Republic of Sudan
Ministry of Higher Education and Scientific Research
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School of Mechanical Engineering

FAILURE ANALYSIS OF TRANSFORMER BY USING FAILURE MODES, EFFECT AND CRITICALITY ANALYSIS

A graduation project is submitted to the School of Mechanical Engineering in partial fulfillment of the requirements for the degree of Bachelor in Mechanical Engineering-Production

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Dedication

I dedicate this research to my Parents, lecturers, who taught me to think, understand and express I earnestly feel that without their inspiration, able guidance and dedication I would not be able to pass through the tiring process of this research.

Acknowledgment

First and foremost, I like thank my family, especially my parents, for their encouragement, patient, and assistance over years. I would also like to express my gratitude and appreciation to Dr. ELkhawad Ali Alfaki for all the help and guidance he provided throughout my research.

ABSTRACT

This project presents a failure analysis of power transformer using Failure Modes, Effect and Criticality Analysis (FMECA) method. With the aims to analyzing potential failure modes, possible causes, their effects and find reliability, risk priority number and rank. A general FMECA for outage causes of 500kv power transformer is presented, including the local effects and final effects, and recommended actions to avoid these outages. Assignment of risk priority numbers to various outage causes, which might occur at this voltage level are, carefully considered.

المستخلص

يتمثل الهدف من هذا المشروع في تحليل انماط الفشل المحتملة, اسباب الممكنة وتاثيره و ايضا ايجاد الموثوقية والرقم اولوية الخطر و ترتيبها على حسب الاولوية لمحول باستخدام المنهجية تحليل تاثير حرجية انماط الفشل وتتمثل مشكلة البحث في دراسة القطوعات (الاعطال) للمحول (500 كيلو فولت) حيث اعتبر هذه القطوعات بمثابة الفشل,لذلك تم تطبيق المنهجية تحليل تاثير حرجية انماط الفشل على هذا المحول. تم تحليل كل انماط الفشل المحتملة و الاسباب حدوثه و تاثيراته سواء كانت تاثير على جزء معين من المحول او على كل النظام و ترتيب هذه الاعطال على حسب خطورتها على المحول. لقد تم اتخاذ اجراءات الوقائية المناسبة لتقليل ظهور هذه الاعطال وازالة اسباب حدوثه حتى يتمكن المحول من اداء وظيفته بالشكل المطلوب.

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CHAPTER ONE
Introduction

Chapter one: Introduction

1.1- Introduction

Every machine and process in daily manufacturing /service operations has it owns modes of failure. An analysis of these failures will help to focus and understand the impact they may portray into the day to day processes and operations. It is important to determine the causes and characteristics of failures in order to prevent future occurrence and improve the performance of the device, component and structure.

One of the well-known methods in conducting the failure analysis is the Failure Modes, Effect and Criticality Analysis (FMECA) [1].

The FMECA is first developed as formal design methodologies in the 1960's by the aerospace industry with their obvious reliability and safety requirements, in which it is extended version of Failure Modes and Effect Analysis (FMEA). Since then, it has been extensively used to help in ensuring the safety and reliability of system employed in a wide range of industries.

Failures of transformers in sub-transmission systems not only reduce reliability of power system but also have significant effects on power quality since one of the important components of any system quality is reliability of that system. The first step of a system failure analysis and reliability study is often the Failure Modes, Effects and Criticality Analysis (FMECA), one of several methods used for risk assessment and management thorough failure analysis. In other words, FMECA is an important procedure to identify and assess consequences or risk associated with potential failure modes [2]. A FMECA is a qualitative or quantitative analysis and typically includes a listing of failure modes, possible causes for each failure, effects of the failure and their seriousness and corrective actions that might be taken.

1.2- Problem Statement

Transformers have a key role in power systems and their reliability directly affects the reliability of the whole network. Outage of transformers is considered a failure, since it is an event that determines a fault state (the transformer cannot perform its specified function).so that Failure Modes, Effect and Criticality Analysis (FMECA) suggested to analyze all potential failure modes, possible causes, their effects and corrective actions to eliminate this outages.

1.3-Objectives

1- Analyzing potential failure modes, possible causes and their effects for power transformer using FMECA.

2- Find the Reliability, Risk Priority Numbers and Rank for power transformer.

1.4- Project Significance

Power transformers in addition to playing an important role in the efficiency and reliability of power transmission networks, are also the most expensive network equipment. It is important to know when the transformer is the most dangerous element because it contains a great quantity of oil in contact with high voltage elements and this may lead to fires and forced unexpected outages. Thing which favors the risk of outages in case of abnormal circumstances or technical failures. So, it is necessary to plan and to focus the efforts by set of priorities with a general aim is to minimizing unexpected outage and improve the reliability of the system, and consequently, to reduce their failure risk by using the FMECA.

1.5- project Scope

This project contains the failure modes, effects, and criticality analysis for all parts of the power transformer (500kv). This FMECA analysis consists of an outlining of all possible failure modes of all elements, possible causes and then a determination of the effects and criticality of these failure modes.

