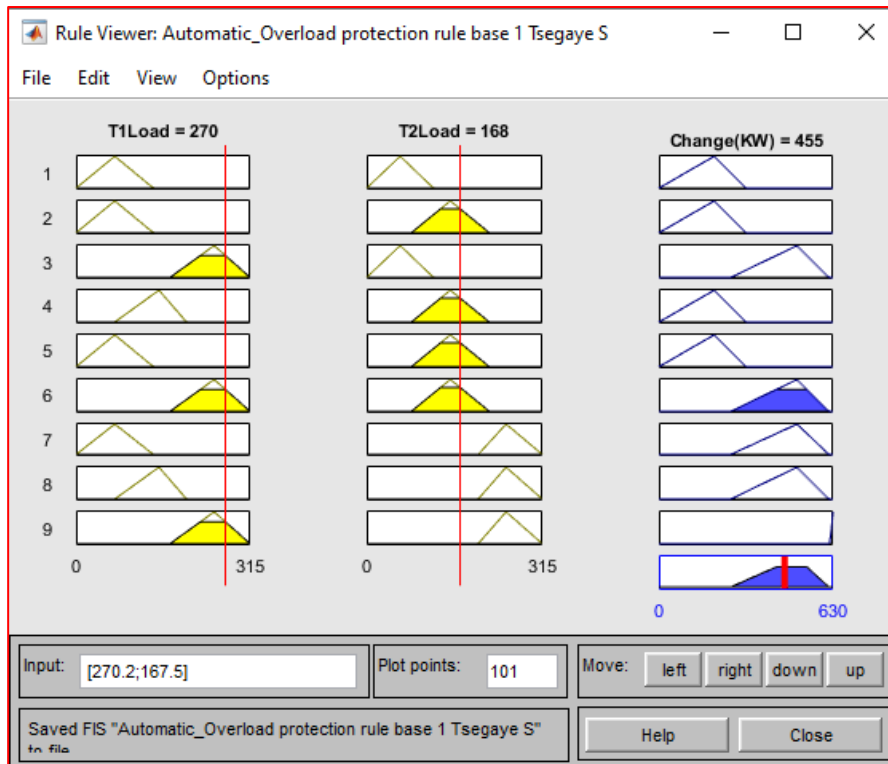


Figure 5.4 Rule evolution of the load at normal

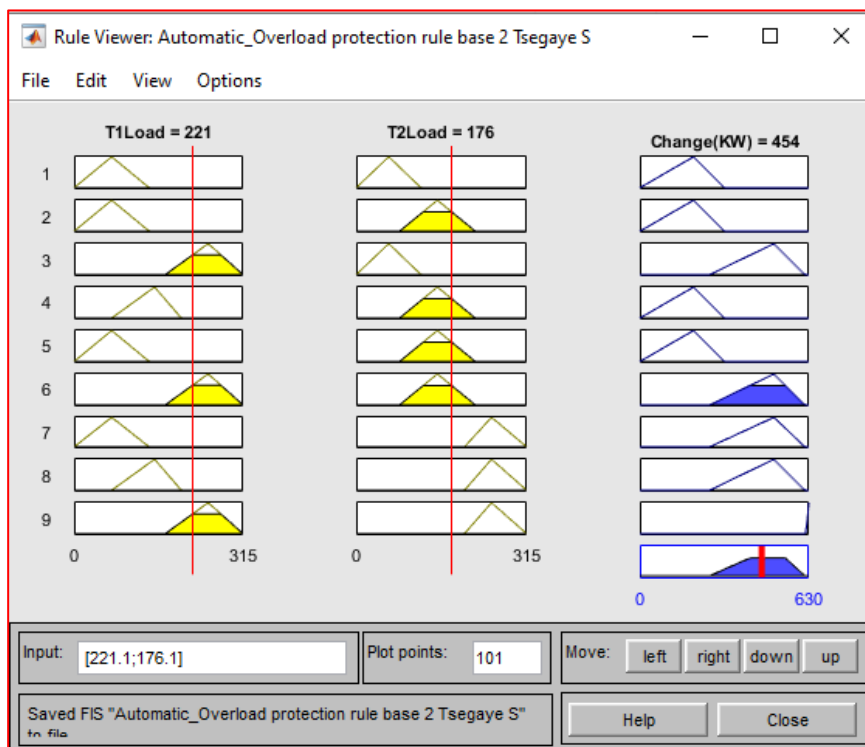


Figure 5.5 Rule evolution of the load at large and small

5.3. DGA Parameter Estimation Result

In this study, dissolved gas analysis was carried out by using the gas densities released as a result of failures in power transformers. As mentioned in *Chapter 4* IEC fuzzy logic systems have been applied to different ratings of transformer samples gas concentration values for failure analysis. Taking into account the limit values of the gases formed as a result of the fault, IEC methods are applied to the fuzzy logic, which is one of the smart systems, and the fault is evaluated and the results are tabulated. The Standard offers the existence of three ratio codes presented in Table 5.3 to diagnose

Table 5.3 Fault diagnosis

Transformer	Voltage ratio	R1	R2	R3	Output
315	400/220kv	0.024	0.73	0.29	0.043
315	400/220kv	0.696	0.325	2.45	0.759
315	400/220kv	0.417	1.01	0.139	0.5
315	400/220kv	0.0075	0.378	2.96	0.69



Figure 5.6 fault diagnosis

Table 5.4 GDA result

Code	$\frac{C2H2}{C2H4}$	$\frac{CH4}{H2}$	$\frac{C2H4}{C2H6}$	Suggested Fault diagnosis
0	0	0	0	Normal
1	1	0	1	Partial discharge of low energy
2	1	1	0	Partial discharge of high energy
3	1-2	0	1-2	Arcing-discharge of low energy
4	1	0	2	Arcing-discharge of high energy
5	0	0	1	Thermal fault (110°C...150°C)
6	0	2	0	Thermal fault (150°C...300°C)
7	0	2	1	Thermal fault (300°C...700°C)
8	0	2	2	Thermal fault (>700°C)

DGA results of 18 different oil samples are taken, and these values are applied to MATLAB Scripts that are programmed separately for Conventional IEC Three Ratio Method and Fuzzy Three Ratio Method and results are presented below. Whereas Fuzzy Three Ratio Method provides 4 fault which fails correct diagnosis, and one fault in which wrong multiple faults out of the 18 results hence provides 88.89 % Accuracy Therefore it shows that this proposed method is more appropriate.

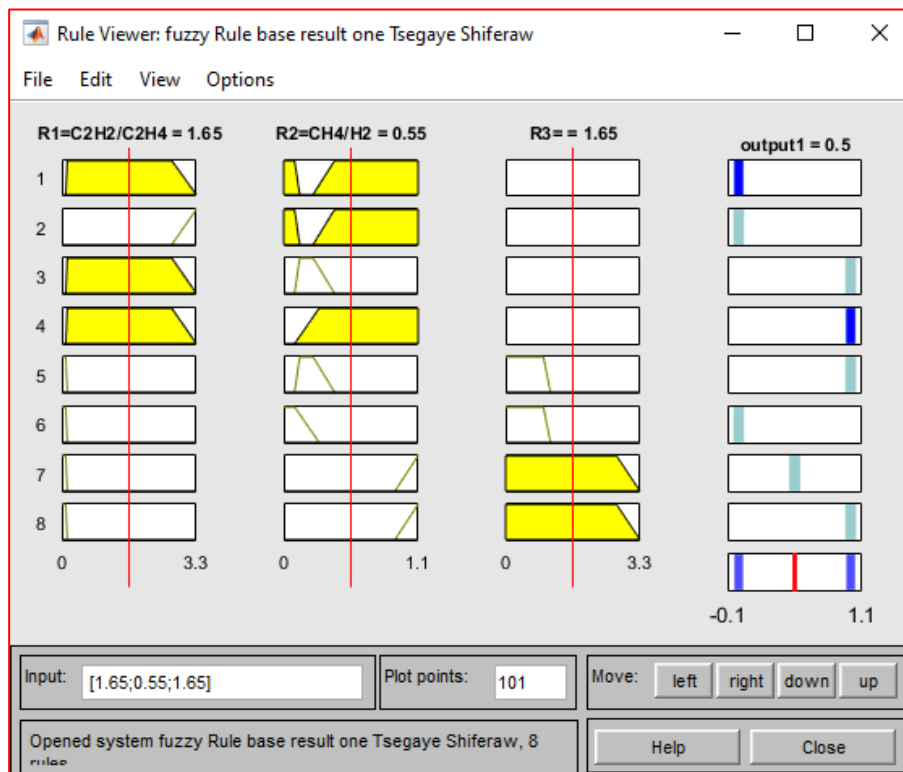


Figure 5.7 Graphical representation of rules

Table 5.5 Transformer Checking the Performance

Transformer MVA	Vo ratio	R1= C₂H₂/C₂H₄	R2= CH₄/H₂	R3= C₂H₄/C₂H₆	Fault conditions in fuzzy output
315	400/220kv	0.417	1.05	0.139	D2
315	400/220kv	0.024	0.73	0.29	NF
315	400/220kv	0.69	0.325	2.45	T1
315	400/220kv	0.0775	0.375	2.96	D1

To evaluate the performance of the rule-based load-sharing system, three various types of So from the above results, the initial condition was that the main transformer was delivering load at normal load. When the load on the main transformer increases, the voltage decrease and the load of the main transformer also increases, the sharing breaker circuit will sense through the controller and add a slave (second) transformer in parallel to share the load equally. When the load is shared by two transformers equally, voltage regulation increases and proficiency also increases. We can see that unbalance and protection are reduced by a factor of 95% after the implementation of fuzzy logic error correction. Hence, by performing this thesis I have successfully demonstrated the requirements and implementation of overload protection in the real world.