1.6- Project Layout

This project consists of five chapters:

Chapter one: Introduction

Chapter two: Literature Review

Chapter three: Methodology

Chapter four: Results and Discussion

Chapter five: Conclusion and Recommendation

CHAPTER TWO
Literature Review

Chapter Two: Literature Review

2-1 Failure Modes, Effect and Criticality Analysis (FMECA)

FMECA extends FMEA by introducing the notion of criticality into the analysis. All aforementioned characteristics of FMEA are applicable to FMECA as well. In addition a criticality analysis is performed as part of the procedure. We may distinguish two basic types of criticality analysis, according to MIL-STD-1692A standard [1]:

The FMECA is composed of two separate analyses, the Failure Mode and Effects Analysis (FMEA) and the Criticality Analysis (CA). The FMEA analyzes different failure modes and their effects on the system

while the CA classifies or prioritizes their level of importance based on failure rate and severity of the effect of failure. The ranking process of the CA can be accomplished by utilizing existing failure data or by a subjective ranking procedure conducted by a team of people with an understanding of the system. Although the analysis can be applied to any type of system, this manual will focus on applying the analysis to a facility The FMECA should be initiated as soon as preliminary design information is available. The FMECA is a living document that is not only beneficial when used during the design phase but also during system use. As more information on the system is available the analysis should be updated in order to provide the most benefit. This document will be the baseline for safety analysis, maintainability, and maintenance

Plan analysis, and for failure detection and isolation of subsystem design. Although cost should not be the main objective of this analysis, it typically does result in an overall reduction in cost to operate and

maintain the facility.

2.1.1- Standards and History

There are many standards and quality systems incorporating FMEA/FMECA, often specifically designed for certain area, such as automotive and avionic industry, power plants (especially nuclear), space programs, etc.

The first standard which introduced the ideas of FMEA and FMECA was, however, a U.S. military standard MIL-STD-1629[1], published in 1949 as a procedure and standardized in 1974. Even before standardization, many industries adopted these methods in their processes. This standard was later updated by MIL-STD-1629A. Other industry standards include for instance SAEJ1739 or ALAG FMEA-3. In 1960s FMEA and FMECA began to be used in NASA and its partners and since then it was used in many NASA programs, including Apollo, Viking, Voyager and Galileo. In the same time, the civil avionic industry also started to use these techniques in designing aircraft. In 1970s it spread also to automotive industry, beginning with the Ford Motor Company.

2.1.2- CRITICALITY ANALYSIS (CA)

The CA is an analysis procedure for associating failure probabilities with each failure mode. Since the CA supplements the FMEA and is dependent upon information developed in that analysis, it should not be attempted without first completing the FMEA.

The CA is probably most valuable for maintenance and logistic support oriented analyses since failure modes which have a high probability of occurrence (high criticality numbers) require investigation to identify changes which will reduce the potential impact on the Maintenance and logistic support requirements for the system.

The analysis approach to be used for the CA will generally be dictated by the availability of specific configuration data and failure rate data. There are two approaches for accomplishing the CA. One is the qualitative approach which is appropriate only when failure rate data are not available. The preferred method is the quantitative approach which is utilized where failure rate data have been derived.

2.1.3- FMECA APPLICATION

A FMEA and CA when performed concurrently are referred to as a FMECA. The FMECA, if applied properly, can be one of the most beneficial and productive tasks in a well-structured reliability program[1][2]. Since individual failure modes are listed and evaluated in an orderly, organized fashion, the FMECA serves to verify design integrity, identify and quantify undesirable failure modes and document reliability risks. Results of a FMECA can be used to provide the rationale for changes in operating procedures, maintenance strategies, and design to remove undesirable failure modes.

Although the FMECA is an essential reliability task, it is a concurrent engineering tool which should be used to supplement and support other engineering tasks by identifying areas in which effort should be concentrated. FMECA results not only provide design guidance, but can be used advantageously during maintenance planning analysis, logistics support analysis, survivability and vulnerability assessments, safety and hazards analysis, and for fault detection and isolation design. This coincident use of the FMECA must be considered by program management during FMECA planning and every effort made to prevent duplication of analyses by the various program elements which utilize FMECA results.

2.1.4- FMECA DESCRIPTION

An FMECA is a powerful tool to optimize the performance/life-cycle cost tradeoffs between mission reliability and basic reliability at the

black box or subsystem level, where these tradeoffs are most appropriately analyzed and evaluated[3]. Potential design weaknesses are determined by using functional block diagrams, reliability block diagrams, engineering schematics, and mission rules (mission functions, operational modes, environmental profiles, and times) to systematically identify the likely modes of failure, the possible effects of each failure (which may be different for each life/mission profile phase), and the criticality of each effect on safety, readiness, mission success, demand for maintenance/logistics support, or some other outcome of significance. A reliability criticality number may be assigned to each failure mode usually based on failure effect, severity and probability of occurrence. These numbers are sometimes used to establish corrective action priorities, but because of the subjective judgment required to establish
them, they should be used only as indicators of relative priorities. The FMECA can also be used to confirm that new failure modes have not been introduced in transforming schematics into production drawings. The initial FMECA should be done early in the conceptual phase, and because limited design definition may be available, only the more obvious failure modes may be identified. This can help identify many of the single failure points, some of which can be eliminated by simple design changes. As greater mission and design definitions are
developed in the validation and full scale development phases, the analysis can be expanded to successively-more-detailed levels and ultimately to the part level. The usefulness of the FMECA is dependent on the skill of the analyst, the available data, and the information the analyst provides as a result of the analysis.