5.4. Transformer current analysis

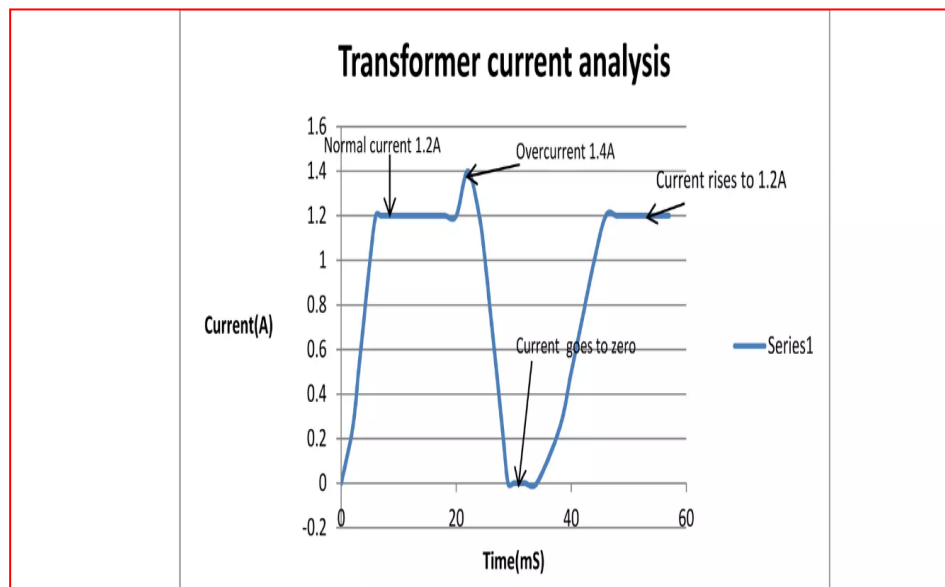


Figure 5.8. Transformer Current analysis

As in Figure 5.8. If loads are added to the secondary side of the transformer, the secondary current rises. Therefore the load is proportional to the secondary current. If the load connected does not exceed the rated current of the transformer which is 1.2A, the relay continues to be on. But as soon as the load current exceeds the transformer-rated current, the microcontroller sends a trip signal to the overcurrent relay goes off, thereby protecting the transformer from burning due to overloading. When the overcurrent is rectified, the relay goes on and continues to allow the flow of electric current through the load.

5.5. Transformer voltage analyses

Figure 5.9. When no overvoltage is detected by the sharing circuit breaker through the voltage sensing circuit, the fuzzy logic controller energizes the overvoltage circuit which allows the flow of current and voltage through the transformer primary. When the input AC voltage is varied through the sharing transformer above the rate of the transformer which is 230VAC, the fuzzy logic controller detects an overvoltage condition through the voltage sensing circuit, therefore it sends a trip signal to the overvoltage circuit breaker, and the cuts off the primary of the transformer from the input AC voltage thereby saving the transformer from damaging due overvoltage. As soon as the fuzzy

logic controller detects normal voltage, it sends back a switch-on signal to relay thereby allowing the flow of electric current and voltage through the transformer primary.