The FMECA format is tailor able and additional pertinent information such as, failure indication, anticipated environment under which the failure may be expected to occur, time available for operational corrective action, and the corrective action required could be included. The amount of detail and type of information supplied is a function of mission criticality.

In general, engineering manpower should be focused on those potential failures which imperil the crew or preclude mission completion. FMECA results may suggest areas where the judicious use of redundancy can significantly improve mission reliability without unacceptable impact on basic reliability, and where other analyses such as electronic parts tolerance or sensitivity analyses be performed, or other provisions such as environmental protections be considered.

Additionally, FMECA results can be used to provide rationale for operating procedures used to ameliorate undesirable failure modes and document residual risks.

2.1.5- FMECA Types

Three types of FMECA are described when developing FMECAs at the component, assembly, subsystem, and system levels[2][3]. These are functional, interface, and hardware. These three FMECA types follow the development phases as the evaluation proceeds from a "functional evaluation of failure modes and effects" to increased levels of detail as potential problems are surfaced and additional analyses in selected areas are needed (e.g., at redundancy cross-straps). Functional FMECAs are performed and documented for proposals, trade studies, and PDRs to evaluate and provide support for the resulting design redundancy architecture. Interface and hardware FMECAs then follow at the piece-part/harness level as the detailed design unfolds during the CDR Timeframe.

Because modified and improved designs are based upon heritage designs, detailed design data during the PDR time-frame must be made available to complete a detailed analysis for evaluating the design candidates during trade studies.

2.1.6- FMECA Benefits

The FMECA facilitates identification of potential design reliability problem areas which must be eliminated or their effect minimized, by design modification or tradeoffs [4]. Specific defects identified can include:

Circuit failures that may cause the failure of a related critical circuit

Areas where fail safe or fail soft features are required Primary failures which may cause costly secondary failures Information and knowledge gained by performing the FMECA can also be used as a basis for trouble shooting activities, maintenance manual development and design of effective built-in test techniques. The FMECA provides valuable information for maintainability, safety and logistic analysis.

2.1.7- Definition of FMECA Terms

The following list describes important terms often used in FMECA[1][3][4].

- **Compensating Provision**: Actions available or that can be taken to negate or reduce the effect of a failure on a system.
- **Corrective Action**: A documented design, process or procedure change used to eliminate the cause of a failure or design deficiency.
- **Criticality**: A relative measure of the consequences of a failure mode and the frequency of its occurrence.
- **Criticality Analysis (CA):** A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence.

- **Damage Effects:** The results or consequences a damage mode has upon system operation, or function.
- **Damage Mode**: The way by which damage occurs and is observed.
- **Damage Mode and Effects Analysis:** The analysis of a system or equipment to determine the extent of damage sustained from given levels of weapon damage mechanisms and the effects of such damage on the continued operation and mission of the specified system or equipment.

Detection Method: The method by which a failure can be discovered by the system operator under normal system operation or by a maintenance crew carrying out a specific diagnostic action.

- **End Effect**: The consequence a failure mode has upon the operation, function or status at the highest indenture level.
- **Failure Cause:** The physical or chemical processes, design defects, quality defects, part misapplication or other processes which are the basic reason for failure or which can initiate the physical process by which deterioration proceeds to failure.
- **Failure Effect**: The consequence a failure mode has upon the operation, function or status of a system or equipment.
- **Failure Mode:** The way in which a failure is observed, describes the way the failure occurs, and its impact on equipment operation.

Fault Isolation: The process of determining the location of a fault to the indenture level necessary to effect repair.

- **Indenture Levels:** The levels which identify or describe the relative complexity of an assembly or function.

- **Local Effect:** The consequence a failure mode has on the operation, function or status of the specific item being analyzed.

Maintainability Information: A procedure by which each potential failure mode in a system is analyzed to determine how the failure is detected and what actions will be needed to repair the failure.

- **Mission Phase Operational Mode:** The statement of the mission phase and mode of operation of the system or equipment in which the failure occurs.
- **Next Higher Level Effect:** The consequence a failure mode has on the operation, functions, or status of the items in the next higher indenture level above the specific item being analyzed.
- **Primary Damage Effects:** The results or consequences a damage mode has directly on a system or the components of the system.
- **Redundancy:** The existence of more than one means for accomplishing a given function.
- **Secondary Effects:** The results or consequences indirectly caused by the interaction of a damage mode with a system, subsystem or component of the system.
- **Severity:** Considers the worst possible consequence of a failure classified by the degree of injury, property damage, system damage and mission loss that could occur.
- **Single Point Failure:** The failure of an item which can result in the failure of the system and is not compensated for by redundancy or alternative operational procedure.

2.1.8-Team effort

The FMECA should be a catalyst to stimulate ideas between the design engineer, operations manager, maintenance manager, and a representative of the maintenance personnel (technician)[3].

The team members should have a thorough understanding of the systems operations and the mission's requirements. A team leader should be selected that has FMECA experience. If the leader does not have experience, then a FMECA facilitator should be sought. If the original group of team members discovers that they do not have expertise in a particular area during the FMECA then they should consult an individual who has the knowledge in the required area before moving on to the next phase.

The earlier a problem in the design process is resolved, the less costly it is to correct it. Two basic types of criticality analysis, according to MIL-STD-1692A standard[1]:

• **Qualitative** – this approach is very similar to computing of the risk priority numbers (RPNs), but only severity and occurrence are taken into account. Failure modes are compared according to the Criticality Matrix which has severity levels on the horizontal axis and occurrence on the vertical axis.

• **Quantitative –** this type of criticality analysis computes modal **criticality numbers** (Cm) for each failure mode of each item and item **criticality numbers** (Cr) for each item using this formulas:

$$\boldsymbol{Cm}=\boldsymbol{\lambda p}\beta\boldsymbol{\alpha} \qquad \boldsymbol{Cr}=\sum(\boldsymbol{Cm})\boldsymbol{n}$$

Where:

• λp is the basic failure rate of an item

• α is the failure mode ratio, i.e. "the fraction of the part failure rate (λp) related to the particular failure mode under consideration …"9

• β is "the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs" 10

• t is the duration of the mission phase or simply the operating time

• N is the number of failure modes related to the analyzed item.

2.2 Power transformer

A case study has been performed in power transformer. The focused subject in this study is 500kv power transformer. A transformer is a static electric device consisting of a winding or two, or more coupled windings, with a magnetic core for introducing mutual coupling between electric circuits through electromagnetic induction. The transformer includes all transformer-related components, such as bushings, load tap changers, fans, temperature gauges, etc., and excludes all system-related components (e.g. surge arresters, grounding resistors, high voltage switches, low-voltage switches and house service equipment). Transformers can be classified into many types such as power transformers, autotransformers, regulating transformers, etc. Based on their application, transformers are classified into substation transformers, transmission tie transformers, unit transformers, etc. Generally, transformer outages are either forced or scheduled, and both are done by means of switching operations. Forced outages of transformers are mainly due to automatic switching operations performed by protection systems. They are caused by either external (such as transmission line faults) or internal causes (such as core failure and winding failure).

2.2.1-Transformer Construction

Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core. A transformer may also consist of a container for winding and core assembly (called as tank), suitable bushings to take the terminals, oil conservator to provide oil in the transformer tank for cooling purposes. The figure1 illustrate the basic construction of a transformer.

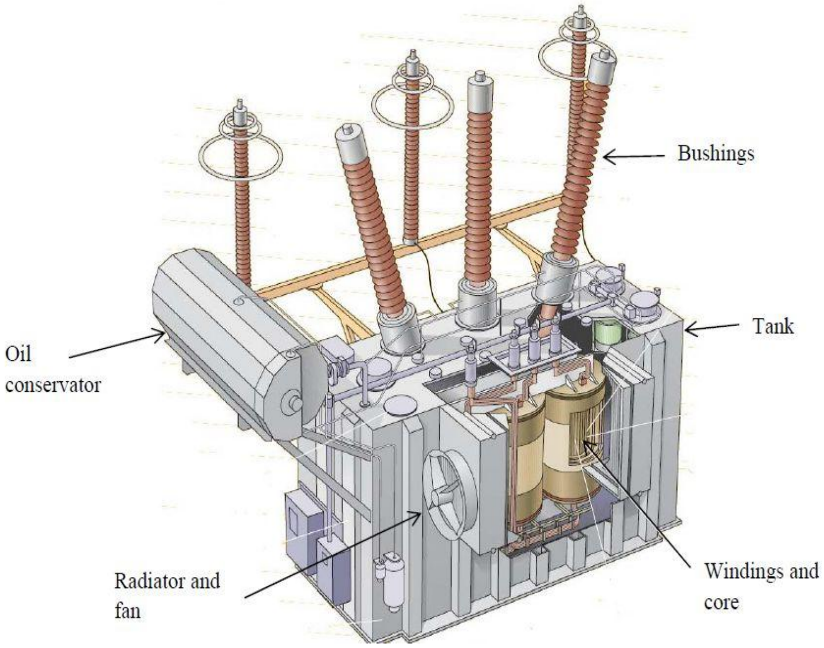

Fig 2.1- Basic construction of transformer

2.2.2- Some major and minor causes of power transformer outages

Transformers are critical links in power systems, and can take a long time to replace if they fail. Through faults cause extreme physical stress on transformer windings, and are the major cause of transformer failures. When a transformer becomes hot, the insulation on the windings slowly breaks down and becomes brittle over time.

Fig 2.2- Power transformer failure

There is almost twice the moisture near bottom as there is at the top. So, this transformer failed in the lower one-third of the windings due to paper insulation breakdown Fig 2.3.