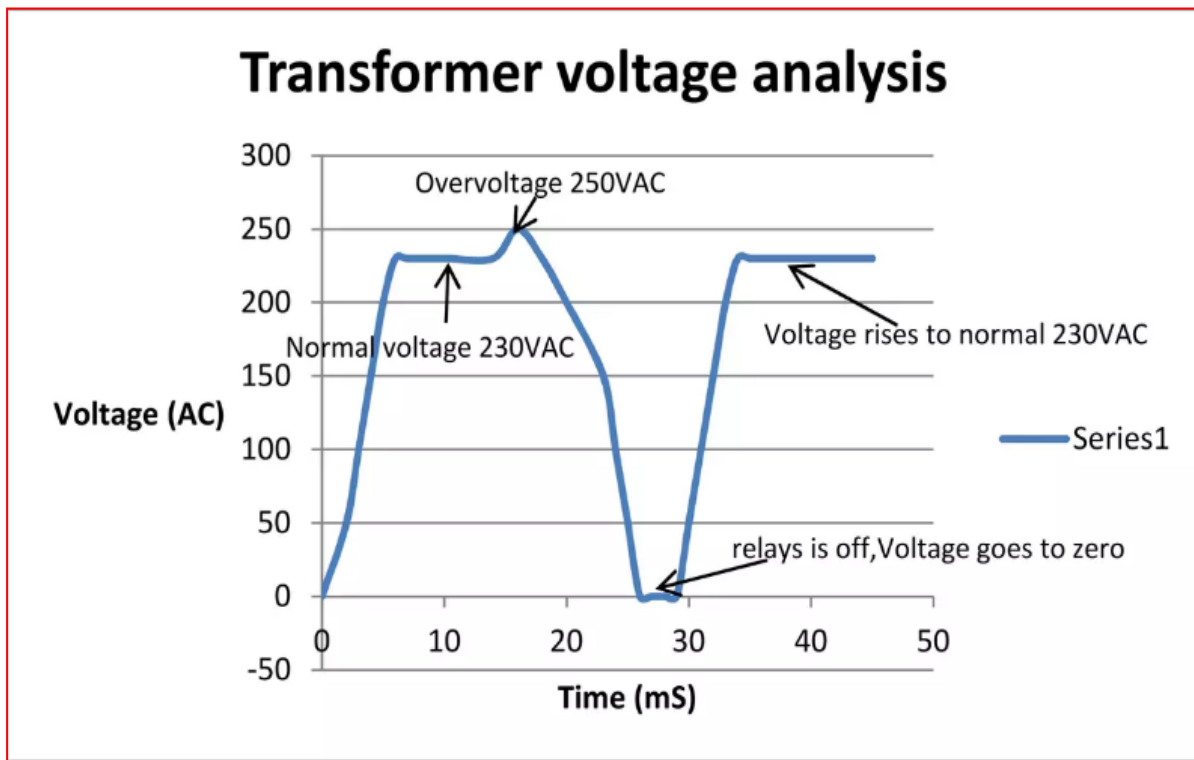


Figure 5.9 Transformer voltage analyses

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

The fuzzy logic toolbox provided by MATLAB is used in this thesis for the design and development of monitoring and protection systems for the automatic load sharing of power transformers. MATLAB is provided by Math Works incorporation and it covers areas of applications like data algorithms, matrix manipulation, and data manipulation. Fuzzy logic is a toolbox that provides a graphical user interface-based implementation of a fuzzy system. Before consumer usage of power, it has to be properly generated, transmitted, and distributed. Power stations generate power by converting one form of energy into electrical energy. Once power is generated, it should be transmitted to the subsystems near consumers. So proper power and distribution Transformer is required to reduce distribution losses. The transformer can be overhead or underground depending upon requirements. The critical stage is power distribution. Depending upon consumer usage, the distribution should be such that it can avoid overloading situations. The automatic overload protection profile gives a graphical representation of the customer transformer usage.

The work was all about how to supply power intelligently and manage an overload condition. The system automatically connects and disconnects the switch to share the transformer loads. Most of the Tatek Transformer factories were suffering from electric instructions. This was due to transformer failure. A recommendation to decrease power interruption in the Tatek transformer factory was: Load sharing of the transformer to protect it from failures. This load-sharing was modelled to the factory; therefore, this transformer load-sharing system was the best solution to protect against equipment failure and electric instructions.

An intelligent controller was used to make intelligent decisions by sensing the amount of the load on the transformer. Rule base fuzzy logic controller manages the load and transformers were protected from overload conditions.

In this thesis, control of temperature of a transformer has been demonstrated resulting in optimum use of transformers. The Mamdani type of fuzzy inference system is adopted for air blast cooling of transformers. The two input parameters i.e. load and temperature

has been taken for controlling the speed of fan in the literature, whereas in this work, four parameters i.e. moisture contents, pressure has also been considered in addition to load and temperature to achieve the real practical goal.

6.2. Future Works and Recommendations

Any work and investigation on transformer load sharing are very advantageous and challenging. Based on the present time, it can be observed that the Tatak transformer factory is increasing rapidly. Therefore demands for electricity will be high and these will lead to demands for highly sophisticated protection devices, which will be incorporated into transformer load-sharing schemes. Based on the work done in this thesis which is automatic load sharing of the transformer using a fuzzy logic controller, some improvements need to be made in future work. One of the best solutions for overcoming this is by connecting transformers in parallel. In this thesis on Automatic Load Sharing of Transformers Using a fuzzy logic controller, a technology is implemented to share the load on the transformers. This provides an uninterrupted power supply and avoids blackouts in particular areas where there are varying loads. With the advancement of communication technology, now it is possible to receive overload conditions of the transformer by sharing a circuit breaker with the control room. During overload conditions exceeding specified limits, information is immediately communicated through fuzzy logic controller technology to the concerned authority for possible remedial actions. Hence the transformer is protected from the overload condition and an uninterrupted power supply is available to the consumers

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APPENDIXES

Appendix A1: Table Result of analysis for different cases

Sample	C ₂ H ₆	C ₂ H ₄	CO	CO ₂	H ₂	CH ₄	C ₂ H ₂	Thermal and electrical conditions fuzzy output
1	514	2824	748	6021	53	49.2	31	0.938
2	2.9	0	11.8	787	12	325	108.5	0.8911
3	0.6	0.7	33.6	322	0	2.2	0	0.09437
4	57.2	0	140	1879	0	19.3	0	0.139
5	157	0	432	3114	18.9	303	0.8	0.9311
6	16.4	6.02	219.2	9909	0	46.3	0	0.6897
7	0.6	0.7	33.7	327	0	2.08	0	0.0989
8	60	47	159	3303	0	18.8	0	0.4957
9	4834	11990	317	2959	12	8778	18.7	0.9419
10	88.2	0	123.7	6660.6	0	73.4	0	0.914

Appendix B2: Table transformer fault Diagonisis

Code	$\frac{C2H2}{C2H4}$	$\frac{CH4}{H2}$	$\frac{C2H4}{C2H6}$	Suggested Fault diagnosis
0	0	0	0	Normal
1	1	0	1	Partial discharge of low energy
2	1	1	0	Partial discharge of high energy
3	1-2	0	1-2	Arcing-discharge of low energy
4	1	0	2	Arcing-discharge of high energy
5	0	0	1	Thermal fault (110°C...150°C)
6	0	2	0	Thermal fault (150°C...300°C)
7	0	2	1	Thermal fault (300°C...700°C)
8	0	2	2	Thermal fault (>700°C)

Appendix C3: Table

Iteration	G_E	G_{CE}	G_U	G_I	f_{val}
1	0.0078	0.0521	0.0617	1.832	2.89230
2	0.0072	0.0500	0.0589	1.721	2.89121
3	0.0066	0.0422	0.0542	1.1039	2.84243
4	0.0081	0.0631	0.0712	1.912	2.91321
5	0.0070	0.0481	0.0571	1.612	2.89251

Fuzzy logic reasoning is superset of standard Boolean logic i.e. if we take fuzzy values to extremes of 1 (totally true) and 0 (totally false) then standard Boolean logic will be obtained. By using fuzzy logic reasoning, the AND operation has been replaced by min function, OR operation by max function and NOT operation by 1-A operation as given in Tables 1-3

Appendix D4: Table min function of fuzzy logic reasoning

A	B	Min (A, B)
0	0	0
0	1	0
1	0	0
1	1	1

Table 1 min function of fuzzy logic reasoning

A	B	Max (A, B)
0	0	0
0	1	1
1	0	1
1	1	1

Table 2 Max function of fuzzy logic reasoning

A	1-A
0	1
1	0

Table 3 1-a operation of fuzzy logic reasoning

It is observed from the above tables that behind a standard truth table of Boolean logic, there is a fuzzy logic function (min-max). Similarly, the values other than 0 and 1 in fuzzy logic operation can be taken.

While forming the fuzzy matrix, use of fuzzy arithmetic is involved. This work presents the four input variables in combination to determine the output. Max operation is used which is performed on related degree of inputs to determine the output. Thus temperature load conditions may be specified in 5×5 matrix which is given in table no. 4. This table also shows that how fan speed functions with temperature for the different values of load.

Appendix H8: Table table . operating conditions of temperature and load for fan speed (output)

TEMPERATURE						
		COOL	AMBIENT	WARM	HOT	VERYHOT
L O A D	VLOW	ZERO	SLILOW	MED	QHIGHIGH	VVHIGH
	SMALL	LOW	SLILOW	MED	QHIGHIGH	VVHIGH
	RATED	MODLOW	MODLOW	MODLOW	QHIGHIGH	VVHIGH
	HIGH	MODHIGH	MODHIGH	MODHIGH	QHIGHIGH	VVHIGH
	VHIGH	VVHIGH	VVHIGH	VVHIGH	VVHIGH	VVHIGH

Appendix G9 standard circuit breaker

Type	Rated Power (VA)	Input Voltage (V)	Nominal current (A)	Type	Current setting (A)
TM-...50...	50	230	0.22	MS132-0.25T	0.22
TM-...100...	100	230	0.43	MS132-0.63T	0.43
TM-...160...	160	230	0.70	MS132-1.0T	0.70
TM-...200...	200	230	0.87	MS132-1.0T	0.87
TM-...250...	250	230	1.09	MS132-1.6T	1.09
TM-...320...	320	230	1.39	MS132-1.6T	1.39
TM-...400...	400	230	1.74	MS132-2.5T	1.74
TM-...630...	630	230	2.74	MS132-4.0T	2.74
TM-...1000...	1000	230	4.35	MS132-6.3T	4.35
TM-...1600...	1600	230	6.96	MS132-10T	6.96
TM-...2000...	2000	230	8.70	MS132-10T	8.70
TM-...2500...	2500	230	10.87	MS132-12T	10.87
TM-...50...	50	400	0.13	MS132-0.16T	0.13
TM-...100...	100	400	0.25	MS132-0.25T	0.25
TM-...160...	160	400	0.40	MS132-0.4T	0.40
TM-...200...	200	400	0.50	MS132-0.63T	0.50
TM-...250...	250	400	0.63	MS132-0.63T	0.63
TM-...320...	320	400	0.80	MS132-1.0T	0.80
TM-...400...	400	400	1.00	MS132-1.6T	1.00
TM-...630...	630	400	1.58	MS132-2.5T	1.60
TM-...1000...	1000	400	2.50	MS132-4.0T	2.50
TM-...1600...	1600	400	4.00	MS132-6.3T	4.00
TM-...2000...	2000	400	5.00	MS132-10T	6.30
TM-...2500...	2500	400	6.25	MS132-10T	6.30