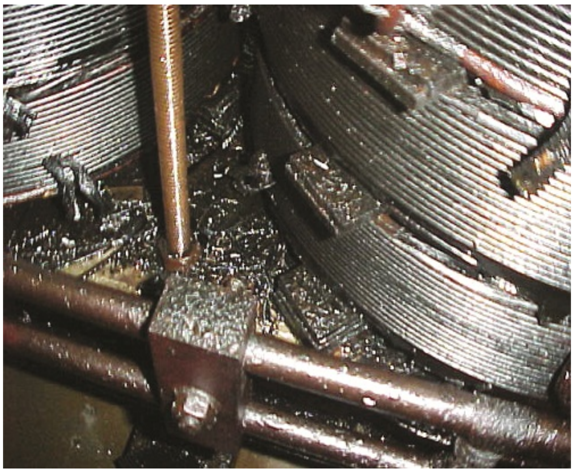

Fig 2.3- Failure due to moisture content in oil

Lightning strike occurs when the voltage generated between a cloud and the ground exceeds the dielectric strength of the air Fig 2.4.

Fig 2.4- Lightning strike – transmission tower

Birds are the most common cause of animal faults on both transmission systems and insulated substations. Nesting birds commonly build their homes on transmission towers and in substation. Nesting materials can cause faults.

Fig 2.5- Bird nest on the transmission system

2.3- Related Studies

In the literature, the publication on the applications of FMECA for the past five years are considered and it have been applied in different field and scope of problems.

2.3.1- Study (1):

Title:

Reliability analysis of metro door system based on FMECA

Author/s:

Xiaoging Cheng

Date:

2013

Scope of the project:

The FMECA method is applied to the door system of metro train. The FMECA analysis is carried out on the several key components which have a high failure rate, so the failure modes which have a great effect on the door system are obtained and auxiliary decision-making reference could be provided for maintenance of door system.

Project Conclusion and result:

Through statistical analysis of defective components of metro door system. The FMECA method is utilized to analyze four components which have a high failure rate. The results show that the EDCU function failure and the breakage of limit switch s1 are the weakness of door system, and should be concerned in the maintenance operation.

2.3.2- Study (2):

Title:

Study of centrifugal pump using FMECA analysis based on cost estimation

Author/s:

Deeptesh Singh, Amit Suhane

Date:

2013

Scope of the Project:

This project presents the generic process of FMECA for centrifugal pump failures and a case study on centrifugal pump failure cost estimation actual and after implementation of optimum strategies of maintenance.

Project Conclusion and Results:

1- The cost based FMECA presents graphic representation , and provides an efficient classification of failure based on faults priority and economic profit.

2- To select the best mix of failures to be repaired and this type of problem is easily resolvable through priority of critical index of components and diagnose them appropriate maintenance strategies.

3- Enhance the profit with 36.74% overall (including labor, downtime and spare parts cost only) per year by proper selection of maintenance strategies with the help of FMECA

2.3.3- Study (3):
Title:

Reliability Analysis of Aircraft Equipment Based on FMECA Method

Author/s:

Li Jun, Xu Huibin

Date:

2012

Scope of the project:

FMECA is applied in an aircraft equipment to analyze its reliability and improve operational reliability of the product.

Project Conclusion and Results:

This project conducts the reliability modeling of aircraft equipment and predicts its MTBF. In order to analyze and improve its reliability, reliability technique FMECA method is used to analyze its failure models and destructive degree, thus propose content, key point and method which be pay attention to while using and maintaining the equipment. The result shows that reliability analysis and the application of FMECA method prolong the life span of this equipment and improves the operational reliability greatly, thus proves that it is correct to apply this method to reliability analysis and improvement of operational reliability of a product. In mean time, it may help to improve the reliability of other aviation products.

2.3.4- Study (4):

Title:

Safety Analysis of Airborne Weather Radar Based on FMECA Analysis

Author/s:

MA Cunbao, GAO Zi, Yang Lin

Date:

2011

Scope of Project:

The safety of the airborne weather radar (WXR) will directly affect the safety of the whole aircraft and the flight. Taken the WXR as an illustrative system , the FMECA method in the safety analysis of system investigated in this project.

Project Conclusion and Results:

Based on the typical fault of WXR, the FMECA method of system safety analysis is studied. This project calculated the criticality of the failure modes , drawn criticality matrix , classified the failure mode, and rank the failure mode in order of criticality.

All the above studies focused on the analyzing failure modes, failure causes, and their effects and rank this failure according to their priorities. Improve reliability and reduce risks by reducing severity and occurrence. But they tend to use quantitative analysis rather than qualitative analysis. In this research I used qualitative analysis, because failure rates for power transformer are not available to calculate critical index.

CHAPTER THRE
METHODOLOGY

Chapter Three: Methodology

3.1-Analysis Methodology

This project methodology requires gathering relevant data about 500kv transformer from the central workshop in Khartoum bahary, which will be used to analyze potential failure modes, possible causes, and their local and final effects and rank according to risk priority number.

Generally, there are two parts to be completed in performing the FMECA. The first part is to perform the failure modes and effect analysis (FMEA). The second part is to classify the failure mode according to the severity and probability of occurrence for the criticality analysis (CA). Also, in details there are several steps into performing the FMECA applied herein [1][2][3]:

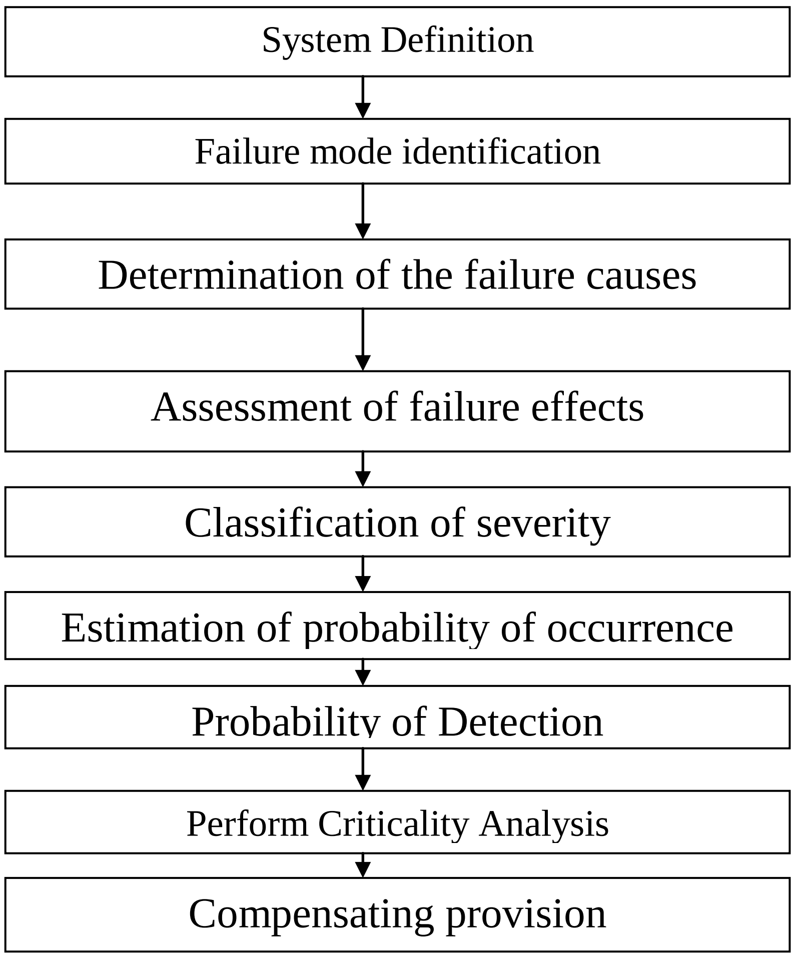

Fig 3.1- Systematic procedures to create FMECA

- **System Definition**

System definition provides the transformer and transformer components functions and features, such as performance, interface, monitoring, . This is a precursor to the FMECA process.

- **Failure mode identification**

Here, all failure modes data are determined based on the computerize failure record system. The main focus will be the major component failures with highest frequencies or the number of occurrence. This step must be through because this information will feed into the risk ranking for each of the failures.

- **Determination of the failure causes**

Based on the record data, the major components failures are coming from the highest frequencies of occurrence. In order to find the failure causes, a study has been conducted at the transformer with help from the engineering personnel and process specialist.

It is based on their intuitive and judgment through experiences and expertise of what are the failure modes, how the failure occur, why the failure happen in the first place from a discussion and brainstorming session.

- **Assessment of failure effects**

It is a step whereby measurements of how the failure will influence the transformer components performances is determine whether the failure will cause a complete system failure, partial degradation or there is actually no impact at all to the power transformer performance. It is actually a continuity of discussion and brainstorming step from the previous step 3 activities.

- **Classification of severity**

It is a determination step of how serious the effects identified in step 4 would be if a given failure occurs. There could be other factors to consider that contributes to the overall severity of the each of the failures. Each effect is given a severity numbers from 1 (no danger) to 10 (critical).

These numbers help to prioritize the failure modes and their effects. If the sensitivity of an effect has a number 9 or 10, action is considered to change by eliminating the failure mode, if possible.

- **Estimation of probability of occurrence**

In this step, it is necessary to look at the number of times a failure occurs. For the purpose of the case study, it is based on the actual figures of the failures frequencies collected from the power transformer system. In general, a failure mode is given an occurrence ranking, 1 (no occurrence) to 10 (high occurrence). If the occurrence is high, meaning more than 4 for non-safety, failure modes actions are to be determined.

- **Probability of Detection**

The Detection Rating is the numerical estimate of the probability of Detecting a failure mode arising from a particular cause such that the effect of failure is prevented. A scale of 1 to 10 is used in which 1 indicates that detection is highly likely and 10 almost impossible.

- **Perform Criticality Analysis**

A procedure by which each potential failure mode is ranked according to the combined influence of severity, and probability.

Qualitative analysis:

Used when specified power transformer failure rates are not available.

- **Quantitative analysis:**

Used when sufficient failure rate data is available to calculate criticality numbers.

In this project I used qualitative analysis (severity*occurrence), because transformer failure rates are not available to compute criticality numbers.