Appendix H10 Table Thermal and electrical condition of transformer result

Sample	C ₂ H ₆	C ₂ H ₄	CO	CO ₂	H ₂	CH ₄	C ₂ H ₂	Thermal and electrical conditions fuzzy output
1	514	2824	748	6021	53	49.2	31	0.938
2	2.9	0	11.8	787	12	325	108.5	0.8911
3	0.6	0.7	33.6	322	0	2.2	0	0.09437
4	57.2	0	140	1879	0	19.3	0	0.139
5	157	0	432	3114	18.9	303	0.8	0.9311
6	16.4	6.02	219.2	9909	0	46.3	0	0.6897
7	0.6	0.7	33.7	327	0	2.08	0	0.0989
8	60	47	159	3303	0	18.8	0	0.4957
9	4834	11990	317	2959	12	8778	18.7	0.9419

Mathlab code

Name='Automatic overload protection'

Type='mamdani'

Version=2.0

NumInputs=2

NumOutputs=1

NumRules=9

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='T_{IL}(kW)'

Range=[0 315]

NumMFs=3

MF1='SL': 'trimf',[0 50 100]

MF2='ML': 'trimf',[100 150 200]

49

MF3='LL': 'trimf',[180 250 315]

[Input2]

Name='T1L(kW)'

Range=[0 315]

NumMFs=3

MF4='SL': 'trimf', [0 60 90]

MF5='ML': 'trimf', [90 150 215]

MF6='LL': 'trimf', [200 250 315]

[Output1]

Name='Change(kW)'

Range=[0 630]

NumMFs=3

MF1='Not_share': 'trimf', [0 200 315]

MF2='Share': 'trimf', [315 500 630]

MF3='trip': 'trimf', [620 625 670]

system;

Name='overload protection'

Type='mamdani'

Version=2.0

NumInputs=1

NumOutputs=1

NumRules=8

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='Load(kW)'

Range=[0 630]

NumMFs=8

MF1='VLL': 'trimf', [0 50 100]

MF2='LL': 'trimf', [70 120 170]

49

MF3='ML': 'trimf', [130 180 230]

MF4='PL': 'trimf', [200 250 300]

MF5='SOL': 'trimf', [250 300 350]

MF6='MOL': 'trimf', [330 380 430]

MF7='OL': 'trimf', [400 450 500]

MF8='HOL': 'trimf', [470 535 600]

[Output1]

Name='Change(kW)'

Range=[-300 300]

NumMFs=8

MF1='HS': 'trimf', [-300 -235 -170]

MF2='S': 'trimf', [-200 -150 -100]

MF3='MS': 'trimf', [-130 -80 -30]

MF4='SS': 'trimf', [-100 -25 50]

MF5='PA': 'trimf', [-0 50 100]

MF6='MA': 'trimf', [70 120 170]

MF7='LA': 'trimf', [130 180 230]

MF8='VLA': 'trimf', [200 250 300]

Implementation (FLC Parameters) While implementing the fuzzy logic on transformer temperature control problem, the following Transformer Temp Control.fis file is obtained.

[System]

Name='Transformer Temperature Control'

Type='mamdani'

Version=2.0

NumInputs=4

NumOutputs=1

NumRules=22

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='Temperature'

Range=[30 250]

NumMFs=5

MF1='cool': 'trimf', [30 60 130]

MF2='amb': 'trimf', [30 140 250]

MF3='warm': 'trimf', [139.41 249.41 359.41]

MF4='hot': 'trimf', [-80 30 140]

MF5='very_hot': 'trimf', [30 140 250]

[Input2]

Name='Load'

Range=[0 6]

NumMFs=5

MF1='very_low': 'trimf', [0 2 4]

MF2='small': 'trimf', [0.6 3 5.4]

MF3='rated': 'trimf', [3.58412698412698 5.98412698412698

8.38412698412698]

MF4='high': 'trimf', [-6 1.11e-016 6]

MF5='very_high': 'trimf', [0 6 12]

[Input3]

Name='Moisture'

Range=[0 5]

NumMFs=5

MF1='very_low': 'trimf', [-2 0 2]

MF2='small': 'trimf', [0.5 2.5 4.5]

MF3='low': 'trimf', [3 5 7]

MF4='high': 'trimf', [-5 0 5]

MF5='very_high': 'trimf', [0 5 10]

[Input4]

Name='Pressure'

Range=[0 8]

NumMFs=5

MF1='very_low': 'trimf', [-3.2 0 3.2]

MF2='low': 'trimf', [0.8 4 7.2]

MF3='small': 'trimf', [4.8 8 11.2]

MF4='high': 'trimf', [-8 0 8]

MF5='very_high': 'trimf', [0 8 16]

[Output1]

Name='Fan_Speed'

Range=[0 1500]

NumMFs=8

MF1='low': 'trimf', [0 0 375]

MF2='slilow': 'trimf', [150 750 1350]

MF3='modlow': 'trimf', [900 1500 2100]

MF4='med': 'trimf', [-500 -7.105e-015 500]

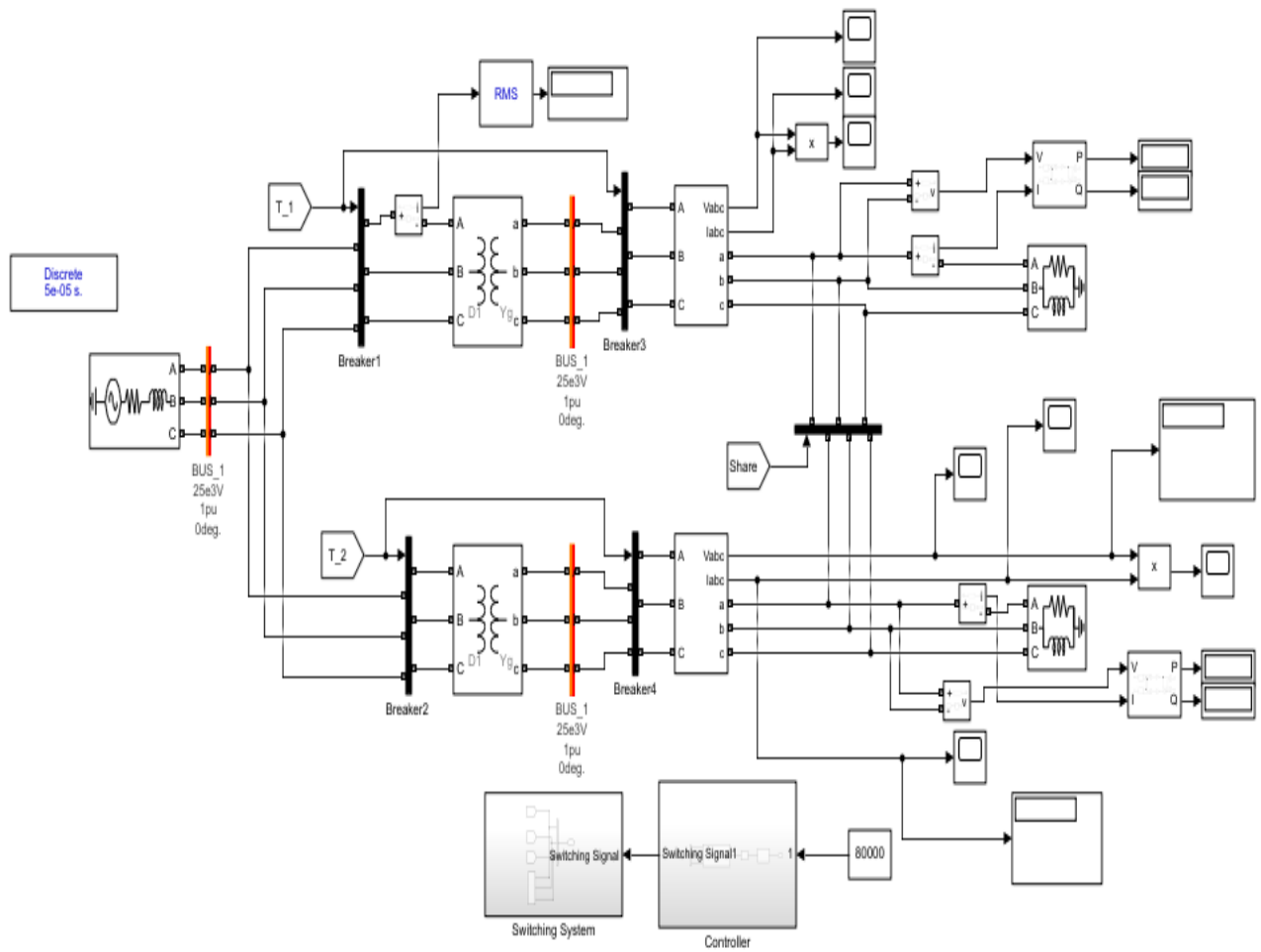
MF5='modhigh': 'trimf', [-3.96 496.03 996.03]

MF6='qhigh': 'trimf', [500 1000 1500]

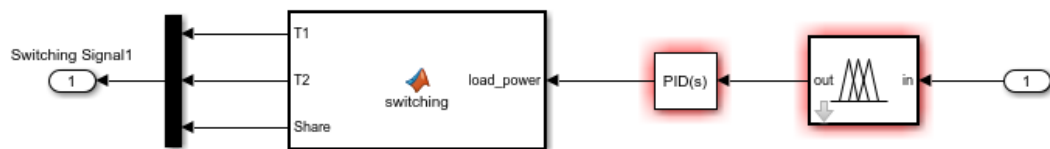
MF7='vvhigh': 'trimf', [1000 1500 2000]

MF8='zero': 'trimf', [0 750 1500]

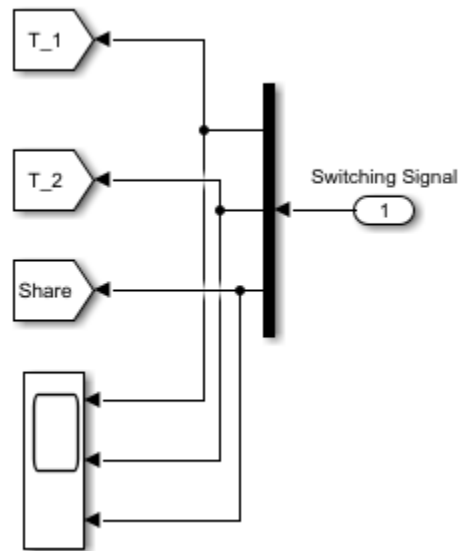
Appendix I 11 Overall protection systems for overloading protection interface