- **compensating provision**

Identify the corrective action that need to be taken in order to eliminate or mitigate the risk and then follow up on the completion of those recommended actions. Here it is important to focus on the removing of the failure cause, decreasing the probability of the occurrence and reducing the severity of the failure.

3.2- How to Evaluate Risk Priority Number (RPN)?

A FMECA can be performed to identify the potential failure modes for a power transformer. The RPN method then requires the analysis team to use past experience and engineering judgment to rate each potential problem according to three ratings:

- **Severity(S)**, which rates the severity of the potential effect of the failure.
- **Occurrence (O)**, which rates the likelihood that the failure will occur.
- **Detection (D)**, which rates the likelihood that the problem will be detected.

RPN = Severity*Occurrence*Detection

CA = Severity*Occurrence

TABLE 3.1. Evaluation criteria for severity, occurrence and detection

Severity(S)	**Occurrence(O)**	**Detection(D)**	**Ranking**
No effect	Failure is unlikely	Almost certain	1
Very minor	**Low**	Very high	2
Minor	**Low**	high	3
Very low	**Moderate**	Moderate high	4
Low	**Moderate**	Moderate	5
Moderate	Moderate: Occasional failures	Low	6
High	High	Very low	7
Very high	High: Repeated failures	Remote	8
Hazardous with warning	Very high	Very remote	9
Hazardous without warning	Very high: Failure is almost unavoidable	Absolutely uncertain	10

CHAPTER FOUR
Results and Discussion

Chapter Four: Results and Discussion

4.1- Power Transformer Components

To completely analyze failures of a transformer it should be broken to subsystem, component and parts. In this research, 500kv power transformers considered to study under FMECA technique. Different components of a power transformer are [5]:

4.1.1- Core

The function of core is to concentrate magnetic flux.

4.1.2- Tank

The tank is primarily the container for the oil and a physical protection for the active part. It also serves as support structure for accessories and control equipment.

The tank has to withstand environmental stresses, such as corrosive atmosphere, high humidity and sun radiation.

4.1.3- Windings

The function of the windings is to carry current. In addition to dielectric stresses and thermal requirements the windings have to withstand mechanical forces that may cause windings replacement.

4.1.4- *Bushings*

A bushing is a component that insulates a high voltage conductor passing through a metal enclosure, i.e. a current path through the tank wall. The inside of the bushing may contain paper insulation and the bushing is often filled with oil to provide additional insulation.

4.1.5-Tap changer

The On-Load Tap-Changer (OLTC) is the most complex component of the transformer and its function is to regulate the voltage level by adding or subtracting turns from the transformer windings.

The OLTC is built in two separate sections; the diverter switch and the tap selector. Due to the fact an interrupting of the supply is unacceptable for a power transformer, these are fitted with a complex mechanism that change turns ratio without interrupting the load current.

4.1.6- Insulation system

The insulation system in a transformer consists of two parts, a solid part (cellulose) and a liquid part (transformer oil), and where the liquid part has a double function.

- **Solid insulation**

The solid insulation in a transformer is cellulose based products such as press board and paper. Its main function is to isolate the windings.

- **Transformer oil**

The oil serves as both cooling medium and as part of the insulation system. The quality of the oil greatly affects the insulation and cooling properties of the transformer.

There are two kinds of failure sources of transformer outages [6]. Major failures those that are severe and require the removal of transformer to be reprocessed under factory conditions or its replacement. Minor failures can repair on site as shown on table 4.1.

TABLE 4.1. Transformer outage causes

Failure	Outage causes	
Minor	Outage category	
	Electrical outage	• Buchholz & Pressure relief (B&P) • Over current (OC) • Earth fault protection (EFP) • Differential protection (DP) • Outage of incomers (OI)
	Mechanical outages	• Breakdown & Damage (B&D)* • Fire Fighting System (FFS) • Oil or Air leakage
	Environmental outages	• Bad weather (BW) • Animal & birds (A&B) • Human mistakes (HM)
	Others outage	• No Flags (NF) • Others
Major	• Tap changer • Winding • Core • Bushing • Tank and Conservator • Insulation System	

4.2 FMECA for 500kv transformers

FMECA should include a list of transformer failure, reasons of these failures, local effects that refer to the consequences of each possible failure on the transformer elements, final effects that describe the impact of those possible failures on the whole transformer, an alternative provision or recommended actions to avoid these failures. Finally, a criticality analysis (CA) allowing assigning a Risk Priority Number (RPN) to each failure mode must be done.

$$\mathbf{RPN = S*O*D}$$

The FMECA of Components minor and major failures of power transformer are estimated in table 3 and table 4 respectively. In these tables attention is given to all possible major and minor failures that might result interruption of transformer service. The impact of minor failures is not significant on transformer life. Therefore, the final effects of minor failures are interpreted in terms of repair time duration. However, the frequent over current outages in the long run, resulting from overloading, lead to insulation degradation over time. As, reported in table 3 over current outage scores the highest RPN.

On other hand, earth fault and differential protection have the same RPN. Their occurrences represent a hazard for the transformer operation.