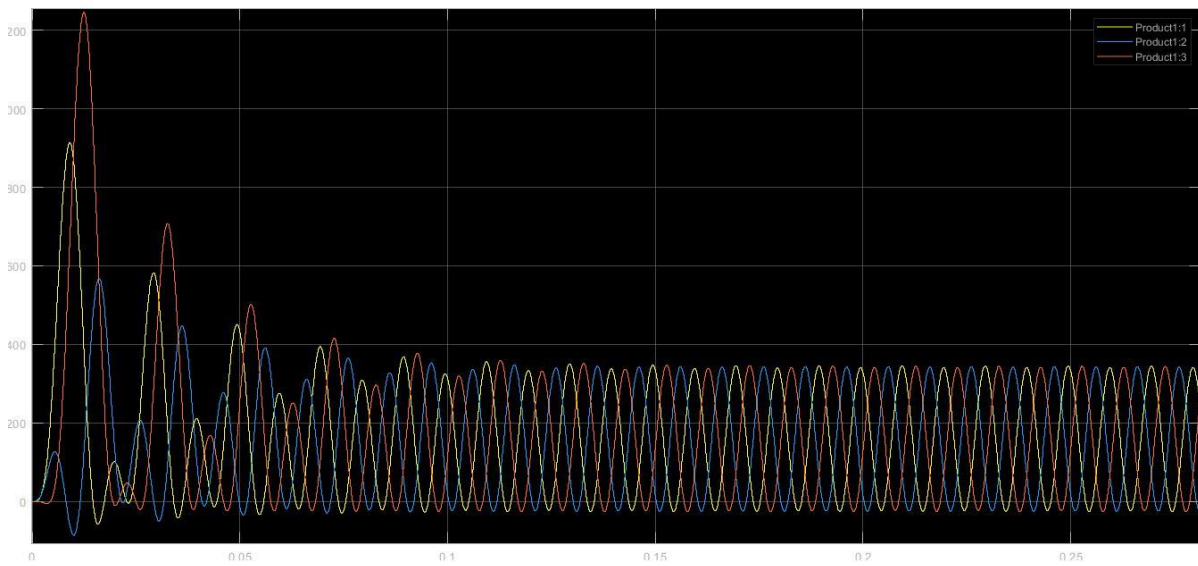
Appendix J12 Controller



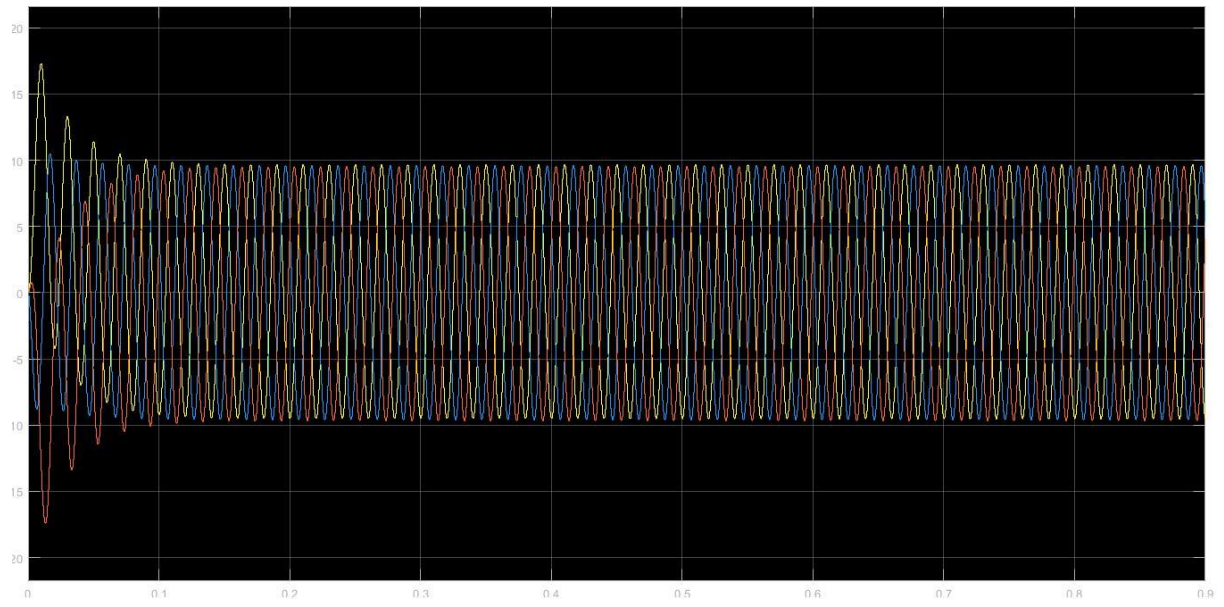
Appendix K 13 Switching System



Power



Current



Voltage