Table 4 assigned highest RPN in transformer major failures to insulation system and on-load tap changer respectively. Insulation system is an irreversible phenomena associated with transformers in service that result from oxygen, moisture and temperature. Tap changer is the only moveable element in the transformer, and had been a prone to range of failures associated with the switching contacts and drive mechanism [7]. Therefore, the condition of the top changer oil and its contacts resistance are the most encountered problem to power utilities.

Core and windings failures are the most catastrophic scenarios of transformer outages, they require an immediate replacement of the transformer and, in case a spare transformer is not directly available, additional costs for not delivered power and penalty costs should also be considered. The frequency of their occurrence is very low but their impact on the network operation is extremely high.

TABLE 4.2. Minor Failures FMECA of Transformer

Failure	Outage mode	Possible outage cause	Local effect	Final effect	Compensating provision	S	O	D	RPN
Minor	B&P	Internal arcs	Excessive pressure and combustion gases	Long repair time	Dissolved gas analysis	5	5	2	50
	OC	Overloadin g	Thermal ageing	Intermediate repair time	System monitoring	6	6	2	72
	EFP	external faults	Loss of power	Short repair time	System monitoring	5	4	3	60
	DP	Internal fault within the Protected region	Loss of power	Intermediate repair time	Preventive maintenance of transformer	5	4	3	60
	OI	faults at bus bar incomers	Immediate shutdown of transformer	Short repair time	System monitoring	6	4	2	48
	B&D	Breakdown & damage of transformer /main circuit HV equipment	Power Interruption during the replacement of damaged equipment	Long repair time	Preventive maintenance through electrical tests to check up insulation condition	7	3	2	42
	FFS	Breakdown & damage of transformer /main circuit HV equipment	Immediate shut down of FFS for malfunction	Short repair time (FFS malfunctioning)	Scheduled maintenance program to check the valves and sensor conditions	2	3	3	18
	Leakage	Leakage of oil from main tank	Low level of oil operates buchholz relay	Long repair time	Periodic visual inspection of pressure gauges	2	4	3	24
	BW	Wind and rains	Slippage of transformer accessories and protection devices	Intermediate repair time	Checking the outdoor protection wires /cables and clearance distances	4	3	2	24

	A&B	Crossing the magnetic field of the transformer	Phase to phase or phase to ground faults	Intermediate repair time	Caging outdoor visible connections	4	3	2	24
	HM	Wrong switching, intervening actions within transformer magnetic field	Human injury risk, loss of power	Short repair time	Following up a firmly safety rules	7	3	2	42
	NF	No alarm or indication to transformer outage	Overloading risk on nearby parallel transformer	Intermediate repair time for investigating the exact outage reason	Considering the design of protection & alarm system	3	3	4	36
	Others	Malfunction of circuit breakers, over flux protection , abnormal sounds of operation, tap changer control, etc.	Loss of power	High repair time	Preventive maintenance of transformer	3	5	3	45

TABLE 4.3. Major Failures FMECA of Transformer

Failure	Outage (Failure) mode	Possible outage causes	Local effect	Final effect	Compensating provision	S	O	D	RPN
Major	On-load tap changer	loose spring, low insulation of oil	Overheating and excessive pressure	Replacement of tap changer and loss of power	Preventive maintenance	7	4	7	196
	Winding	Continuous Overloading, oxidation	Thermal and mechanical ageing of winding	Transformer ageing, and replacement of transformer	Mechanical and Electrical condition assessment (SFRA, DC resistance of winding, turns ratio)	9	2	9	162
	Core	excessive heating or burning of the laminations insulation	Hot spot, high losses as a result of eddy current	Transformer ageing. Replacement of transformer	Condition monitoring through Dissolved gas analysis	9	2	9	162
	Bushings	mechanical and environmental conditions.	Conducting tracks that can short out one or more layers of the bushing.	Bushing replacement	Periodic inspection of oil level of the busing window	6	2	7	84
	Tank	Tank rupture as a result of severe short circuit and malfunction in protection system	Transformer replacement	Loss of power	Regular testing of protection systems	9	2	3	54
	Insulation system	Oxidation, high acidity, low breakdown of oil, moisture of windings paper	High arcing	Oil filtration or oil replacement in site	Dissolved gas analysis monitoring, Furan test, tan delta of oil, and chemical analysis of oil characteristics	8	4	8	256

CHAPTER FIVE Conclusion and Recommendation

Chapter Five: Conclusion and Recommendation

Conclusion

The aim of presenting a FMECA on a power transformer is to analyzing potential failure modes, possible causes, their effects and find risk priority number and rank according to their priority and improve reliability through. A step by step approach of the FMECA has provide a sequential results of the failure modes identification, failure causes and assessment of local and final effects.

FMECA risk priority number depends on many factors and varies according to the operating and environmental condition of power transformer. With the application of the FMECA, a clear and systematic failure data analysis of the power transformer components has been presented which highlighting the major and minor components failures of the transformer.

Recommendation

I recommend through:

1-Periodic preventive maintenance, perform some analysis like dissolved gas analysis, systems monitoring and periodic inspection power transformer to reduce failures.

2-following up safety rules for operators to avoid human mistakes

3-Also, these results significantly help the related engineering team to focus the improvement of transformer performance for the right problems at the right places.

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